Deregulated Real-Time Pricing for the Promotion of Distributed Renewables

by

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ABSTRACT

This thesis pursues a method to deregulate the electric distribution system and provide support to distributed renewable generation. A locational marginal price is used to determine prices across a distribution network in real-time. The real-time pricing may provide benefits such as a reduced electricity bill, decreased peak demand, and lower emissions. This distribution locational marginal price (D-LMP) determines the cost of electricity at each node in the electrical network. The D-LMP is comprised of the cost of energy, cost of losses, and a renewable energy premium. The renewable premium is an adjustable function to compensate 'green' distributed generation. A D-LMP is derived and formulated from the PJM model, as well as several alternative formulations. The logistics and infrastructure an implementation is briefly discussed.

This study also takes advantage of the D-LMP real-time pricing to implement distributed storage technology. A storage schedule optimization is developed using linear programming. Day-ahead LMPs and historical load data are used to determine a predictive optimization. A test bed is created to represent a practical electric distribution system. Historical load, solar, and LMP data are used in the test bed to create a realistic environment. A power flow and tabulation of the D-LMPs was conducted for twelve test cases. The test cases included various penetrations of solar photovoltaics (PV), system networking, and the inclusion of storage technology. Tables of the D-LMPs and network voltages are presented in this work.

The final costs are summed and the basic economics are examined. The use of a D-LMP can lower costs across a system when advanced technologies are used. Storage improves system costs, decreases losses, improves system load factor, and bolters voltage. Solar energy provides many of these same attributes at lower penetrations, but high penetrations have a detrimental effect on the system. System networking also increases

these positive effects. The D-LMP has a positive impact on residential customer cost, while greatly increasing the costs for the industrial sector. The D-LMP appears to have many positive impacts on the distribution system but proper cost allocation needs further development.

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TABLE OF CONTENTS

Page

CHAPTER Page

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table Page

Table Page

Table Page

NOMECLATURE

Δ_P	Average load variability
$D_i(t)$	Demand at node *i* at time *t*
D_j	Demand at distribution node *j*
f	Optimization function
γ	Determines aggressiveness of renewable DG premium
I_{line}	Current flow on a line
I_{max}	Current limit on a line
L_{DA}	Day-ahead LMP vector
$L(t)$	Marginal cost of losses at time *t*
$\mathcal{L}_i$	Marginal cost of losses factor at transmission node *i*
$\mathcal{L}_j$	Marginal cost of losses factor at distribution node *j*
λ	Marginal cost of energy
λ_i	Marginal price of electricity at transmission node *i*
LF	Load Factor
Λ_j	Marginal cost of electricity at distribution node *j*
$\eta_k(t)$	The shadow price for additional generation at time *t* and is non-zero only when line *k* is fully loaded
N	Percent solar penetration
N_j	+1 if distribution node *j* is load, -1 if node is generation
P_j	Renewable power injected at distribution node *j*
ρ	Penalty factor used in alternative D-LMP formulas
$p_i^*(t)$	Marginal price of electricity at node *i* at time *t*
PF	Power Factor
P	Power at the load
P_{avg}	The average power of *P*
P_{max}	the maximum power of *P*

Pk	Total power vector
P_m	Demand at hour *m*
PV_{DC}	Photovoltaic rated DC power
P_{pk}	Peak annual demand
S	Storage schedule vector
S_m	Storage power at hour *m*
S_{ik}	The generation shift factor for line *k* at node *i*
$\theta(t)$	Marginal cost of energy at time *t*
THD%	Percent Total Harmonic Distortion
ub	Upper bound on the optimization
μ	Establishes a price cap on renewable DG premium
μ_k	Shadow price on line *k*
ω	Weight on D-LMP cost of energy
$Z_k(t)$	Load on line *k* at time *t*

GLOSSARY OF ACRONYMS

CSPC	Columbus Southern Power Company
DALMP	Day-Ahead LMP
DG	Distributed Generation
D-LMP	Distribution Locational Marginal Price
EV	Electric Vehicle
FACTS	Flexible AC Transmission Systems
Ind	Industrial Sector
ISO	Independent System Operator
Lg Com	Large Commercial Sector
LMP	Locational Marginal Pricing
LSE	Load Serving Entity
OPF	Optimal Power Flow
PV	Photovoltaic
Res	Residential Sector
RTO	Regional Transmission Operator
RTP	Real-Time Pricing
RYG	Red, Yellow, Green
SCADA	Supervisory Control and Data Acquisition
SCED	Security Constrained Economic Dispatch
Sm Com	Small Commercial Sector

CHAPTER 1

POWER DISTRIBUTION IN A DEREGULATED MARKET

1.1 Objectives

The main objective of this thesis is to develop a deregulated pricing methodology for the electric distribution system, which includes distributed renewable generation. Several selected implications of such a system will be studied. The proposal in this thesis is to adapt the deregulated spot pricing used in wholesale electricity markets to the distribution system. The wholesale electricity markets currently apply locational marginal pricing (LMP) to the transmission system to determine prices. The LMP is the cost to deliver the next unit of energy at any point on the transmission system.

The distribution locational marginal price (D-LMP) will be an extension of the traditional transmission LMP. The D-LMP is designed to reflect the real-time cost of supplying power at any point in the distribution network and provide any renewable generation with appropriate reimbursement. The further objectives of this thesis are to examine the economic and engineering implications of the D-LMP on distributed renewable generation and distributed storage. Basic economic analysis will be performed on interactions between these technologies and real-time pricing while perusing varying optimization goals. The engineering aspects will also be investigated to determine the effect on reliability and network performance.

1.2 Motivation

The motivation for this project comes from the recent success of the LMP in the deregulated wholesale power market. The LMP is more precisely defined as the marginal cost at any point of connection or interconnection in the system (i.e. location). These locations are known as nodes, and are often electrical buses in the transmission network.

A marginal cost is the cost to produce the next unit of a product. For example, if 10 MWh of electricity costs $20 USD/MWh to produce, and 11 MWh of electricity costs $25 USD/MWh to produce. Then the marginal cost while 10 MWh of electricity is being produced is $25. The economic theory behind electricity markets suggests that any producer would maximize their product profit at the marginal price. This is the highest price which one could sell without another producer supplying the product at a lower price. This is how prices for electricity are determined [1]. Market operators determine these marginal prices across their footprint, and electricity is bought and sold in real-time at these prices. The LMP is determined both spatially and temporally. The LMPs are calculated every 5 minutes on a real-time basis and consist of three components: cost of energy, cost of losses, and cost of congestion. Further details on the nature of the LMP are in the literature review.

The real-time nature of the D-LMP enables increased market efficiency and should stabilize the volatility of the electricity market. Market efficiency is the ability of the market to determine the most accurate price reflective of supply and demand. The presently used flat-rate pricing system for the retail customer does not allow the demand to respond to supply, thus reducing market efficiency [2]. Parallel to market efficiency is social welfare. The social welfare problem seeks to maximize profit for the seller and minimize cost for the buyer. The electricity market is presently only elastic on the supply-side. An advanced grid and D-LMP will enable demand-side management and an increased elasticity on the demand-side, thus providing the lowest cost to the customer and the maximum social welfare to the market [2], [3]. Real-time pricing offers many of these same incentives, but the D-LMP takes it a step further. The D-LMP allows the utility to charge the true cost of electric service to the individual customer rather than mass cross-subsidization. The D-LMP also allows for inclusion of additional factors such as pollution, greenhouse gases, renewables, and harmonics [4], [5].

A grid with D-LMP in place allows the individual customer to become a market participant. The retail customer can use the D-LMP as a financial instrument to alter one's bill using generation and/or demand curtailment. Renewable and storage technologies can buy and sell power at optimal times, enabling the customer to hedge volatility and further manage one's power consumption. Advanced technology and computers can minimize the customer's personal involvement in managing one's power usage. The use of these technologies can also be optimized to maximize load factor and reduce peak line flows, allowing for increased reliability and decreased capital investment. It appears that many economic and system performance metrics may be improved with a D-LMP.

1.3 Literature Review: The LMP

The literature on LMPs is vast and cannot be entirely covered here, but this section provides an evolution of the LMP and its context in this work. The idea of spot pricing for utilities was first suggested by William Vickrey [6] in 1971. Vickrey suggested the real-time rate quoting of electric power and allowing the retail customer to react. He postulated that utilities could minimize peak usage and use congestion driven rates to invest in new capital investments. Vickrey's ideas were further built upon by Bohn, Caramanis, and Schweppe [7] and in 1984 they proposed a rudimentary spatial and temporal spot pricing methodology. Their proposition included the marginal price of energy, losses, and congestion as shown in the below formula,

$$p_i^*(t) = \theta(t)\left[1 + \frac{\partial L(t)}{\partial D_i(t)}\right] + \sum_k \frac{\partial Z_k(t)}{\partial D_i(t)}\, \eta_k(t). \tag{1.1}$$

Where p_i* is the marginal price at node i and time t, θ is the marginal cost of energy, L is the loss component, D_i is the demand at node i, Z_k is the flow on line k. η_k is the shadow price for additional generation and is non-zero only when line k is fully loaded.

These are the same three basic components used in the contemporary locational marginal price (LMP). The spot price at time t and place i are to be cleared on a regular time interval to capture the tightening of any congestion. The energy component, θ, was the marginal cost of an optimized dispatch of generation. The second component captures the marginal cost of transmission line losses to deliver power to node i. The final component uses the line limits and corresponding flows to determine any marginal congestion costs. Schweppe, Caraminis, Tabors, and Bohn [3] laid out the modern nodal (locational) pricing scheme in 1988 and it is nearly identical to Equation (1.1). This text is the basis for modern day LMP calculation [8].

Modern utilities have opened electricity markets to buy and sell wholesale power in real-time. Many of these markets utilize the LMP to determine the cost of transferring power from one network location to another and set the market price. The LMP is a marginal cost function; it represents the cost to utilize the next Megawatt hour of energy. The electric market is structured such that the ideal price for suppliers to sell their generation for a price equal to the marginal price. Previously, financial instruments (contracts, agreements) determined bulk electrical purchases. These contracts unfortunately had no concept of the law of physics or bearing on the reality of the electric grid. The LMP uses physical, real data of the system to construct prices that reflect the state of the system. This LMP calculation is performed for every network bus in the Independent System Operator (ISO) or Regional Transmission Operator (RTO) market footprint on a 5 minute basis. Many ISOs use a method called Security Constrained Economic Dispatch (SCED) to determine the generation dispatch and the LMPs. The real-time energy market process is outlined in Figure 1.1.

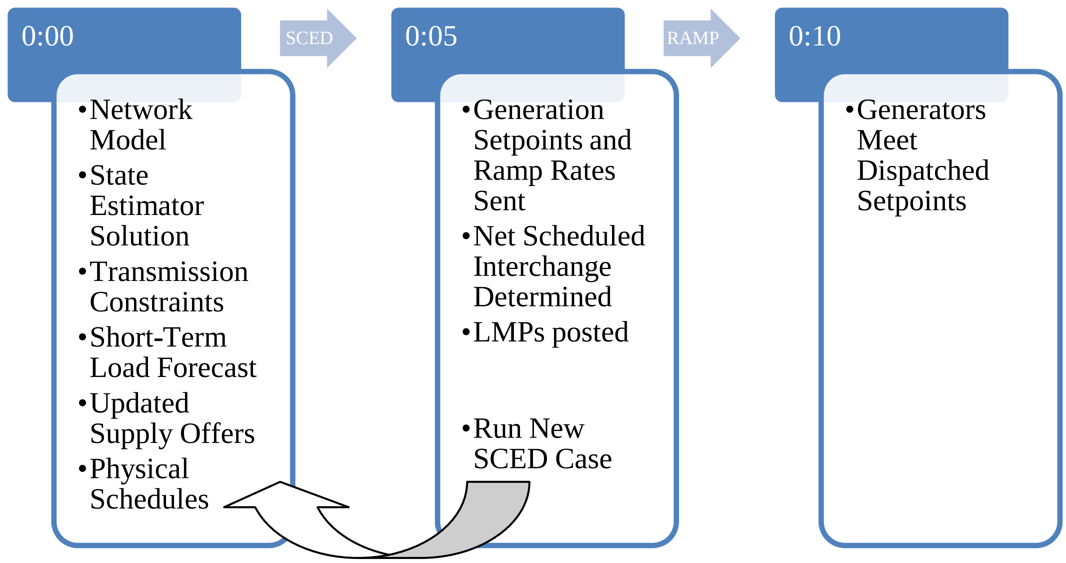

Figure 1.1 – The Real-Time Energy Market

The prices vary temporally as demand and supply change. The required balance between supply and demand can in fact lead to negative LMP prices when generation is in excess. During times of congestion, as the transmission lines become loaded to the point of threatening the thermal or security limit of a particular line, the LMP is increased or decreased accordingly. The cost of buying power at any particular bus is the LMP, and vice versa, the payment for selling power into that bus is also the LMP [8], [9]. The LMP can also readily be extended to include any number of factors such as pollution or harmonic injection [4], [5].

There have been a few proposals to introduce nodal pricing to the distribution system. Schweppe et. al. made the suggestion that nodal prices be determined throughout the electric system, from transmission to distribution, and loads charged accordingly [3]. The practically of one entity determining the LMPs at that number of buses is questionable and the idea has never been pursued. The use of nodal pricing with distributed generation was the focus of a 1998 study [10]. This paper includes background and context, but its focus is not on the development of a nodal pricing scheme. Sotkiewicz and Vignolo [11] introduce a method for calculating nodal prices in the distribution system based on the work of Schweppe. Their method includes using the transmission interface for the cost of energy, in addition to the cost of both real and reactive power losses. They found that such nodal pricing allows for additional compensation via the cost of losses for distributed generators. Singh, Choudhury, and Goswami [12] build upon the work of Sotkiewicz and Vignolo to determine the optimal siting of distributed generation in a distribution system using nodal pricing. Others have proposed establishing and clearing a distributed generation market separate from the wholesale market and using nodal pricing in the process [13].

1.4 Literature Review: Real-Time Pricing

Real-time pricing has long been dabbled with in the retail electricity market. Vickrey's 1971 paper [6] made note of a French company which sent price signals to its customers. The D-LMP is a natural extension from the transmission system to provide a real-time price to the customer that is reflective of the state of the system. Borenstein [14], [15] explains the market inefficiency of the flat rate-retail system. Markets function optimally when both the demand and supply have elasticity and one reacts to the abundance of the other. Electric retail prices are predetermined and the end user is sheltered from the costs of supply shortages. Flat average price encourages under consumption during off-peak hours and over consumption during peak hours. This reality requires that additional capacity (peak capacity) be built to meet the flat-rate demand. Herein lies the market inefficiency [2], [15].

Time-of-use rates are an approximation of real-time pricing (RTP) but it is only able to capture 20% of the available efficiency gains [16]. Increased time granularity equates to increased market efficiency. The use of RTP has several system impacts. In the short run generators will receive less revenue as they will sell less peak power. In the long run this would mean fewer power plants and less capital investment. The ability of the customer to respond to prices would also minimize the market power of the seller. Any undue increase in price would be met with a reduced volume of sales. RTP would also decrease the likelihood of system shortages and temporary blackouts as demand can respond like reserves [17], [2].

Several companies are or have run trials using RTP pricing. They have mixed results depending on who their customers are, their geographic location, and their lifestyle tendencies. Faruqui and George [15] found that generally the investment into the technology did return favorable gains to both the customer and the utility. Holland and Mansur [18] simulated the short-term effects of implementing RTP. They found a stabilizing in LMP prices and load, as well as an increase in market efficiency. Bornstein [19] examined the long-term implications and found that the utility made large savings in not having to create additional capacity. He also found that the largest customers offered the greatest gains and there is diminishing return with the amount of RTP penetration.

Several studies have examined the implications on the customer and their response. Molohkar, Klinkhochorn, and Feliachi [20] examined data from Alabama Power and San Diego Gas & Electric and found that the average customer could reduce their electric bill by 10%. Much greater gains could be made possible with the addition of intelligent demand response, further adding elasticity to the load. Another study conducted by Faruqui and George [21] found that the customer can save 8-15% on their electric bill with no enabling technology and 25-30% with enabling technology in addition to reducing load peaks by a factor of 5 to 10. Bornstein [22] has shown that minimal hedging by the utility on the customer's behalf can provide excellent protection from any RTP volatility. The use of RTP may also have positive environmental impacts by reducing emissions and greenhouse gases by changing generation patterns [23], [18].

1.5 Literature Review: Distributed Generation and Storage

Storage and distributed generation are vast and well covered topics. Their context within this thesis is largely based on their economic performance. This section reviews the literature on storage with RTP and distributed generation with nodal pricing. Distributed generation offers several benefits to the end user and to the system as a whole. Coupled with storage technology, distributed generation (DG) offers a way for demand to "push back" on high LMP prices, thus offering more price stability for all. DG has the ability to serve local load, provide service during an interruption, increase reliability, and decrease transmission congestion [24].

With high-speed internet available to many residents the sending of LMP information becomes a possibility and the LMPs themselves can become a price incentive to the installation of DG technologies [24]. Gautam and Nadarajah [25] performed DG placement studies to maximize the benefit from the LMP. This naturally was at buses where congestion charges were common. They were shown to have a reducing effect on the congestion component, in turn levelizing and lowering the LMP. Several studies determine nodal pricing to be more reflective of the benefits of DG on the system [10], [11], [12].

The use of time-varying electricity prices allows for economic storage of electricity. Electricity can be bought when prices are low and sold when prices are high. The increasing prevalence of electric vehicles may naturally provide a distributed storage infrastructure [26], although the economics of this approach are in question. Graves, Jenkin, and Murphy [27] examine the opportunities for distributed storage. They found storage may reduce volatility in prices and increase market competition. The outcomes depend on the constraints of the storage. The storage may be capacity constrained, power constrained, or both [28]. Maly and Kwan found that small storage units have a faster payback time than their larger counterparts [28].

Sioshansi, Denholm, Jenkin, and Weiss examined the economic benefits of storage in the PJM network. They found the value of arbitrage to be driven by location, fuel prices, fuel mix, efficiency, storage size, and load profile. The storage can produce an annual arbitrage of $110 per installed kW in a 12 kWh storage system. Up to $140/kW can be attained at heavily congested buses. Negative price feedback may also reduce the value of arbitrage as the storage unit becomes larger [29]. Hu, Chen, and Bak-Jensen optimize a storage schedule in the Nord Pool spot market using day-ahead LMPs. They also found large storage units do not pay themselves off in a timely fashion while small and medium sized units can reach breakeven in approximately 20 years [30]. Energy storage systems may prove to be more economically fruitful when used for ancillary services [31].

1.6 Organization of the Thesis

This thesis has been organized into 5 chapters with accompanying subsections and 4 appendices. Chapter 1 includes the objectives and motivation of this thesis. Chapter 1 also provides a review of literature supporting this study and its results. The literature summary covers the LMP, real-time pricing, storage and DG. The LMP formulation is covered, as well as its history and its contemporary implementation. Several proposals for nodal pricing in the distribution system are also covered. The effects, variations, and efficacy of real-time pricing are summarized in the following subsection. Finally, the economics of DG and storage with time-varying pricing are summarized.

Chapter 2 derives the distribution locational marginal price formula used in this thesis. It discusses the relation of the D-LMP to the transmission LMP and the addition of a premium for renewable generation. Chapter 2 continues to develop a number of possible alternative formulations and overviews the infrastructure requirements for an implementation. Chapter 3 develops a storage scheduling methodology and justification for its optimization constraints. Chapter 3 also presents several examples of the storage algorithm with real data.

Chapter 4 develops a test bed to test a D-LMP price signal. The test bed is used with historical data to produce the results. Chapter 4 presents the results of each test case in tables of D-LMPs, voltages, and contour maps and briefly summarizes each case. Chapter 4 concludes with discussion of the results and trends found in the test cases. Chapter 5 concludes the thesis and provides recommendations for future work.

Appendix A contains the computer code used in the storage schedule optimization of Chapter 3. Appendix B provides additional details on the test bed use in Chapter 4. Appendix C has an explanation and derivation of the solar data used to generate the results. Appendix D lists additional test case details omitted from Chapter 4.

CHAPTER 2

DISTRIBUTION LOCATIONAL MARGINAL PRICING FORMULATION AND CONSIDERATIONS

2.1 D-LMP Power Marketing

This section seeks to develop a real-time pricing scheme for the electric distribution system using locational marginal pricing. An LMP will allow for a price to be assigned to each node in the distribution system. A node in the distribution system will defined as any metered point. The PJM formulation is used as the basis for the distribution LMP. Several alternative potential D-LMP formulations will be also be developed. The required hardware and infrastructure requirements are also examined. Finally, the repercussions of a D-LMP system failure are briefly discussed.

2.2 The PJM LMP Model

PJM was the first ISO and RTO in the United States [32]. Many other electric market designs (e.g. Midwest ISO, ISO New England) are based on the PJM model and it will be mentioned here, as it is important to the contemporary understanding of the LMP and its usage. The PJM model uses the following equation, which is quite similar to Schweppe's original model, to calculate the LMP at any given node *i*,

$$\underbrace{\lambda_i}_{LMP} = \underbrace{\lambda}_{Energy} - \underbrace{\lambda \mathcal{L}_i}_{Losses} + \underbrace{\sum_{k=1}^{K} S_{ik}\mu_k}_{Congestion}. \tag{2.1}$$

Where λ is the cost of energy, $\mathcal{L}_i$ is the losses factor, S_{ik} is the generation shift factor for line k at node i, and μ_k is the shadow price on line k. The PJM LMP is composed of three fundamental components, energy, losses, and congestion. The energy component of the LMP, λ, is determined by optimally solving a unit dispatch problem. Unit dispatch software solves for the lowest cost generation scenario to balance the demand and determines a cleared energy price homogenously across the system. The highest dispatched marginal cost generator with remaining capacity sets the value of λ. With no losses or congestion, the LMP would be the same at every bus.

The loss component is determined using penalty factors, $\mathcal{L}_i$, to make utilization of that node more or less favorable. In the PJM formulation the loss component takes a negative value and thus increases the value of the LMP. The sensitivity of the losses due to increased load at bus i is captured by $\mathcal{L}$ and the LMP price is adjusted accordingly. The load will in effect be paying for the losses from its use at node i to the generators. To counter this, a generator supply curve is also assessed a penalty factor. This penalty factor is used in the unit dispatch algorithm to make dispatch more or less favorable if a generator increases or decreases system losses.

Congestion is calculated by evaluating the difference between the optimal economic dispatch and the constrained economic dispatch. On a constrained line, the source node will have a low LMP to discourage further generation or encourage more load to tap inaccessible cheap generation. The sink side of the line will have a high LMP to discourage further consumption and encourage more generation to satisfy the load [9], [33]. The loss and congestion costs are used to encourage further infrastructure to mitigate high LMPs. A visual depiction of the LMP is seen in Figure 2.1.

A D-LMP will have to interact with the transmission LMP on a continuous basis. The optimum temporal granularity for LMP calculation seems to be five minutes, as a compromise between computational intensity and power balance. The D-LMP will have to use the LMP data to reflect the transmission system as well as the distribution system and be timed accordingly to properly interact with the LMP. Figure 2.2 is an example of a LMP contour map of a major RTO.

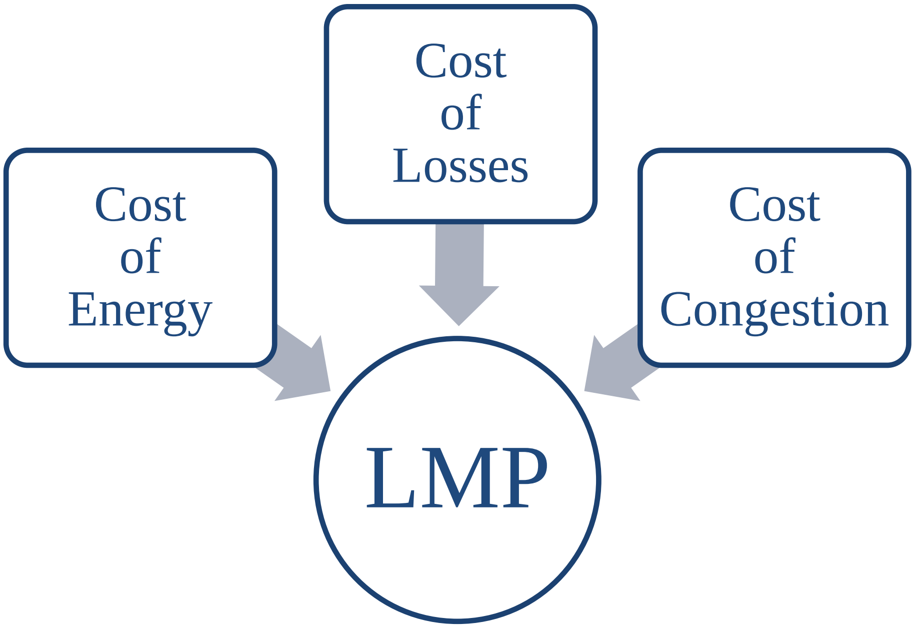

Figure 2.1 - Components Comprising the LMP

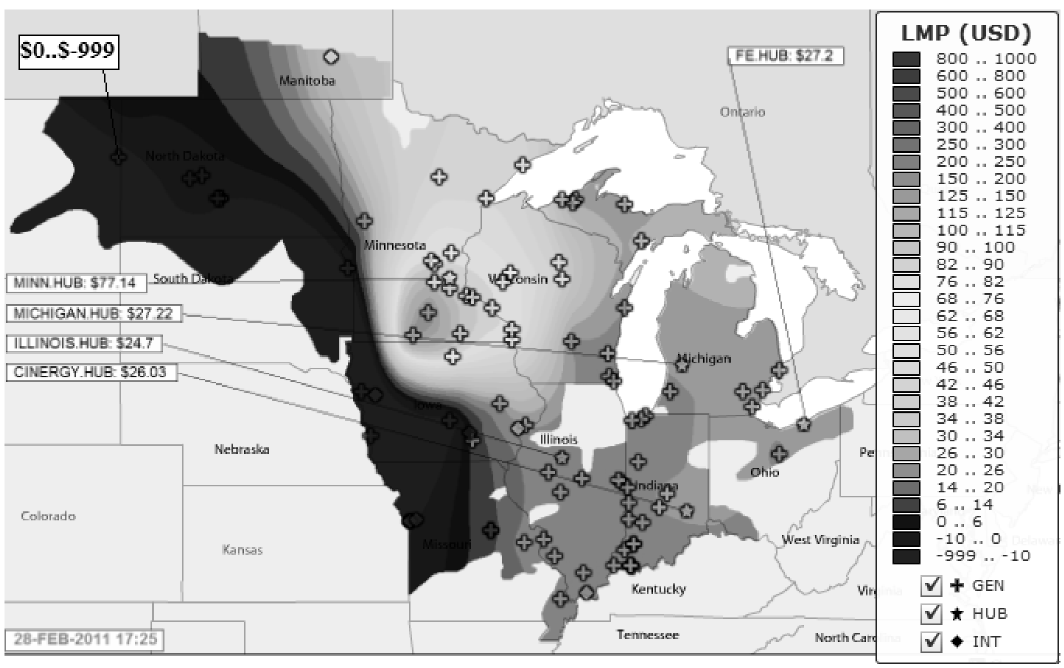

Figure 2.2 - An Example of a LMP Contour Map [34]

2.3 The D-LMP Formulation

The purpose and goals of the D-LMP will drive its structure. Using the traditional LMP as a starting point, a suitable D-LMP can be created. The basis for this D-LMP will be drawn from the PJM implementation as seen in Equation (2.1). The starting point for the formulation is,

$$\underbrace{\Lambda_j}_{D-LMP} = \underbrace{\omega\lambda_i}_{Energy} - \underbrace{\omega\lambda_i\mathcal{L}_j}_{Losses}. \tag{2.2}$$

The D-LMP at node j is given by Λ. A distribution node can be any point in the system, but here it will generally be referring to a retail meter. The λ_i component is the transmission LMP value at the feeder bus for the distribution network, which is denoted as bus i. The energy component, λ_i, is weighted by a variable ω. The weight is needed to compensate the utility for the use of its lines and services. The $\mathcal{L}$ factor is a penalty factor, like that in Equation (2.1), but is now for distribution bus j. The congestion factor has been dropped for two reasons:

- In the short-term, congestion is managed primarily by dispatch and control. There is little controllability in the distribution network, especially for prolonged periods of time. The supply power cannot be redispatched and demand curtailment may be limited. Flexible AC Transmission Systems (FACTS) devices could allow for redispatch of power flows in a distribution network, but the costs would be exceedingly prohibitive and negatively affect losses.
- Continuing to build the distribution network to near today's standards would be wise in the case of a communication system failure. If D-LMP prices fail to reach the customer and the usual demand reactions do not take place, the system could easily overload if the margins were tight and

the system was fully dependent on load curtailment. If the system is overbuilt for reliability, congestion should not be an issue.

The congestion component is replaced with a renewable distributed generation component, which can be used to reward the injection of renewable energy into the system. The finalized D-LMP is as follows,

$$\underbrace{\Lambda_j}_{D-LMP} = \underbrace{\omega\lambda_i}_{Energy} - \underbrace{\omega\lambda_i\mathcal{L}_j}_{Losses} + \underbrace{\frac{\mu P_j}{P_j+\gamma}}_{Renewable\ DG} . \tag{2.3}$$

The finalized D-LMP has a functional renewable generation component. Where P_j is the injected renewable power at node j. μ and γ affect the characteristics of the renewable DG component of the D-LMP. This component was derived from a simple function,

$$y = \frac{x}{1+x}. \tag{2.4}$$

This component encourages small producers to deliver the next megawatt but prevents the return for very large producers from becoming exceedingly high. Figure 2.3 shows the function *y(x)* discussed here with different values of μ.

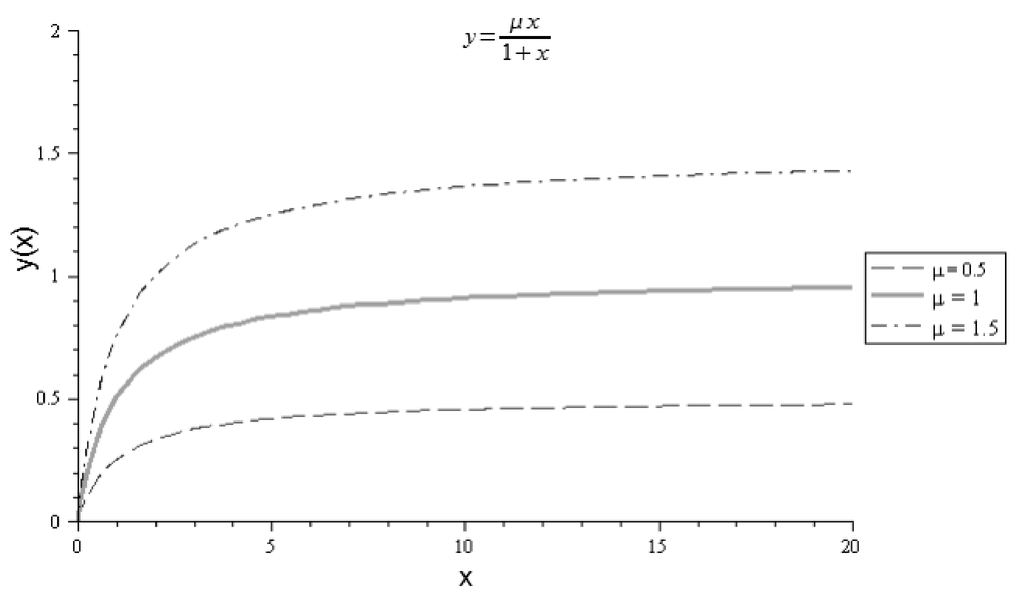

Figure 2.3 - The Effects of Values of μ on the Function *y*

Here μ serves as a hard cap for the renewable function and prevents payments from becoming excessive for large producers. This hard cap would be changed rarely, depending on how the renewable sector grows in the system and the utilities' ability to finance the renewables. The other constant in the equation is located in the denominator. This constant can be manipulated and it represents how aggressively the curve reaches the hard cap, i.e. the asymptote. In this equation it is renamed as variable γ. Figure 2.4 shows the function *y(x)* discussed here with different values of γ.

The variable γ can be changed when the utility would like to encourage renewable growth among the smaller producers, encourage or discourage renewable generation at a certain point in time, and/or limit payments to generators. The manipulation of μ and γ determines the aggressiveness of the renewable component of the D-LMP.

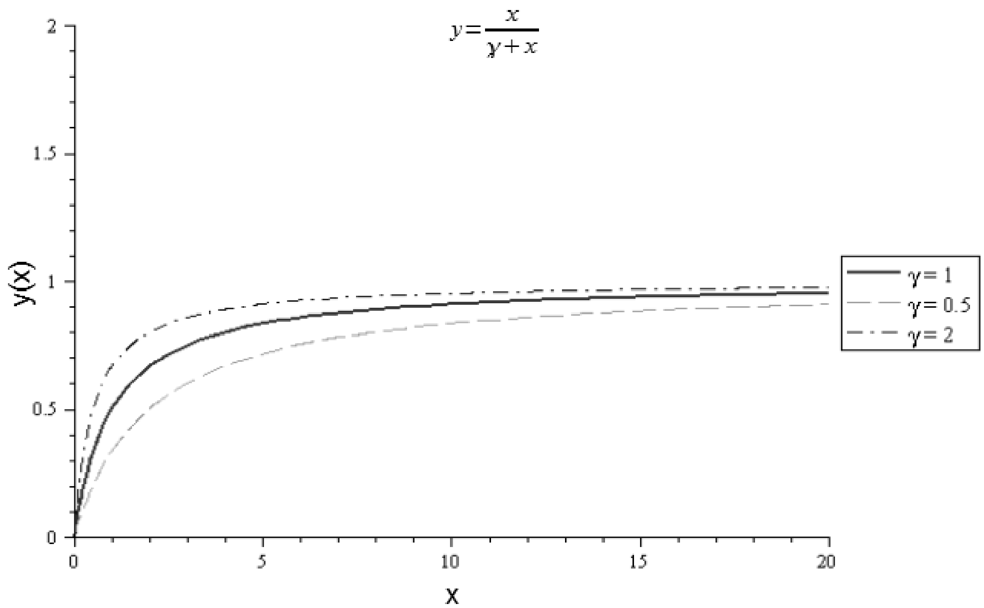

Figure 2.4 - The Effects of Values of γ on the Function *y*

The renewable component essentially increases the D-LMP if there is renewable generation being injected at that node. This fact creates a very important caveat for this formulation of the D-LMP, *a node can be generation or load, but never both.* This is important because if the D-LMP were determined for a node and which had both demand and generation, the renewable generation would increase the D-LMP at the node and the load would also have to pay this increased price. The generator would be paid more and the load would be charged more, and it would in effect disincentivize any generation at all. This caveat prevents such a discrepancy. This means that a home with renewable generation will have two calculated nodes, one for generation and one for load, or the home will be net metered. Net metering is a schema which after a load serves its own demand, it can sell its excess generation into the grid. The node will always be a seller or a buyer, but never both simultaneously. There are many solutions to this dilemma, but this formulation was chosen because of its minimal complexity. The problem of increasing the D-LMP to pay renewable generators and penalizing demand or vice versa is a common situation in the D-LMP but can usually be solved with a fundamental rule of some sort. Figure 2.5 summarizes the composition of the D-LMP.

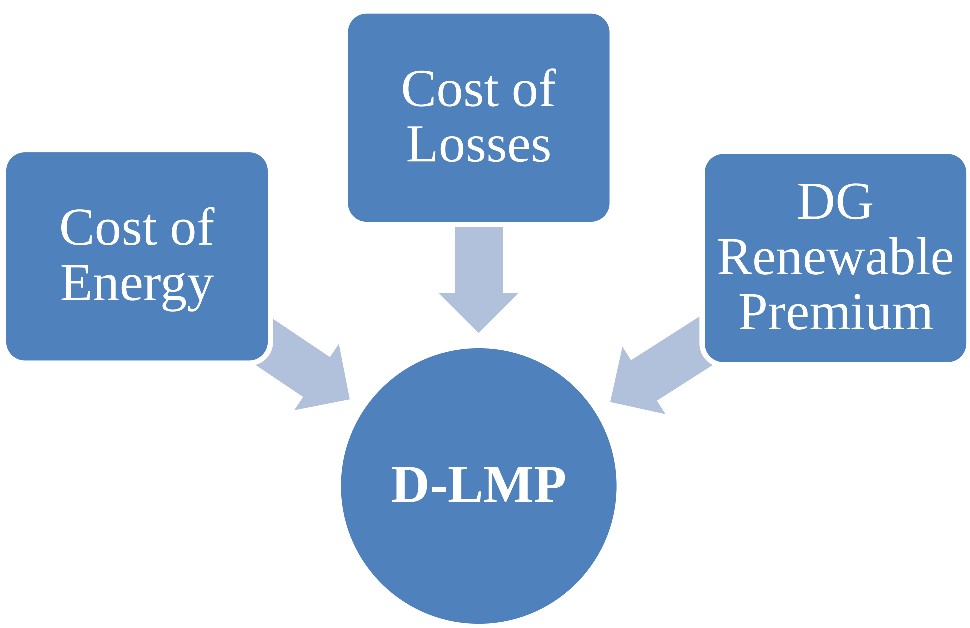

Figure 2.5 - Components Comprising the D-LMP

2.4 Alternative D-LMP Formulations

There are countless alternatives and variations to the D-LMP. Any Load Serving Entity (LSE) could customize it to suit their needs and load type; the D-LMP is only limited by what can be measured and calculated. Harmonics and load factor are some straight forward additions to the D-LMP. A more complicated formulation will be derived and several alternatives will be presented in this section.

For even greater renewable use one can incentivize the customer for meeting their own load with their domestic generation,

$$\underbrace{\Lambda_j}_{D-LMP} = \underbrace{\lambda_i}_{Energy} - \underbrace{\lambda_i \mathcal{L}_j}_{Losses} - \underbrace{\frac{\mu P_j}{P_j + \gamma D_j} \lambda_i}_{Renewable\ DG}. \qquad (2.5)$$

Where P_j is the renewable power generated at node j and D_j is the demand at node j. Like Equation 2.3, μ and γ control the aggressiveness of the incentive equation. An example is illustrated in Figure 2.6.

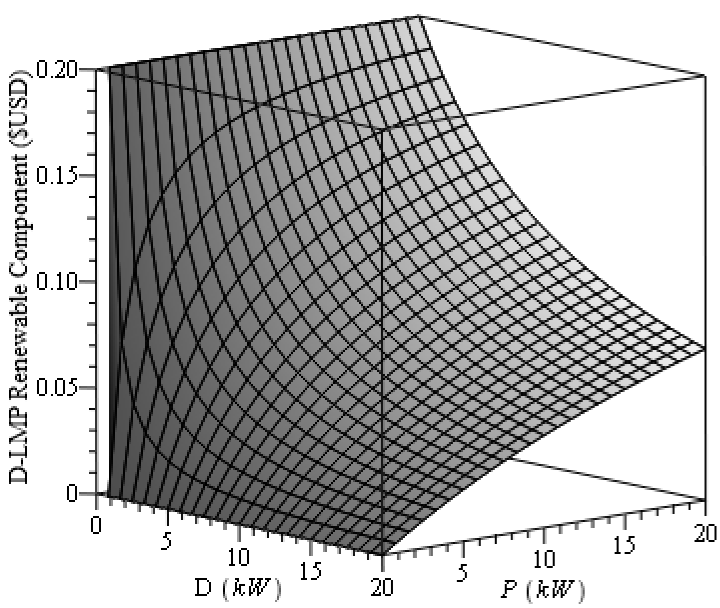

Figure 2.6 - A Graphical Representation of the Renewable Component in Eq. (2.5)

To aid in the understanding of this alternative D-LMP the derivation of the renewable component will be explained. Using Equation (2.4), x is substituted for the ratio of renewable power to demand power, $\frac{P_j}{D_j}$. This substitution yields,

$$y = \frac{\mu \frac{P_j}{D_j}}{\gamma + \frac{P_j}{D_j}}. \tag{2.6}$$

Simplifying Equation 2.6, the renewable component is recognized,

$$y = \frac{\mu P_j}{P_j + \gamma D_j}. \tag{2.7}$$

Table 2.1 presents some additional alternative D-LMP formulations.

Table 2.1 - Various D-LMP Formulations

D-LMP Formula	Notes
$\underbrace{\Lambda_j}_{D-LMP} = \underbrace{\lambda_i}_{LMP} - \underbrace{\lambda_i \mathcal{L}_j}_{Losses} - \underbrace{\frac{\mu P_j}{P_j + \gamma D_j}\lambda_i}_{Renewable}$	Load and generation are linked at the same node. The price is determined by the ratio of the two and the current LMP value. *Power at node j is always taken to be positive.*
$\underbrace{\Lambda_j}_{D-LMP} = \underbrace{\lambda_i}_{LMP} - \underbrace{\lambda_i \mathcal{L}_j}_{Losses} - \underbrace{\frac{\mu P_j}{P_j + \gamma D_j}}_{Renewable}$	Load and generation are linked at the same node. The price is determined by the ratio of the two and is invariant of the LMP. *Power at node j is always taken to be positive.*
$\underbrace{\Lambda_j}_{D-LMP} = \left[\underbrace{\lambda_i}_{LMP} - \underbrace{\lambda_i \mathcal{L}_j}_{Losses}\right] \underbrace{\frac{\mu P_j + \gamma D_j}{P_j + \gamma D_j}}_{Renewable}$	Load and generation are linked but are at separate nodes. Renewable generation premium is determined by ratio of load and generation. *Node j can only be a generating node or a demand node, never both.*
$\underbrace{\Lambda_j}_{D-LMP} = \underbrace{\lambda_i}_{LMP} - \underbrace{\lambda_i \mathcal{L}_j}_{Losses} + \underbrace{N_j\, THD\%\, \rho}_{Harmonic}$ $N_j = \begin{cases} +1 & if\ j\ is\ load \\ -1 & if\ j\ is\ gen \end{cases}$	A load or generator is assessed a penalty factor, ρ, for injecting harmonics measured in Total Harmonic Distortion (THD). *Node j can only be a generating node or a demand node, never both.*
$\underbrace{\Lambda_j}_{D-LMP} = \underbrace{\lambda_i}_{LMP} - \underbrace{\lambda_i \mathcal{L}_j}_{Losses} + \underbrace{N_j\,(1 - PF)\rho}_{Power\ Factor}$ $N_j = \begin{cases} +1 & if\ j\ is\ load \\ -1 & if\ j\ is\ gen \end{cases}$	A load or generator is assessed a penalty factor, ρ, for having load factor less than 1. *Node j can only be a generating node or a demand node, never both.*
$\underbrace{\Lambda_j}_{D-LMP} = \underbrace{\lambda_i}_{LMP} - \underbrace{\lambda_i \mathcal{L}_j}_{Losses} + \underbrace{\frac{I_{line}}{I_{max}}\rho}_{Congestion}$	A load or generator is assessed a penalty factor, ρ, for adding simplified congestion to a line. *Node j can only be a generating node or a demand node, never both.*

2.5 Required Hardware and Infrastructure for the D-LMP

Implementation of a distribution level location marginal pricing system requires a substantial upgrade of the present distribution system. Fortunately, an initiative to implement many of the required technologies is underway; this is known as the "Smart Grid" in the United States. The United States Department of Energy defines the Smart Grid on its website [35]. Figure 2.5 illustrates the basic flow of the D-LMP system.

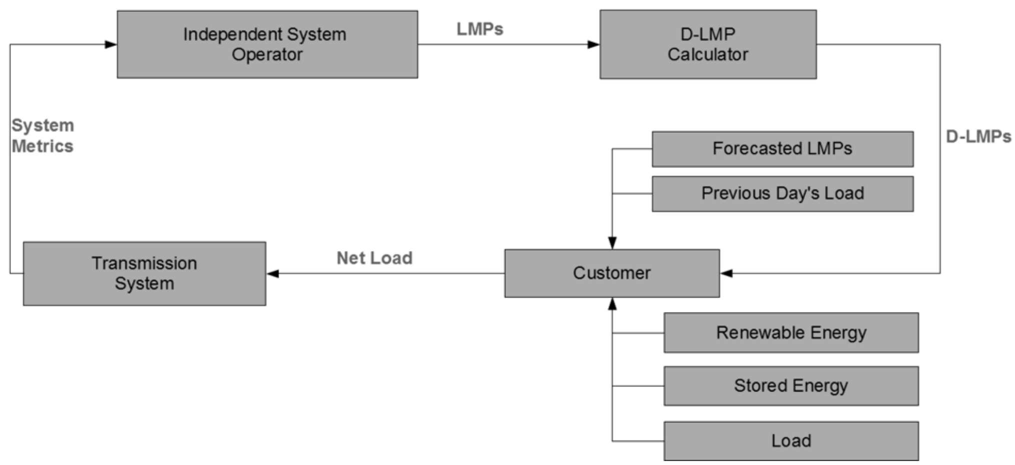

Figure 2.7 - The Data Flow of a Smart Distribution System

The left side of the flow chart is already captured by the Independent System Operators' system. They capture supervisory control and data acquisition (SCADA) data at many of the transmission system buses and can directly measure the load on the system. They then use this data to calculate system-wide LMPs at each bus for every five minute interval of the day. These LMPs are then published and the prices are set in the transmission system. The D-LMP system will interface with the transmission system at this point, collecting LMP prices for that particular LSE's feeder buses.

The utility will then use metrics from the distribution system to calculate the D-LMP and publish it to the customers. The customer can then manually or automatically make control and storage decisions for their home. The communication metrics and price data to and from the customer require a reliable broadband connection. The customer will also need a home energy computer capable of interfacing with the utility and making intelligent decisions with the current data. This requires a large advancement from the present day distribution network. The feedbacks of this system will become important if the D-LMP becomes widespread.

2.6 Consequences of D-LMP Interruption

Consequences of failure in the D-LMP system may prove to be complicated, especially with monetary exchanges involved. System-wide and localized outages would likely be treated differently. ISOs determine the actual cost and billing the day following the real-time market. The ISOs use the previous day's metrics and bids to clear ex-post LMPs and the market is settled using these numbers. The ex-post LMPs should, and largely do, match the real-time (ex-ante) LMPs. Any LMPs that were unavailable during the real-time are calculated then and prices are assessed at this time. As long as the state estimator can provide a solution for the network and generator bid data is known, the ex-post LMP and costs can be determined after-the-fact. Such a scheme could also be used for the D-LMP system.

Localized failures, such as in a single home, could be addressed in a more traditional fashion. The LSE would know instantly when a meter, or communication to that meter, is no longer functional. A serviceman could be sent immediately and minimal downtime would occur. Presently, if a traditional meter fails the utility will not be aware until the next reading and this could be a major loss of sales.

2.7 Conclusions

The D-LMP is a highly flexible formulation and can easily be customized to each utility's objective and desired outcomes. Traditional transmission LMPs used by ISOs incorporate three components into their calculation: energy, losses, and congestion. Because the D-LMP will be interfacing with the transmission LMP, the transmission LMP is a natural starting point for the creation of a D-LMP. The D-LMP will be composed of an energy, loss, and renewable component. The congestion component was dropped because of a lack of network controllability and network robustness. The renewable component rewards renewable energy injection, but contains several variables to limit excessive payments while small producers are encouraged to build further capacity.

A D-LMP implementation would require extensive infrastructure build out, including data centers, advanced metering, home energy computers, and reliable broadband data to each customer. Fortunately, a US initiative is already underway called the Smart Grid, which may address many of these infrastructure needs. The flexibility of the D-LMP allows for many different formulations that can be mixed and matched to achieve any number of outcomes for the operating LSE and customer. Several options are highlighted in Table 2.1. Additionally, such a complicated and advanced metering and pricing system is prone to some failure. Mitigation schema, backup plans, and default functionality needs to be addressed and understood. With Smart Grid advancing into the distribution system a wide opportunity exists for real-time pricing using a D-LMP.

CHAPTER 3

DEVELOPMENT OF AN ELECTRIC ENERGY STORAGE STRATEGY

3.1 Motivation for Using Storage Technology with the D-LMP

Real-time pricing using the D-LMP will bring dynamic prices to the customer, allowing the customer to use a storage technology to buy energy at a low price and later sell the energy at a higher price for a net profit. By this strategy, the D-LMP facilitates the US Department of Energy Smart Grid philosophy of power marketing. Figure 3.1 represents a sampling of real-time LMPs on a typical day. The load serving entity stands to profit because the implementation of storage elements can levelize the load, thus maximizing the utilization of distribution system assets. Figure 3.2 and Figure 3.3 illustrate the variation in typical loads at the Columbus Southern Power Company (CSPC).

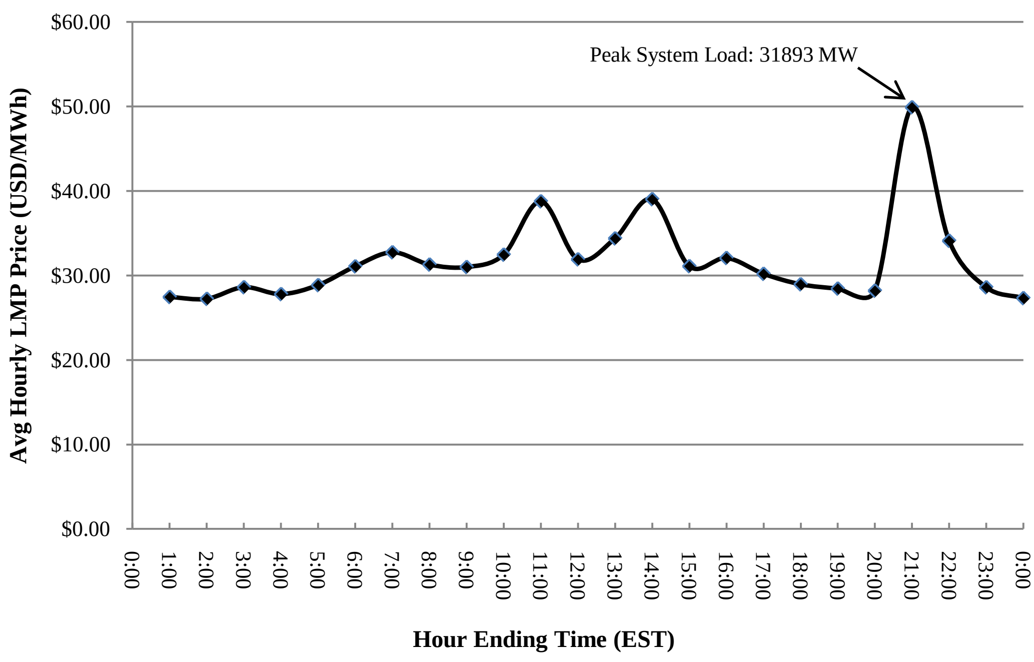

Figure 3.1 – Real-Time LMP Prices for the PJM AEP Buckeye Node April 23, 2009

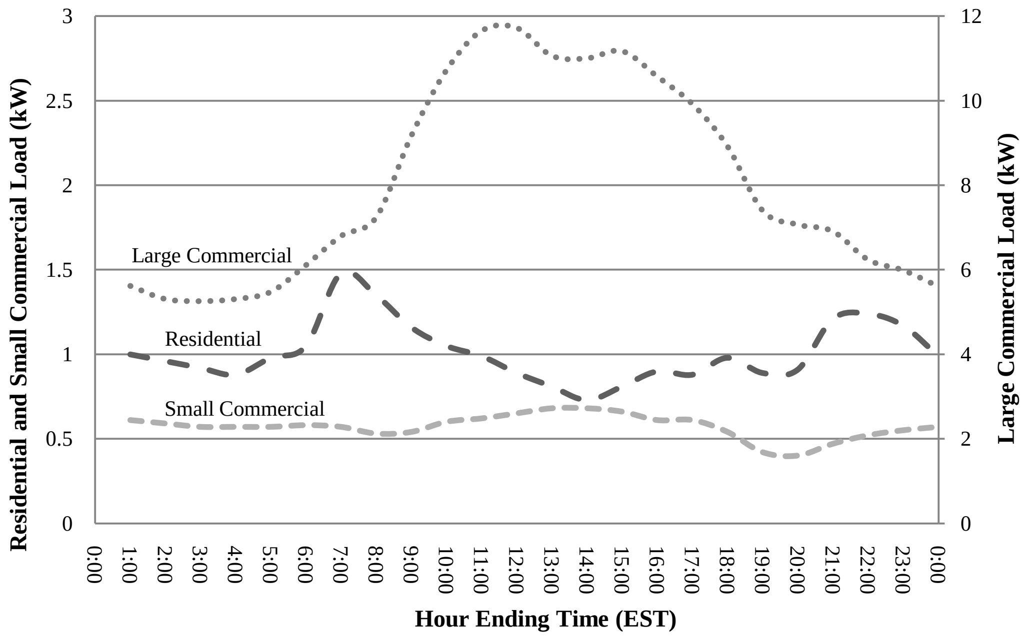

Figure 3.2 – Average Hourly Loads for Small Rates at CSPC April 23, 2009

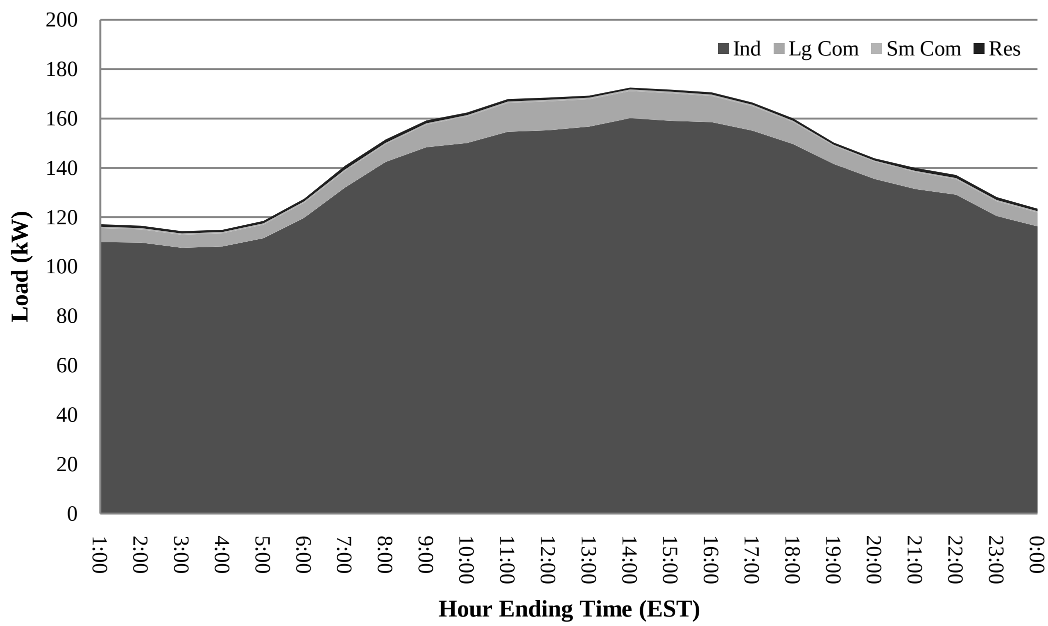

Figure 3.3 - Total Average Hourly Loads for CSPC April 23, 2009

Four metering rates are featured: Residential (Res), Small Commercial (Sm Com), Large Commercial (Lg Com), and Industrial (Ind). The storage could also provide energy during a blackout and form a microgrid, provide voltage support, and regulate frequency. Many opportunities exist for storage technology implementation.

3.2 Storage Methodology and Assumptions

Electric energy storage strategy can be a complex problem with many nonlinearities concerning the performance and operation of storage technology. The storage strategy can also be designed for many different desired outcomes and optimizations. The goal of this storage strategy is mainly to maximize profit for the storage system owner. The constraints in storage system optimization are to prevent degradation of system performance and operability.

In this approach, the modeling of the storage system has been simplified. The system is assumed to be lossless; the energy stored is equal to the energy recovered. No considerations are taken to optimize battery life and discharging the battery to zero has no ill effects. These assumptions remove the primary nonlinearities from the system and allow for linear programming optimization to determine the schedule for each hour of the day. The battery is also taken to be completely discharged at 0:00 and completely discharged at 24:00. The optimization must charge and then fully discharge the storage system in one 24 hour cycle.

To optimize for cost, a prediction of future costs is needed. Electric energy costs are a complex phenomenon and a prediction of energy use and price is needed. Electric utilities forecast loads for the next day for generation scheduling purposes, but these forecasts are aggregates for the system and are of little use to the storage system owner. A very simple, yet reasonably accurate forecast for demand is load data from a similar day in the past. Figure 3.4 plots the average percent difference between hourly demand on a given day and the 30 days prior.

The data were created using 2009 load data from Columbus Southern Power Company and finding the percent difference between the demand from the last day of the month and every other day of that month. The 12 sets of monthly data were averaged by day and the data seen in Figure 3.4 were created. The forecasted days (i.e. last days of the months) represent every day of the week and include some holidays. The load for a previous day is the best indicator for the smaller rates, residential and small commercial, and capture greater than 85% of the total load. The demand for large industrials and large commercial sectors are more dependent on the day of the week than the lower demand sectors (e.g. residential). Large commercial and industrial loads are best forecasted by looking 7 days prior, which can capture greater than 92% of the actual load. This statement is confirmed by examining Figure 3.4. Past load data will be readily available at the LSE from the smart meter data.

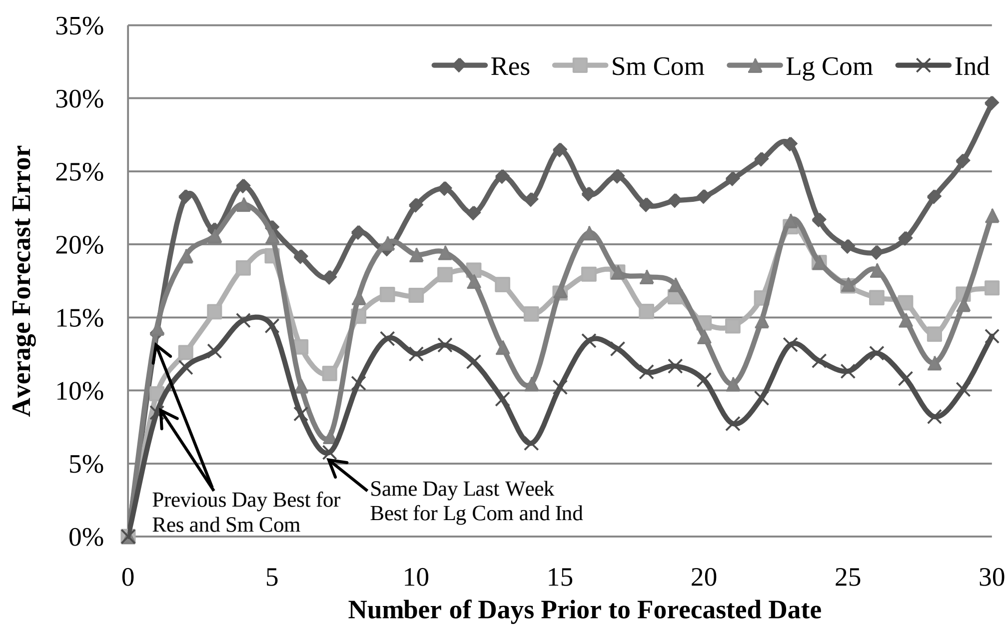

Figure 3.4 - Average Error in Load Forecasts using Past Load Data

Where wholesale power markets exist, the prices for the optimization (i.e. maximization of storage owner profit) are already widely available. The ISOs publish LMP forecasts for the next day, known as Day Ahead LMPs (DALMP). The ISOs publish a study for the next day using demand forecasts and generation offers to determine the DALMPs. The DALMPs are used to clear the majority of the market transactions, about 70% [1], and the real-time LMPs capture the remaining variability in the prices. The DALMPs are posted to the public in the late afternoon. Figure 3.5 illustrates the day-ahead market process for a major ISO.

The LSE also needs to be compensated for its services. This is accounted for by using a multiplier for the energy component of the D-LMP. The average real-time AEP Buckeye LMP for 2009 was $33.31/MWh and the average retail price of electricity across all sectors in Ohio was $0.0901/kWh [36]. Dividing the latter by the former yields a multiplier of 2.7. This shall be the LMP multiplication factor. The D-LMP is largely comprised of the energy component and the DALMP should capture the majority of the price.

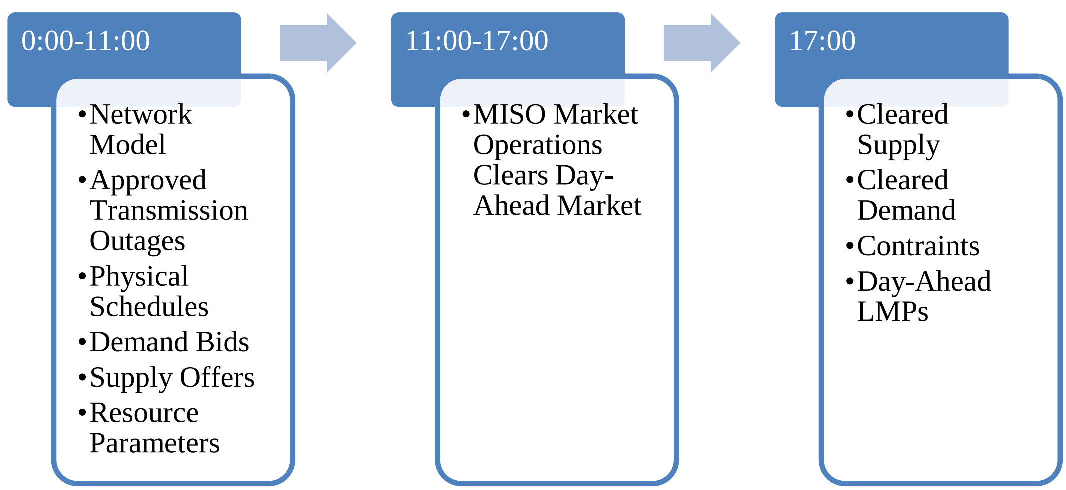

Figure 3.5 – The Midwest ISO Day Ahead Market Process

3.3 Storage Strategy: Base Case

In this section, a storage strategy for distribution engineering is discussed. To facilitate the discussion, a power marketing milieu is assumed, and the specific example of the PJM RTO footprint is chosen. The historical day-ahead LMPs and real-time LMPs are all readily available online from PJM. Load data have also been acquired from Columbus Southern Power Company, which is in the PJM footprint. The focus in this section will be on the residential data, but could be expanded to include all rate schedules. The PJM commercial pricing node associated with CSPC is AEP Buckeye. With actual load and price data available, a realistic optimization problem can be formed.

Wednesday, November, 18 2009 has been chosen as a test date for its price and load variation, as seen in Figure 3.6. For reference, the weather data for that day is included in Table 3.1. As a starting point, the storage system will have a capacity of 12 kWh, and an inverter of 1 kW power rating is assumed. The measure for system performance will be load factor. Load factor is defined as the average power divided by the peak power over a 24 hour period. The measure for operability shall be the hour-to-hour change in load and termed as load variation. Table 3.2 highlights some of the key metrics for the year 2009 and November 18, 2009.

Table 3.1- Historical Weather Conditions from the National Weather Service

Columbus, OH November 18, 2009	
Mean Temp (°F/°C)	52°F / 11.1°C
Min Temp (°F/°C)	49°F / 9.4°C
Max Temp (°F/°C)	55°F/ 12.8°C
Dew Point (°F/°C)	46°F / 7.8°C
Average Humidity	79%
Precipitation (in/mm)	0.05 in / 1.27 mm
Wind Speed (mph/kph)	11 mph / 17.6 kph (ESE)
Events	Rain

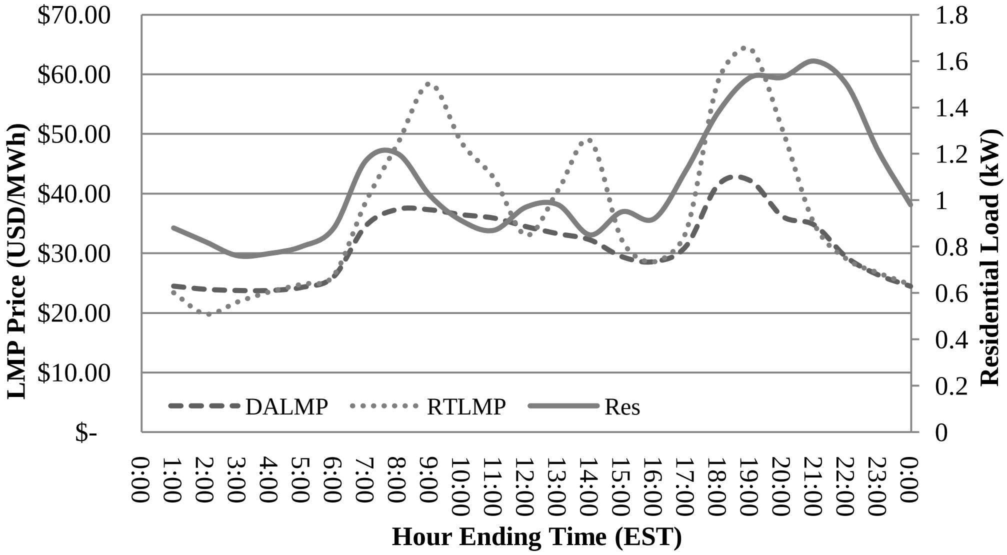

Figure 3.6 - Load and LMP Data for Columbus Southern Power Co.

Table 3.2 - Base Case Data for Storage Strategy

CSPC Residential Base Data		
Metric	2009 Year	November 18, 2009
Peak Load (kW)	3.13	1.6
Average Load (kW)	1.30	1.07
Load Factor	0.73	0.67
Average Load Variation (kW)	0.1	0.11
Min Load Variation (kW)	0	0
Max Load Variation (kW)	0.81	0.29
Cost (USD/Day)	$3.01	$2.65

3.4 Storage Strategy Results: Example 1

Linear programming is used to optimize the storage scheduling for the greatest economic gain, without taking performance constraints into consideration. The optimization problem is summarized in Table 3.4. The schedule and results of Figure 3.7 are determined. This example is denoted as Example 1, and the defining parameters of the example are shown in Table 3.3.

Table 3.3 – Defining Factors of Example 1

Energy Storage Element	
Useable Storage Capacity	12 kWh
Inverter Rating	1 kW
Losses	-0-
System Description	
Type	Residential
Load Factor	0.73
Basic System Description	Table 3.2
Demand Profile	Figure 3.6
Pricing Information	Figure 3.6
Further Constraints: None	

Table 3.4 - Example 1 Optimization Problem

$minimize\ f$ $f(S) = SL_{DA}$	Optimization Function *S* is the storage schedule matrix (neg. values are discharging) L_{DA} is the DALMPs
Constraints	
$0\text{ kWh} \leq S_1 \leq 12\text{ kWh}$ $0\text{ kWh} \leq S_1 + S_{24} \leq 12\text{ kWh}$ … $0\text{ kWh} \leq S_1 + \ldots S_{23} \leq 12\text{ kWh}$	Energy Storage Limit The energy in the storage unit cannot be negative or exceed its capacity. The sum any elements of *S*, S_m, must be within the capacity.
$S_1 + \ldots S_{24} = 0\text{ kWh}$	Full Discharge The storage must be fully discharged at the end of a 24 hour cycle
Bounds	
ub = 1 kW	Converter Power Limit The charging power for any element of *S* is bounded
lb = -1 kW	Converter Power Limit The discharging power for any element of *S* is bounded

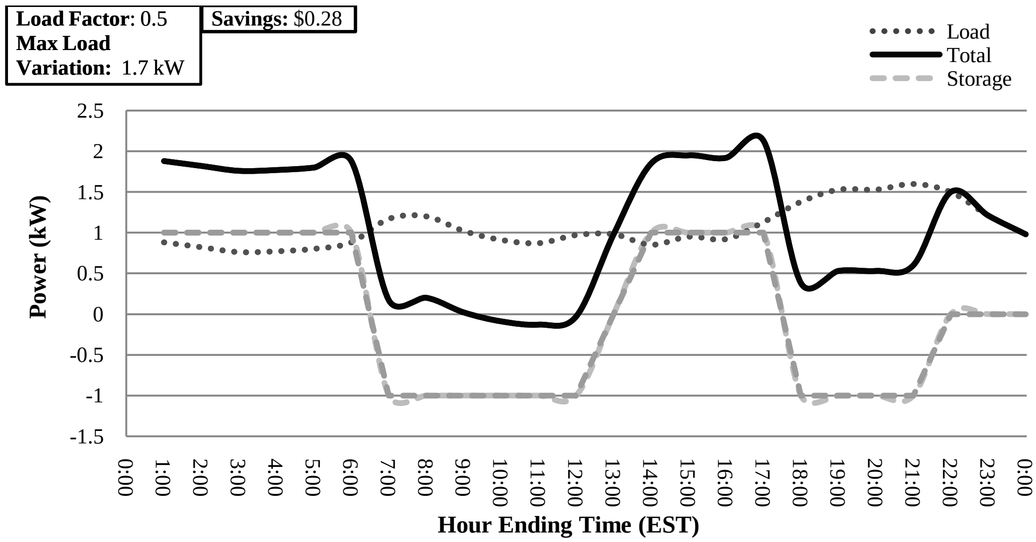

Figure 3.7- Economic Optimization of Storage without Operational Considerations

Example 1 projects $0.28, or 11%, in savings for the day under study. Unfortunately, the load factor was reduced to 0.5 and the maximum load variation was more than doubled to 1.7 kW. Although not a problem on a small scale, rapid load changes on a system-wide scale may lead to large frequency excursions and voltage problems on the grid, threatening the reliability. It should be noted that if this storage methodology was ubiquitous across the system, price feedback would levelize the real-time price.

The economic optimization of storage may degrade some system metrics. The economic solution is to purchase as much energy as possible when is it low cost, constrained by capacity or power. This economic strategy entails discharge at the peak price hour, constrained by the inverter power. This strategy may lead to rapid power swings and increased load peaks as seen in Figure 3.7. Figure 3.8 exemplifies the relationship between economic optimization and load factor.

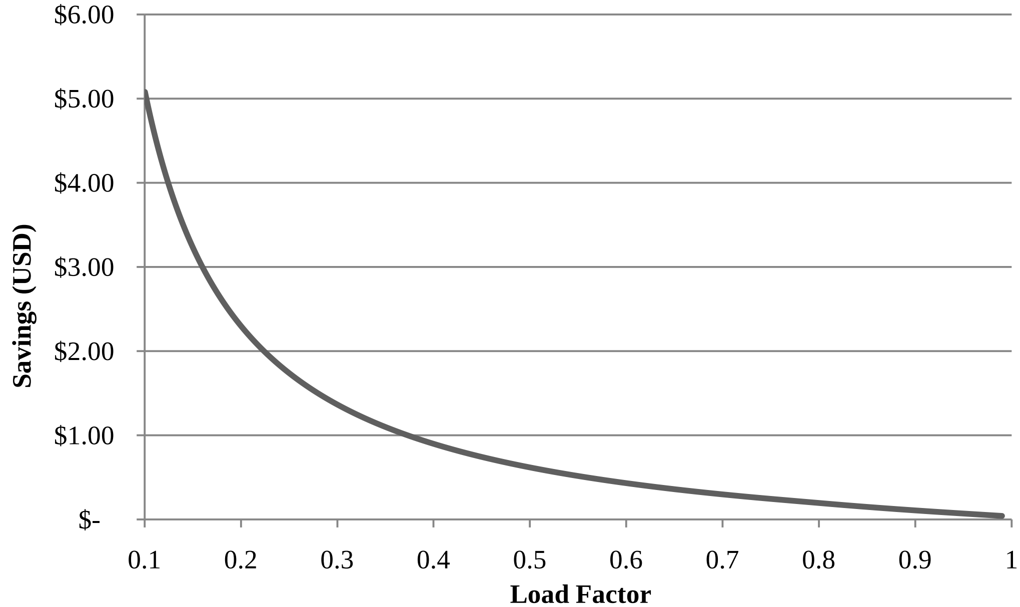

Figure 3.8 – Realized Savings with Constrained Load Factor

3.5 Storage Strategy Results: Example 2

To address the operability, the maximum load variability will be added as a constraint to Example 1. Load variability is defined as the hour to hour change in load. This is done by analyzing the prior load data and determining the constraints. Table 3.5 shows the conditions for a further example denoted as Example 2.

Table 3.5 – Defining Factors of Example 2

Energy Storage Element	
Useable Storage Capacity	12 kWh
Inverter Rating	1 kW
Losses	-0-
System Description	
Type	Residential
Load Factor	0.73
Basic System Description	Table 3.2
Demand Profile	Figure 3.6
Pricing Information	Figure 3.6
Further Constraints	
Load Factor	0.8
Load Variability	0.1 kW

The yearly average load variability is 0.1 kW, and is calculated as,

$$\Delta_P = \sum_{m=1}^{8759} \frac{|P_{m+1} - P_m|}{8759}. \quad (3.1)$$

Where Δ_P is the yearly average load variability and P_m refers to the load demand at hour *m*. The calculated yearly average load variability will be used as a limit of the load variability because the optimization will always be binding against this constraint. Further relaxing it would increase Δ_P. Additionally, the daily starting and ending power is constrained to limit the load variation over the midnight hour. The total service entrance demand powers at hours 1 and 24 are limited to ±0.05 kW of the average power for the day. Although not exact, this method will be greater than 85% accurate as seen in Figure 3.4.

Load factor also must be addressed for the optimization in Example 2. This can readily be done using an upper bound on the converter power and relaxing the specified power and capacity constraints for the storage system. The upper bound vector, *ub*, of the optimization can be reformulated as the peak power at the service entrance at each hour. *Pk* is the total power vector, *P* is the power at the load, and *S* is the storage power,

$$Pk = P + S. \quad (3.2)$$

Since the storage is being constrained, *ub* can be substituted in place for *S*,

$$ub = Pk - P. \quad (3.3)$$

Using Equation (3.3), the upper bound on the storage power for each hour can be found. *ub* is a function of *Pk.* If *Pk* is a constant, then $P + ub$ will equal the same value, the constant, for each hour. The load factor, *LF*, is given by (3.4),

$$LF = \frac{P_{avg}}{P_{max}}. \quad (3.4)$$

Substituting P_{max} into *Pk*, Equation (3.5) is produced,

$$ub = \left(\frac{P_{avg}}{LF}\right) - P. \quad (3.5)$$

To maintain the yearly average load factor, the value of *LF* must be overshot because the prior day is an imperfect replica of the actual load day. An empirically derived *LF* value of 0.8 delivers appropriate results to maintain the yearly average at 0.73. A solution to Example 2 is found by applying the above constraints to the optimization seen in Figure 3.9. The optimization problem is summarized in Table 3.6. The associated MATLAB code is located in Appendix A.

Table 3.6 - Example 2 Optimization Problem

$minimize\ f$ $f(S) = SL_{DA}$	<u>Optimization Function</u> *S* is the storage schedule matrix (neg. values are discharging) L_{DA} is the DALMPs
Constraints	
$0\ kWh \le S_1 \le \infty\ kWh$ $0\ kWh \le S_1 + S_{24} \le \infty\ kWh$ … $0\ kWh \le S_1 + \ldots S_{24} \le \infty\ kWh$	<u>Energy Storage Limit</u> The energy in the storage unit cannot be negative. The capacity limit has been relaxed.
$S_1 + \ldots S_{24} = 0\ kWh$	<u>Full Discharge</u> The storage must be fully discharged at the end of a 24 hour cycle
$\lvert(P+S)_{m+1} - (P+S)_m\rvert \le 0.1\ kW$	<u>Load Variability Limit</u> The hour to hour change is load is limited for operability
$\lvert(P+S)_1 - P_{avg}\rvert \le 0.05\ kW$ $\lvert(P+S)_{24} - P_{avg}\rvert \le 0.05\ kW$	<u>Load Variability Over Midnight</u> The hour to hour change in load over the midnight hour is limited
Bounds	
$ub = \left(\frac{P_{avg}}{0.8}\right) - P$	<u>Load Factor Limit</u> The load factor is bounded for the system
$lb = \infty$	<u>Converter Power Limit</u> The power for any element of *S*, S_m, is relaxed

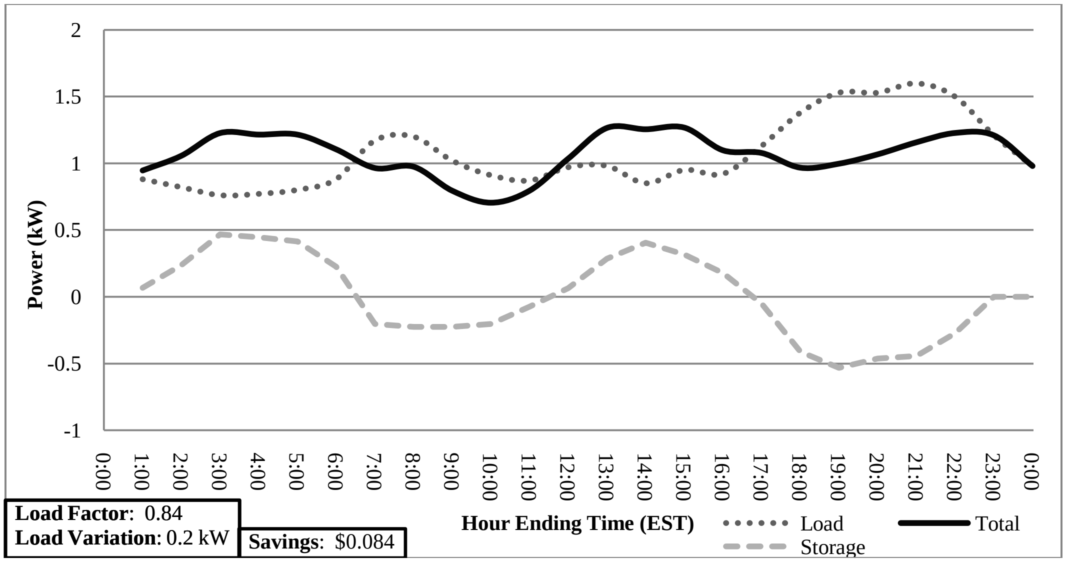

Figure 3.9 - Economic Optimization Example 2

The optimization met all requirements and satisfied all constraints. The projection of November 17, 2009 to November 18, 2009 improved the load factor quite substantially. The load variation increased but the load variation remains well within precedent. The projected savings were reduced to $0.08 or 3%. When the real-time LMPs are used, the savings were $0.16 as the real-time LMPs were much higher than forecasted. A picture of the robustness of this methodology beyond this single day is garnered by extending this model to the entire year. This is summarized in Table 3.7.

Table 3.7 - Comparison of System Characteristics Before and After Optimization

Metric	Base 2009 Year	Optimized 2009 Year
Peak Load (kW)	3.13	2.81
Average Load (kW)	1.30	1.30
Load Factor	0.73	0.76
Average Load Variation (kW)	0.1	0.12
Min Load Variation (kW)	0	0
Max Load Variation (kW)	0.81	0.85
Cost (USD/Day)	$3.01	$2.83

The Example 2 system was improved or unchanged in all categories except for the maximum load variation, which had a marginal increase. Per annum, one would save $64 dollars with this storage configuration. By relaxing the power and capacity constraints of the storage, the power and capacity can be determined by the constraints on load factor and variation. In this example the resulting maximum power was 1.6 kW and the maximum energy was 11.5 kWh. Thus a 2 kW converter and 12 kWh of storage would be sufficient for this example. By comparison, a typical automobile lead-acid storage battery can store about 4.3 kWh of energy.

The income from such a storage system may not pay itself off in a timely fashion. The batteries and power electronics could be cost prohibitive. An LSE may allow for a lower power factor on its system and provide more appealing economic prospects. The opportunity also exists for sub-hourly power ramping, which would allow greater power levels to flow without high load variation. Real-time price triggers may also be a catalyst to make the situation more profitable. The increasing popularity of electric vehicles (EVs) may introduce a storage capability that does not require a payback time as an EV was purchased as transportation. Overall, if such storage methodology becomes wide spread and the grid performance and operability is to be maintained, a storage system may not be economically palatable.

3.6 Summary and Conclusion

Real-time varying prices allow for the strategic buying and selling of electric energy for a net economic gain. These storage systems can provide energy during a blackout, voltage support, and frequency regulation, all of which are a part of a healthy grid. The storage could also levelize the load, while reducing the need for peaking capacity. By simplifying the models used, linear programming can be used to determine the optimum dispatch for each hour of the day. The goal of this optimization is to maximize profit for the day, constrained by load factor and load variation. The day-ahead LMPs and a load from a prior day are used to optimize the cost. The data used in the optimizations are actual values from 2009 at the Columbus Southern Power Company and PJM. The optimal economic scheduling of storage may negatively affect some system metrics and the optimization must be constrained. Applying constraints can meet the requirements for all metric at the expense of profit. The storage system parameters are calculable using the linear programming algorithm. Transmission feedback may alter the final optimal storage schedule and will need to be addressed in future work. These issues were presented in two illustrative examples.

CHAPTER 4

TEST BED, SIMULATION, AND RESULTS

4.1 Introduction and Objectives

The D-LMP is largely built upon existing concepts from the transmission LMP. Many software bundles have the ability to calculate optimal (economic) power flow (OPF) and the associated LMPs. One such piece of software is the Powerworld Simulator developed by the Powerworld Corporation. Powerworld can readily calculate the first two components of Equation (2.3) at each bus in a system, and Excel can be used to calculate the remaining DG component. Equation (2.3) is repeated here for convenience,

$$\underbrace{\Lambda_j}_{D-LMP} = \underbrace{\omega\lambda_i}_{Energy} - \underbrace{\omega\lambda_i\mathcal{L}_j}_{Losses} + \underbrace{\frac{\mu P_j}{P_j + \gamma}}_{Renewable\ DG}. \tag{4.1}$$

Chapter 4 will use this technique to present the operation of the D-LMP in a distribution network test bed and the results will be discussed. Different combinations of storage and penetrations of PV are compared in simulation. Cost analysis will be performed between flat-rate sector pricing and D-LMP pricing. The payment to the DGs and its economic implications will also be discussed. This section should provide an understanding of the role of a D-LMP as a real-time pricing mechanism in a distribution system.

4.2 Development of the Test Bed

A test bed was developed for this thesis with the goal of being both realistic and driven by historic data. A simple 20 bus distribution network was used as the basis. This 13.8 kV network is dubbed the Red, Yellow, Green (RYG) system. The RYG system is shown in Figure 4.1. It consists of 3 color coded radials extending from a feeder bus and has several tie lines which can network each radial to another. Buses 1, 6, and 17 begin the red, yellow, and green radials respectively.

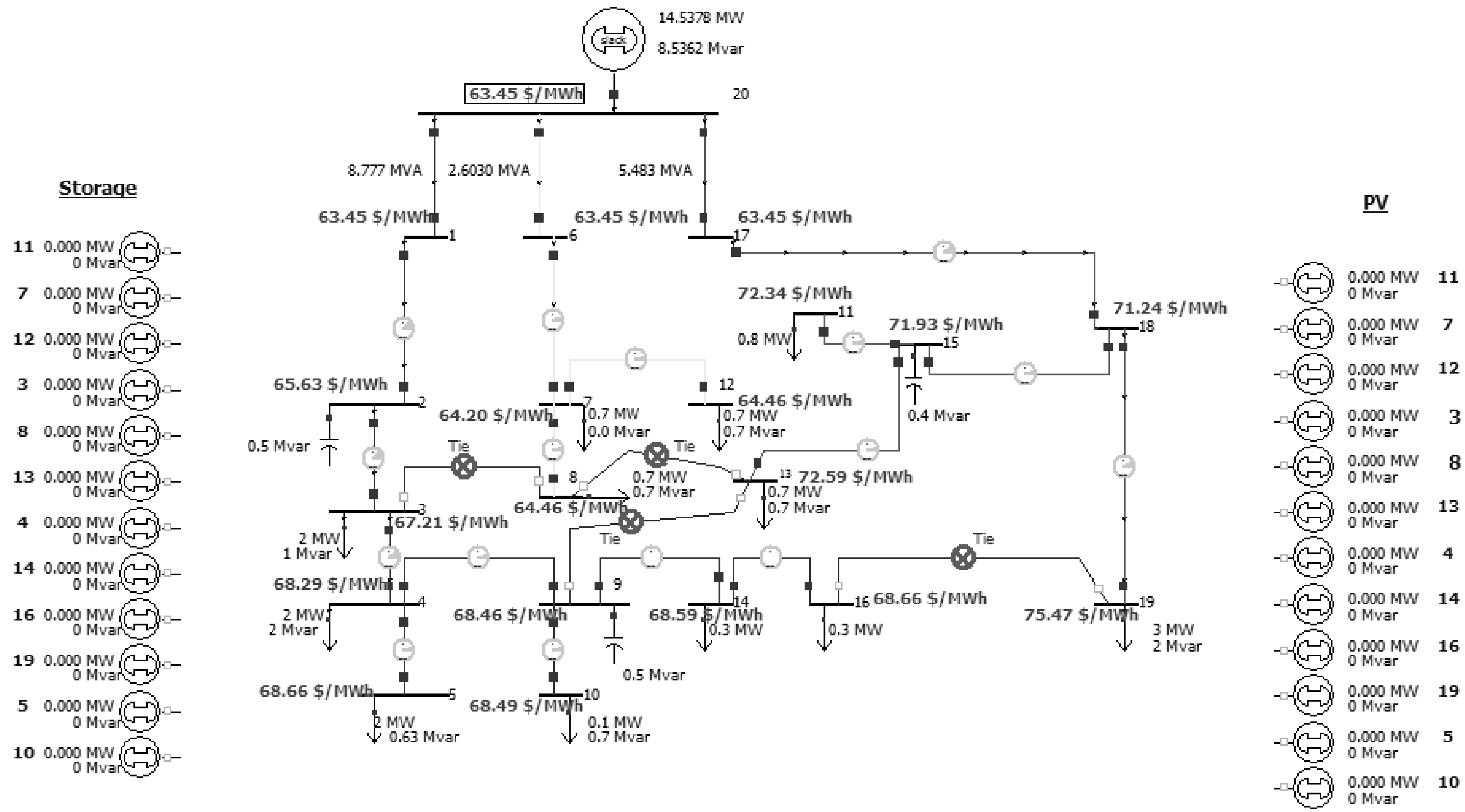

Figure 4.1 – The Powerworld Oneline of the RYG Distribution Network

The feeder bus in this system is bus 20. The feeder bus is modeled as an infinite bus, meaning no effect from the RYG system will change its characteristics (e.g. LMP, voltage). The legacy grid is modeled as a generator capable of infinite positive and negative generation. Negative generation indicates that the system is generating an excess of energy and the excess energy is being sent into the legacy grid. Most buses in the system have a load attached, but some buses only have capacitive load as denoted by the capacitor symbol. Buses 2, 19, 15 are these capacitive loads and are considered static for reactive power support. Further details on the test bed are listed in Appendix B.

The load buses are considered aggregates of a particular class of load, either residential, large commercial, small commercial, or industrial. The bus and load characteristics of the system are described in Table 4.1.

Table 4.1 – Bus Description of the RYG System

Bus	Real Load (MW)	Reactive Load (MVAr)	Radial	Load Class	PV	Storage
1	0	0	RED	-	N	N
2	0	-0.5	RED	-	N	N
3	2	1	RED	IND	Y	N
4	2	2	RED	IND	Y	N
5	1	0.4	RED	LGCOM	Y	Y
6	0	0	YLW	-	N	N
7	0.5	0	YLW	RES	Y	Y
8	0.5	0.5	YLW	RES	Y	Y
9	0	-0.5	RED	-	N	N
10	0.1	0.5	RED	SMCOM	Y	N
11	0.5	0	GRN	LGCOM	Y	Y
12	0.5	0.5	YLW	RES	Y	Y
13	0.5	0.5	GRN	RES	Y	Y
14	0.2	0	RED	RES	Y	Y
15	0	-0.5	GRN	-	N	N
16	0.2	0	RED	RES	Y	Y
17	0	0	GRN	-	N	N
18	0	0	GRN	-	N	N
19	1	0.8	GRN	RES	Y	Y
20	FEEDER	-	-	-	-	-

Each load bus has two generators attached; one models a storage system and the other models a PV array. The PV and storage inject power at a power factor of 1. Every load class has a PV array attached but only residential and large commercial buildings have storage systems. Storage systems only exist for residential and large commercial for several reasons. Small commercial uses very little load and they generally do not own their building, yet they do pay the utility bill. Thus the building owner has no incentive to install a storage system. An industrial storage system would physically be very large and would require a great deal of real estate. Industry also benefited the least from a storage system. Using the methodology of Chapter 3, the yearly utility bill only had a 2% reduction, a minimal benefit. The storage for all of the loads was determined using the methodology presented in Chapter 3. The PV array is sized as a percentage of peak demand for a particular load; described mathematically in Equation (4.2),

$$PV_{DC} = NP_{pk} \ . \tag{4.2}$$

Where PV_{DC} is the rated nameplate DC power of the array, N is the stated percent penetration of PV, and P_{pk} is the annual peak hourly demand for the given load.

The load data for this system was gathered from Columbus Southern Power Company for August 10th, 2009, the peak load day for the year. The utility provided average hourly demand for four load sectors: residential, small commercial, large commercial, and industrial. The Day-Ahead and Real-Time LMP data for August 10th were gathered from PJM for the node, AEP Buckeye. The AEP Buckeye node is the pricing node for Columbus Southern Power Company.

The solar data used is from the National Solar Radiation Database. The radiation data is modeled for the Columbus International Airport in 2005 and recalculated for a South facing 220 Watt BP 3220T solar panel at a 30° angle. Details of the solar calculations are in Appendix C. The 2009 dataset was unavailable and a similar hot and sunny say was chosen, August 12, 2005. This collection of real-time data is used with the test bed in Powerworld to create a 24 hour time series. Flat-rate pricing data for Ohio in 2009 was acquired from the United States Energy Information Administration.

The average 2009 per kWh price for industrial, commercial, and residential sectors were 6.71¢, 9.65¢, and 10.67¢ respectively. Using these rates, the annual revenue for the RYG system can be determined. Using historical data, the weight, ω, in Equation (2.3) can be varied until the same annual revenue is found using the D-LMP. In this case, the breakeven value of ω is 2.56. The value of ω for the test bed is rounded to 2.5, citing the real-time pricing advantages listed in Section 1.4. The variables μ and γ of Equation (2.3) are set to \$0.20/kWh and 1 respectively. As a reminder, μ is the cap on the renewable component and γ is the aggressiveness of the formula reaching the cap.

The load data for the system was modeled using the peak load day from the utility. The hourly loads from August 10th, 2009 were scaled such that the new load average for that day equals the values in Table 4.1 at each respective bus. The storage and PV were also scaled to reflect the size of the aggregation. The number of units in the load aggregate at a particular bus is equal to the scaling factor. This load sizing information is summarized in Table 4.2.

The test bed is simulated with a 24 hour time series in Powerworld for various combinations of PV penetration, storage, and system networking (i.e. closing the tie lines). These test cases are presented in Table 4.3. Each of these cases includes a oneline diagram from the peak hour, D-LMP prices, and cost analysis. The oneline figures do not weight the D-LMP energy cost. For purposes of the presentation of results, the details of cases 1, 2, 3, 4, 9, and 10 are shown here, and the detailed results of the remaining cases are shown in Appendix D.

Table 4.2 – RYG System Load Information

Load Bus	Load Type	Real Load (MW)	Yearly Peak Hourly Load, P_{pk} (kW)	Peak Day Average (kW)	Scaling Factor
3	IND	2	209.97	168.36	11.88
4	IND	2	209.97	168.36	11.88
5	LGCOM	1	17.57	11.06	90.41
7	RES	0.5	3.13	1.80	277.46
8	RES	0.5	3.13	1.80	277.46
10	SMCOM	0.1	1.23	0.82	121.27
11	LGCOM	0.5	17.57	11.06	45.20
12	RES	0.5	3.13	1.80	277.46
13	RES	0.5	3.13	1.80	277.46
14	RES	0.2	3.13	1.80	110.98
16	RES	0.2	3.13	1.80	110.98
19	RES	1	3.13	1.80	1109.43

Table 4.3 - Simulation Test Cases

Case	PV Penetration	Storage	RYG Networked
1 (Base)	0%	N	N
2	0%	Y	N
3	10%	N	N
4	10%	Y	N
*5	25%	N	N
*6	25%	Y	N
*7	50%	N	N
*8	50%	Y	N
9	100%	N	N
10	100%	Y	N
11 (Special)	100%	Y	Y
12 (Special)	200%	Y	Y
*The details of these cases appear in Appendix D			

4.3 Simulation Results: Base Case

Case 1 establishes a baseline to compare further cases against. It contains the loads but no storage and no PV. The tie lines remain open and the system remains radial rather than networked. Figure 4.2 graphs the total effective system load (load, storage, and PV), PV, and D-LMP price at the feeder.

Figure 4.3 is the oneline at 3 pm, the peak demand for the day. The load D-LMP is listed next to each bus and the contouring is based on the D-LMP, with darker color indicating higher prices. The highest price is seen at bus 19 and the lowest price is at the feeder. The line losses in the netowrk are causing a 19% price increase at bus 19. The large loads at the end of the radials have higher D-LMPs, as expected.

Table 4.4 lists the hourly D-LMPs for a load at every bus. The maximum price occurs at 1:00 PM on bus 19, with a value of \$0.303/kWh. In contrast, the lowest price at a load is \$0.063/kWh. The loads are being charged based on their effect on the system losses, as expected in Chapter 2. Because there is no PV, the D-LMPs at DGs in Table 4.5 are equal to Table 4.4. Table 4.6 lists the per unit voltages at each bus for the 24 hour time period. The highest voltage is 1.00 pu and the lowest is 0.90 pu. The lower value is at the threshold of a low voltage situation.

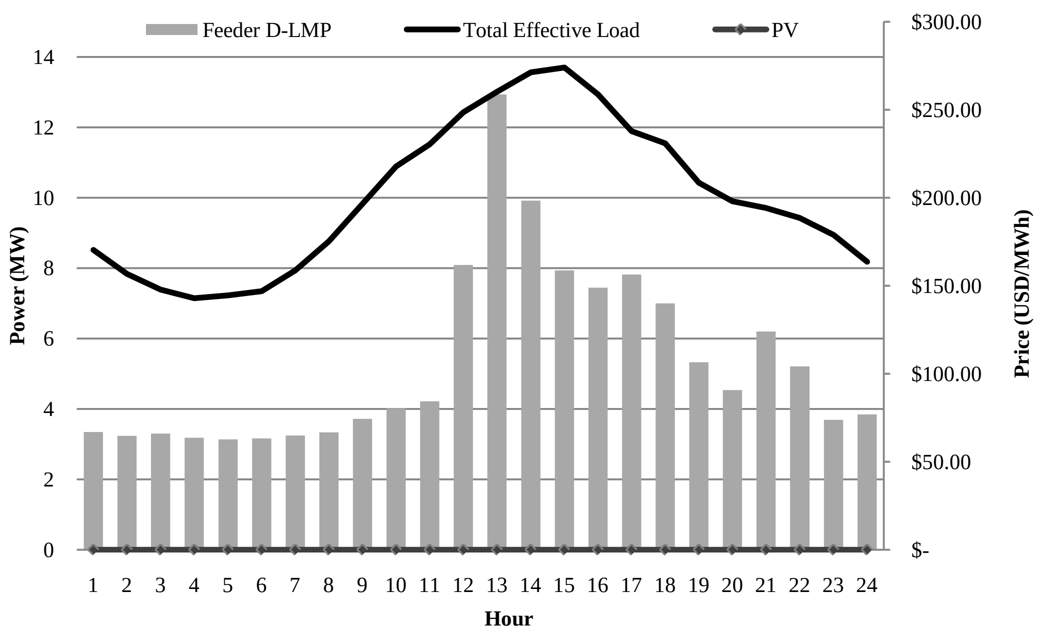

Figure 4.2 – Base Case System Data

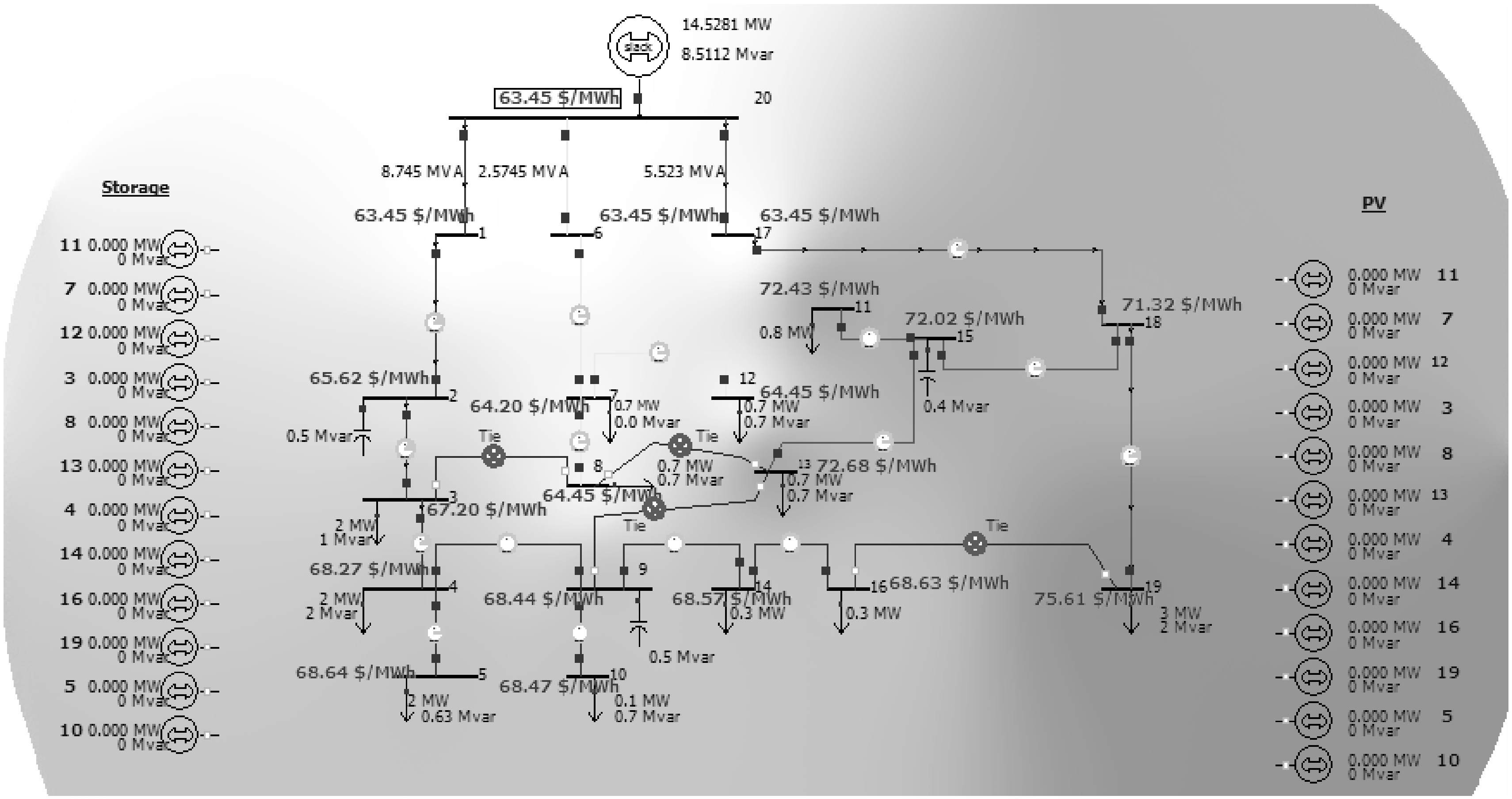

Figure 4.3 – Base Case Oneline at Peak Demand

Table 4.4 – Base Case Load D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Load DLMP (USD/kWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	0.06685	0.06815	0.06908	0.06968	0.06985	0.06685	0.06738	0.06755	0.0698	0.0698	0.07205	0.06755	0.0723	0.06988	0.07188	0.06993	0.06685	0.0715	0.07408	0.06685
2:00:00 AM	64.65	0.06465	0.06588	0.06675	0.0673	0.06745	0.06465	0.06508	0.06523	0.0674	0.0674	0.06893	0.06523	0.0691	0.06748	0.06878	0.0675	0.06465	0.06848	0.07055	0.06465
3:00:00 AM	66.00	0.066	0.06723	0.06808	0.06865	0.06878	0.066	0.0664	0.06653	0.068725	0.06875	0.06993	0.06653	0.07008	0.0688	0.06978	0.06883	0.066	0.06948	0.07135	0.066
4:00:00 AM	63.55	0.06355	0.06473	0.06555	0.06608	0.0662	0.06355	0.0639	0.06403	0.06615	0.06618	0.06703	0.06403	0.06715	0.0662	0.0669	0.06625	0.06355	0.06665	0.06828	0.06355
5:00:00 AM	62.725	0.06273	0.06388	0.0647	0.06523	0.06535	0.06273	0.06308	0.0632	0.0653	0.06533	0.06618	0.0632	0.0663	0.06535	0.06603	0.06538	0.06273	0.06578	0.0674	0.06273
6:00:00 AM	63.175	0.06318	0.06445	0.06535	0.06593	0.06608	0.06318	0.0635	0.0636	0.066	0.06603	0.0665	0.0636	0.06658	0.06605	0.06633	0.06608	0.06318	0.06608	0.06755	0.06318
7:00:00 AM	64.875	0.06488	0.0663	0.06733	0.06795	0.06813	0.06488	0.06523	0.06535	0.06805	0.06805	0.0686	0.06535	0.0687	0.0681	0.06843	0.06813	0.06488	0.06815	0.0698	0.06488
8:00:00 AM	66.70	0.0667	0.06833	0.06948	0.07023	0.07043	0.0667	0.0671	0.06725	0.0703	0.07033	0.07108	0.06725	0.07118	0.07038	0.07088	0.0704	0.0667	0.07053	0.07245	0.0667
9:00:00 AM	74.30	0.0743	0.07633	0.0778	0.07875	0.07905	0.0743	0.0748	0.07498	0.078875	0.07888	0.07995	0.07498	0.08005	0.07895	0.07968	0.079	0.0743	0.0792	0.08165	0.0743
10:00:00 AM	80.275	0.08028	0.0827	0.08445	0.0856	0.08598	0.08028	0.0809	0.0811	0.08575	0.08578	0.08748	0.0811	0.08758	0.08585	0.08708	0.0859	0.08028	0.08648	0.0896	0.08028
11:00:00 AM	84.30	0.0843	0.08695	0.08885	0.09013	0.09055	0.0843	0.08503	0.08525	0.0903	0.09033	0.09265	0.08525	0.09278	0.09043	0.0922	0.09048	0.0843	0.09153	0.0952	0.0843
12:00:00 PM	161.675	0.16168	0.16698	0.17083	0.1734	0.17423	0.16168	0.16325	0.1638	0.17375	0.17383	0.18013	0.1638	0.18055	0.17403	0.17923	0.17418	0.16168	0.17775	0.18625	0.16168
1:00:00 PM	258.7	0.2587	0.26728	0.27353	0.27775	0.2791	0.2587	0.2615	0.26245	0.278375	0.2785	0.2916	0.26245	0.2925	0.27885	0.2901	0.2791	0.2587	0.2875	0.30305	0.2587
2:00:00 PM	198.375	0.19838	0.2051	0.21	0.2133	0.2144	0.19838	0.2007	0.20148	0.213825	0.21393	0.22585	0.20148	0.22668	0.21423	0.22465	0.21443	0.19838	0.22253	0.23578	0.19838
3:00:00 PM	158.625	0.15863	0.164	0.1679	0.17058	0.17143	0.15863	0.16048	0.1611	0.170975	0.17105	0.1806	0.1611	0.18125	0.1713	0.17963	0.17145	0.15863	0.17793	0.18853	0.15863
4:00:00 PM	148.90	0.1489	0.15365	0.15708	0.15943	0.16018	0.1489	0.15058	0.15113	0.1598	0.15988	0.16845	0.15113	0.16905	0.16008	0.1676	0.16023	0.1489	0.1661	0.17553	0.1489
5:00:00 PM	156.25	0.15625	0.16085	0.16418	0.1664	0.16708	0.15625	0.15785	0.15838	0.16675	0.16683	0.1742	0.15838	0.17478	0.16703	0.17343	0.16715	0.15625	0.17208	0.1807	0.15625
6:00:00 PM	140.00	0.14	0.14383	0.14658	0.1484	0.14893	0.14	0.14148	0.14195	0.148725	0.14878	0.15603	0.14195	0.15668	0.14895	0.15543	0.14908	0.14	0.15428	0.16225	0.14
7:00:00 PM	106.50	0.1065	0.10913	0.11103	0.11225	0.11258	0.1065	0.1075	0.10785	0.11245	0.1125	0.11693	0.10785	0.1174	0.11263	0.11658	0.1127	0.1065	0.11585	0.12108	0.1065
8:00:00 PM	90.625	0.09063	0.09288	0.09448	0.09553	0.0958	0.09063	0.09148	0.09178	0.0957	0.09573	0.0995	0.09178	0.0999	0.09583	0.0992	0.0959	0.09063	0.09858	0.10303	0.09063
9:00:00 PM	124.025	0.12403	0.1268	0.1288	0.1301	0.13045	0.12403	0.12513	0.1255	0.130325	0.13038	0.13535	0.1255	0.13588	0.1305	0.13498	0.1306	0.12403	0.13418	0.13988	0.12403
10:00:00 PM	104.10	0.1041	0.10645	0.10813	0.1092	0.1095	0.1041	0.10503	0.10535	0.1094	0.10943	0.1136	0.10535	0.11405	0.10955	0.11328	0.10963	0.1041	0.11263	0.1174	0.1041
11:00:00 PM	73.70	0.0737	0.07528	0.07638	0.0771	0.07728	0.0737	0.07428	0.07448	0.077225	0.07725	0.07955	0.07448	0.07983	0.07733	0.07938	0.07738	0.0737	0.07895	0.08188	0.0737
12:00:00 AM	76.90	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table 4.5 – Base Case Generation D-LMP Prices

	Cost of Energy	Gen DLMPs (USD/MWh)																			
Hour	(USD/MWh)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.15	69.08	69.68	69.85	66.85	67.38	67.55	69.80	69.80	72.05	67.55	72.30	69.88	71.88	69.93	66.85	71.50	74.08	66.85
2:00:00 AM	64.65	64.65	65.88	66.75	67.30	67.45	64.65	65.08	65.23	67.40	67.40	68.93	65.23	69.10	67.48	68.78	67.50	64.65	68.48	70.55	64.65
3:00:00 AM	66.00	66.00	67.23	68.08	68.65	68.78	66.00	66.40	66.53	68.73	68.75	69.93	66.53	70.08	68.80	69.78	68.83	66.00	69.48	71.35	66.00
4:00:00 AM	63.55	63.55	64.73	65.55	66.08	66.20	63.55	63.90	64.03	66.15	66.18	67.03	64.03	67.15	66.20	66.90	66.25	63.55	66.65	68.28	63.55
5:00:00 AM	62.73	62.73	63.88	64.70	65.23	65.35	62.73	63.08	63.20	65.30	65.33	66.18	63.20	66.30	65.35	66.03	65.38	62.73	65.78	67.40	62.73
6:00:00 AM	63.18	63.18	64.45	65.35	65.93	66.08	63.18	63.50	63.60	66.00	66.03	66.50	63.60	66.58	66.05	66.33	66.08	63.18	66.08	67.55	63.18
7:00:00 AM	64.88	64.88	66.30	67.33	67.95	68.13	64.88	65.23	65.35	68.05	68.05	68.60	65.35	68.70	68.10	68.43	68.13	64.88	68.15	69.80	64.88
8:00:00 AM	66.70	66.70	68.33	69.48	70.23	70.43	66.70	67.10	67.25	70.30	70.33	71.08	67.25	71.18	70.38	70.88	70.40	66.70	70.53	72.45	66.70
9:00:00 AM	74.30	74.30	76.33	77.80	78.75	79.05	74.30	74.80	74.98	78.88	78.88	79.95	74.98	80.05	78.95	79.68	79.00	74.30	79.20	81.65	74.30
10:00:00 AM	80.28	80.28	82.70	84.45	85.60	85.98	80.28	80.90	81.10	85.75	85.78	87.48	81.10	87.58	85.85	87.08	85.90	80.28	86.48	89.60	80.28
11:00:00 AM	84.30	84.30	86.95	88.85	90.13	90.55	84.30	85.03	85.25	90.30	90.33	92.65	85.25	92.78	90.43	92.20	90.48	84.30	91.53	95.20	84.30
12:00:00 PM	161.68	161.68	166.98	170.83	173.40	174.23	161.68	163.25	163.80	173.75	173.83	180.13	163.80	180.55	174.03	179.23	174.18	161.68	177.75	186.25	161.68
1:00:00 PM	258.70	258.70	267.28	273.53	277.75	279.10	258.70	261.50	262.45	278.38	278.50	291.60	262.45	292.50	278.85	290.10	279.10	258.70	287.50	303.05	258.70
2:00:00 PM	198.38	198.38	205.10	210.00	213.30	214.40	198.38	200.70	201.48	213.83	213.93	225.85	201.48	226.68	214.23	224.65	214.43	198.38	222.53	235.78	198.38
3:00:00 PM	158.63	158.63	164.00	167.90	170.58	171.43	158.63	160.48	161.10	170.98	171.05	180.60	161.10	181.25	171.30	179.63	171.45	158.63	177.93	188.53	158.63
4:00:00 PM	148.90	148.90	153.65	157.08	159.43	160.18	148.90	150.58	151.13	159.80	159.88	168.45	151.13	169.05	160.08	167.60	160.23	148.90	166.10	175.53	148.90
5:00:00 PM	156.25	156.25	160.85	164.18	166.40	167.08	156.25	157.85	158.38	166.75	166.83	174.20	158.38	174.78	167.03	173.43	167.15	156.25	172.08	180.70	156.25
6:00:00 PM	140.00	140.00	143.83	146.58	148.40	148.93	140.00	141.48	141.95	148.73	148.78	156.03	141.95	156.68	148.95	155.43	149.08	140.00	154.28	162.25	140.00
7:00:00 PM	106.50	106.50	109.13	111.03	112.25	112.58	106.50	107.50	107.85	112.45	112.50	116.93	107.85	117.40	112.63	116.58	112.70	106.50	115.85	121.08	106.50
8:00:00 PM	90.63	90.63	92.88	94.48	95.53	95.80	90.63	91.48	91.78	95.70	95.73	99.50	91.78	99.90	95.83	99.20	95.90	90.63	98.58	103.03	90.63
9:00:00 PM	124.03	124.03	126.80	128.80	130.10	130.45	124.03	125.13	125.50	130.33	130.38	135.35	125.50	135.88	130.50	134.98	130.60	124.03	134.18	139.88	124.03
10:00:00 PM	104.10	104.10	106.45	108.13	109.20	109.50	104.10	105.03	105.35	109.40	109.43	113.60	105.35	114.05	109.55	113.28	109.63	104.10	112.63	117.40	104.10
11:00:00 PM	73.70	73.70	75.28	76.38	77.10	77.28	73.70	74.28	74.48	77.23	77.25	79.55	74.48	79.83	77.33	79.38	77.38	73.70	78.95	81.88	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table 4.6 – Base Case System Voltage

Hour	Voltage (PU)																			
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.96	0.94	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.97	0.97	1.00	0.97	0.95	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
6:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
7:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
8:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	1.00	0.99	0.96	0.96	0.97	0.99	0.96	0.96	0.97	0.96	1.00	0.97	0.95	1.00
9:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.96	0.95	1.00
10:00:00 AM	1.00	0.98	0.97	0.96	0.95	1.00	1.00	0.99	0.96	0.95	0.95	0.99	0.95	0.95	0.96	0.95	1.00	0.96	0.94	1.00
11:00:00 AM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.95	0.99	0.95	0.95	0.95	0.95	1.00	0.95	0.93	1.00
12:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.94	0.99	0.94	0.95	0.94	0.95	1.00	0.95	0.92	1.00
1:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.94	0.99	0.93	0.95	0.94	0.95	1.00	0.94	0.91	1.00
2:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.93	0.99	0.93	0.95	0.93	0.95	1.00	0.94	0.90	1.00
3:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.93	0.99	0.93	0.95	0.93	0.95	1.00	0.94	0.90	1.00
4:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.93	0.99	0.93	0.95	0.94	0.95	1.00	0.94	0.91	1.00
5:00:00 PM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.96	0.95	0.94	0.99	0.94	0.96	0.94	0.95	1.00	0.95	0.92	1.00
6:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.95	0.92	1.00
7:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
8:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
9:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
10:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.96	0.99	0.95	0.97	0.96	0.97	1.00	0.96	0.94	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

Table 4.7 highlights the key economics of the RYG system. D-LMP revenue is greater than the flat-rate by an appreciable amount. It is 39% greater than the flat-rate. This is not unexpected as this is the peak load day of the year and naturally prices are going to reflect this. In addition, the flat-rate pricing does not reflect the cost of losses. The D-LMP energy cost has the opportunity to be much lower on low load days, but ultimately depends on ω in Equation (2.3).

Table 4.7 – Revenue Streams for Base Case

Cost Stream	Cost (USD)
D-LMP Revenue	$29,786.52
Energy	$27,723.90
Losses	$2,062.62
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	N/A
DG Payments	-

The increase in costs for the D-LMP pricing is not equal across load sectors. The residential price increases by 19%, while industrial load costs increase by 77%. Small commercial increased by 28%, and large commercial increased by 33%. The large loads end up paying more under a D-LMP system, especially since losses are a quadratic function of line current.

4.4 Simulation Result: Case 2

Case 2 is the base case with the addition of a storage system. It contains the loads and storage but no PV. The tie lines remain open and the system remains radial rather than networked. Figure 4.4 shows a load profile much different than that of the base case. There has also been an increase in the load factor and a shaving of the peak load. The load peak has also been shifted to the morning hours.

Figure 4.5 is the oneline at 3 pm. The demand D-LMP is listed next to each bus and the contouring is based on the D-LMP, with darker color indicating higher prices.

The highest price is seen at bus 19 and the lowest price is at the feeder. The losses in the system are causing a 9.5% increase in price at bus 19 to pay for losses. This is a 10% improvement over the base case without storage.

Table 4.8 lists the hourly D-LMPs for a load at every bus. The maximum price occurs at 1:00 PM on bus 19, with a value of $0.287/kWh. The storage reduces the peak D-LMP by 5%. Because there is no PV, the D-LMPs at DGs in Table 4.9 are equal to Table 4.8. Table 4.10 lists the per unit voltages at each bus for the 24 hour time period. The highest voltage is 1.00 pu and the lowest is 0.91 pu. The lower value is a modest improvement yet is still near the threshold of a low voltage situation.

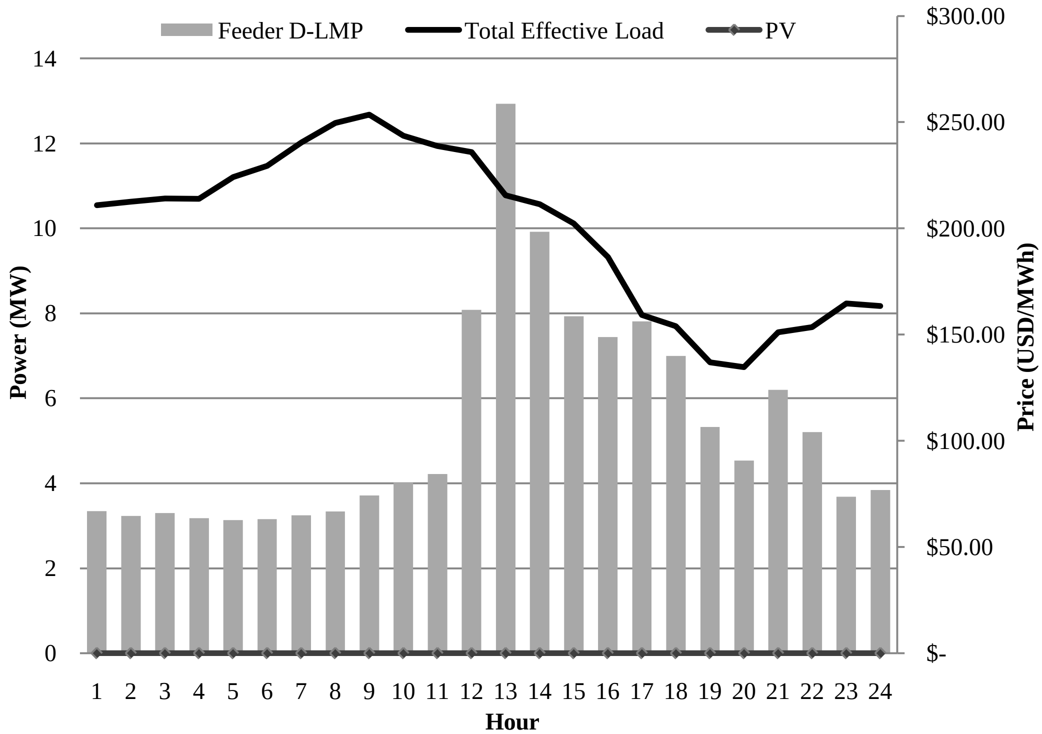

Figure 4.4 - Case 2 System Inputs

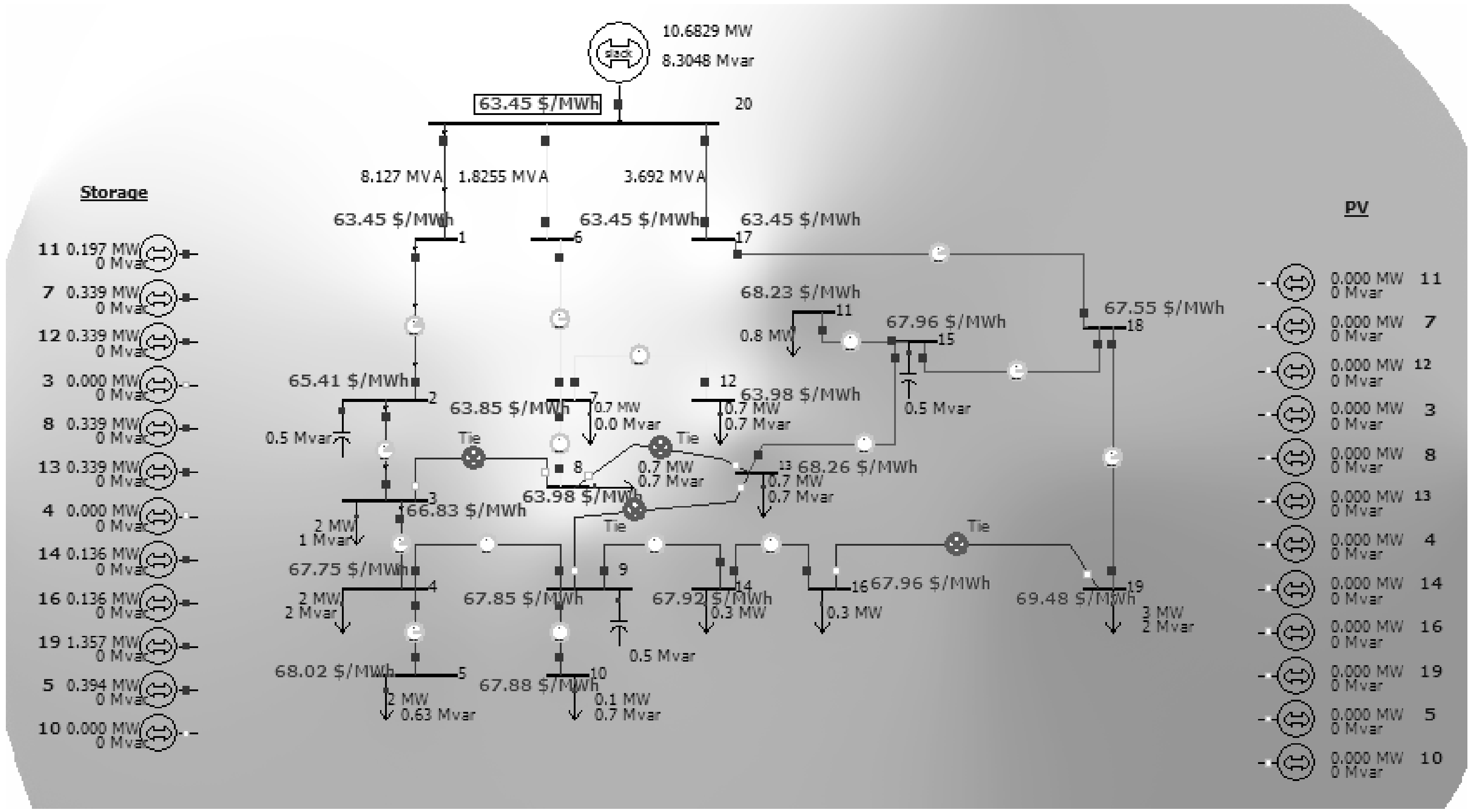

Figure 4.5 – Case 2 Oneline at Peak Demand

Table 4.8 – Case 2 Load D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Load DLMP (USD/kWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	0.06685	0.0683	0.06935	0.07008	0.07033	0.06685	0.06758	0.0678	0.07023	0.07025	0.0744	0.0678	0.0747	0.07033	0.07413	0.0704	0.06685	0.07358	0.07735	0.06685
2:00:00 AM	64.65	0.06465	0.06605	0.06708	0.06778	0.068	0.06465	0.06535	0.06558	0.0679	0.06793	0.072	0.06558	0.0723	0.06803	0.07173	0.06808	0.06465	0.0712	0.0749	0.06465
3:00:00 AM	66.00	0.066	0.06743	0.06843	0.06913	0.06935	0.066	0.06673	0.06698	0.06928	0.0693	0.07363	0.06698	0.07398	0.0694	0.07338	0.06945	0.066	0.07283	0.07673	0.066
4:00:00 AM	63.55	0.06355	0.06493	0.0659	0.06658	0.06678	0.06355	0.06425	0.0645	0.0667	0.06673	0.0709	0.0645	0.07123	0.0668	0.07065	0.06688	0.06355	0.07013	0.07388	0.06355
5:00:00 AM	62.725	0.06273	0.0641	0.06508	0.06575	0.06595	0.06273	0.06348	0.06375	0.06588	0.0659	0.07048	0.06375	0.0709	0.066	0.07025	0.06608	0.06273	0.06973	0.07383	0.06273
6:00:00 AM	63.175	0.06318	0.06463	0.06568	0.06638	0.06658	0.06318	0.06395	0.0642	0.06653	0.06655	0.071	0.0642	0.07143	0.06665	0.07078	0.0667	0.06318	0.07023	0.07438	0.06318
7:00:00 AM	64.875	0.06488	0.06648	0.06763	0.0684	0.06863	0.06488	0.0657	0.06598	0.06855	0.06858	0.0733	0.06598	0.07373	0.06868	0.07305	0.06875	0.06488	0.07245	0.07693	0.06488
8:00:00 AM	66.70	0.0667	0.06848	0.06975	0.07063	0.07088	0.0667	0.06755	0.06783	0.07078	0.0708	0.07555	0.06783	0.07598	0.07093	0.07528	0.071	0.0667	0.07465	0.07928	0.0667
9:00:00 AM	74.30	0.0743	0.07648	0.07805	0.0791	0.07943	0.0743	0.07518	0.07548	0.07928	0.0793	0.08383	0.07548	0.0842	0.07943	0.08345	0.0795	0.0743	0.08275	0.08755	0.0743
10:00:00 AM	80.275	0.08028	0.08275	0.08455	0.08575	0.08613	0.08028	0.08108	0.08135	0.08593	0.08595	0.08935	0.08135	0.08963	0.08605	0.08895	0.08613	0.08028	0.08823	0.0925	0.08028
11:00:00 AM	84.30	0.0843	0.08695	0.08885	0.09013	0.09055	0.0843	0.0851	0.08535	0.0903	0.09035	0.09333	0.08535	0.09355	0.09045	0.0929	0.09053	0.0843	0.09218	0.09633	0.0843
12:00:00 PM	161.675	0.16168	0.16685	0.17063	0.17313	0.1739	0.16168	0.1631	0.16358	0.17345	0.17353	0.17828	0.16358	0.17863	0.1737	0.17745	0.17383	0.16168	0.17613	0.18363	0.16168
1:00:00 PM	258.7	0.2587	0.26678	0.27263	0.27648	0.27763	0.2587	0.26055	0.26118	0.27693	0.27705	0.28098	0.26118	0.28128	0.27725	0.27978	0.2774	0.2587	0.27793	0.28743	0.2587
2:00:00 PM	198.375	0.19838	0.20453	0.209	0.2119	0.21273	0.19838	0.19975	0.2002	0.21225	0.21235	0.21483	0.2002	0.21508	0.21248	0.21398	0.2126	0.19838	0.21263	0.21965	0.19838
3:00:00 PM	158.625	0.15863	0.1635	0.16705	0.16933	0.17	0.15863	0.1596	0.15993	0.1696	0.16968	0.17063	0.15993	0.17073	0.16975	0.16995	0.16985	0.15863	0.16893	0.1738	0.15863
4:00:00 PM	148.90	0.1489	0.15313	0.1562	0.15815	0.15868	0.1489	0.14973	0.15	0.15838	0.15843	0.15888	0.15	0.15898	0.1585	0.15833	0.15858	0.1489	0.1575	0.16163	0.1489
5:00:00 PM	156.25	0.15625	0.16033	0.16328	0.1651	0.16558	0.15625	0.15685	0.15705	0.16528	0.16535	0.16383	0.15705	0.1638	0.16538	0.16335	0.16543	0.15625	0.16268	0.1655	0.15625
6:00:00 PM	140.00	0.14	0.1434	0.14585	0.14738	0.14773	0.14	0.14058	0.14078	0.14753	0.14758	0.14685	0.14078	0.14693	0.1476	0.14648	0.14765	0.14	0.14593	0.14865	0.14
7:00:00 PM	106.50	0.1065	0.10885	0.11055	0.11158	0.1118	0.1065	0.10685	0.10698	0.11168	0.1117	0.11073	0.10698	0.11075	0.11173	0.1105	0.11175	0.1065	0.11015	0.1118	0.1065
8:00:00 PM	90.625	0.09063	0.09263	0.09408	0.09495	0.09515	0.09063	0.09093	0.09103	0.09503	0.09505	0.09423	0.09103	0.09425	0.09508	0.09403	0.0951	0.09063	0.09373	0.09513	0.09063
9:00:00 PM	124.025	0.12403	0.12665	0.12853	0.12973	0.13003	0.12403	0.12465	0.12488	0.12985	0.1299	0.13085	0.12488	0.13103	0.12998	0.13055	0.13003	0.12403	0.13	0.13303	0.12403
10:00:00 PM	104.10	0.1041	0.1063	0.1079	0.10888	0.10913	0.1041	0.10463	0.1048	0.109	0.10903	0.10983	0.1048	0.10998	0.10908	0.10958	0.10913	0.1041	0.10913	0.11165	0.1041
11:00:00 PM	73.70	0.0737	0.07525	0.07635	0.07705	0.07723	0.0737	0.07418	0.07435	0.07715	0.07718	0.07865	0.07435	0.07885	0.07723	0.07848	0.07728	0.0737	0.0781	0.08048	0.0737
12:00:00 AM	76.90	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table 4.9 – Case 2 Generation D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Gen DLMPs (USD/MWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.30	69.35	70.08	70.33	66.85	67.58	67.80	70.23	70.25	74.40	67.80	74.70	70.33	74.13	70.40	66.85	73.58	77.35	66.85
2:00:00 AM	64.65	64.65	66.05	67.08	67.78	68.00	64.65	65.35	65.58	67.90	67.93	72.00	65.58	72.30	68.03	71.73	68.08	64.65	71.20	74.90	64.65
3:00:00 AM	66.00	66.00	67.43	68.43	69.13	69.35	66.00	66.73	66.98	69.28	69.30	73.63	66.98	73.98	69.40	73.38	69.45	66.00	72.83	76.73	66.00
4:00:00 AM	63.55	63.55	64.93	65.90	66.58	66.78	63.55	64.25	64.50	66.70	66.73	70.90	64.50	71.23	66.80	70.65	66.88	63.55	70.13	73.88	63.55
5:00:00 AM	62.73	62.73	64.10	65.08	65.75	65.95	62.73	63.48	63.75	65.88	65.90	70.48	63.75	70.90	66.00	70.25	66.08	62.73	69.73	73.83	62.73
6:00:00 AM	63.18	63.18	64.63	65.68	66.38	66.58	63.18	63.95	64.20	66.53	66.55	71.00	64.20	71.43	66.65	70.78	66.70	63.18	70.23	74.38	63.18
7:00:00 AM	64.88	64.88	66.48	67.63	68.40	68.63	64.88	65.70	65.98	68.55	68.58	73.30	65.98	73.73	68.68	73.05	68.75	64.88	72.45	76.93	64.88
8:00:00 AM	66.70	66.70	68.48	69.75	70.63	70.88	66.70	67.55	67.83	70.78	70.80	75.55	67.83	75.98	70.93	75.28	71.00	66.70	74.65	79.28	66.70
9:00:00 AM	74.30	74.30	76.48	78.05	79.10	79.43	74.30	75.18	75.48	79.28	79.30	83.83	75.48	84.20	79.43	83.45	79.50	74.30	82.75	87.55	74.30
10:00:00 AM	80.28	80.28	82.75	84.55	85.75	86.13	80.28	81.08	81.35	85.93	85.95	89.35	81.35	89.63	86.05	88.95	86.13	80.28	88.23	92.50	80.28
11:00:00 AM	84.30	84.30	86.95	88.85	90.13	90.55	84.30	85.10	85.35	90.30	90.35	93.33	85.35	93.55	90.45	92.90	90.53	84.30	92.18	96.33	84.30
12:00:00 PM	161.68	161.68	166.85	170.63	173.13	173.90	161.68	163.10	163.58	173.45	173.53	178.28	163.58	178.63	173.70	177.45	173.83	161.68	176.13	183.63	161.68
1:00:00 PM	258.70	258.70	266.78	272.63	276.48	277.63	258.70	260.55	261.18	276.93	277.05	280.98	261.18	281.28	277.25	279.78	277.40	258.70	277.93	287.43	258.70
2:00:00 PM	198.38	198.38	204.53	209.00	211.90	212.73	198.38	199.75	200.20	212.25	212.35	214.83	200.20	215.08	212.48	213.98	212.60	198.38	212.63	219.65	198.38
3:00:00 PM	158.63	158.63	163.50	167.05	169.33	170.00	158.63	159.60	159.93	169.60	169.68	170.63	159.93	170.73	169.75	169.95	169.85	158.63	168.93	173.80	158.63
4:00:00 PM	148.90	148.90	153.13	156.20	158.15	158.68	148.90	149.73	150.00	158.38	158.43	158.88	150.00	158.98	158.50	158.33	158.58	148.90	157.50	161.63	148.90
5:00:00 PM	156.25	156.25	160.33	163.28	165.10	165.58	156.25	156.85	157.05	165.28	165.35	163.83	157.05	163.80	165.38	163.35	165.43	156.25	162.68	165.50	156.25
6:00:00 PM	140.00	140.00	143.40	145.85	147.38	147.73	140.00	140.58	140.78	147.53	147.58	146.85	140.78	146.93	147.60	146.48	147.65	140.00	145.93	148.65	140.00
7:00:00 PM	106.50	106.50	108.85	110.55	111.58	111.80	106.50	106.85	106.98	111.68	111.70	110.73	106.98	110.75	111.73	110.50	111.75	106.50	110.15	111.80	106.50
8:00:00 PM	90.63	90.63	92.63	94.08	94.95	95.15	90.63	90.93	91.03	95.03	95.05	94.23	91.03	94.25	95.08	94.03	95.10	90.63	93.73	95.13	90.63
9:00:00 PM	124.03	124.03	126.65	128.53	129.73	130.03	124.03	124.65	124.88	129.85	129.90	130.85	124.88	131.03	129.98	130.55	130.03	124.03	130.00	133.03	124.03
10:00:00 PM	104.10	104.10	106.30	107.90	108.88	109.13	104.10	104.63	104.80	109.00	109.03	109.83	104.80	109.98	109.08	109.58	109.13	104.10	109.13	111.65	104.10
11:00:00 PM	73.70	73.70	75.25	76.35	77.05	77.23	73.70	74.18	74.35	77.15	77.18	78.65	74.35	78.85	77.23	78.48	77.28	73.70	78.10	80.48	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table 4.10 – Case 2 Per Unit Voltage

	Voltage (PU)																			
Hour	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
6:00:00 AM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
7:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.94	0.91	1.00
8:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.93	0.96	0.94	0.96	1.00	0.94	0.91	1.00
9:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.94	0.91	1.00
10:00:00 AM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.95	0.95	0.94	0.99	0.94	0.95	0.95	0.95	1.00	0.95	0.92	1.00
11:00:00 AM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.95	0.99	0.94	0.95	0.95	0.95	1.00	0.95	0.93	1.00
12:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.95	0.99	0.94	0.95	0.95	0.95	1.00	0.95	0.93	1.00
1:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	1.00	0.99	0.95	0.95	0.95	0.99	0.95	0.95	0.95	0.95	1.00	0.96	0.93	1.00
2:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	1.00	0.99	0.95	0.95	0.95	0.99	0.95	0.95	0.95	0.95	1.00	0.96	0.93	1.00
3:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	1.00	0.99	0.95	0.95	0.96	0.99	0.95	0.95	0.96	0.95	1.00	0.96	0.94	1.00
4:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.96	0.94	1.00
5:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.97	1.00	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
6:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.97	1.00	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
7:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.98	0.96	1.00
8:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.98	0.96	1.00
9:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
10:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

Table 4.11 highlights the key economics of Case 2. D-LMP revenue is less than the base case due to the storage. The storage reduced the total system cost by 8.8%. Implementing storage has a positive effect on the system by lowering cost, decreasing line flows, decreasing losses, increasing load factor, and shaving the peak load. Case 2 is an excellent example of the prospects for electric energy storage.

Table 4.11 – Revenue Streams for Case 2

Cost Stream	Cost (USD)
D-LMP Revenue	$26,823.83
Energy	$25,161.36
Losses	$1,662.47
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	$2,600.97
DG Payments	-

4.5 Simulation Results: Case 3

Case 3 is the first case to use PV DG. It contains the loads and 10% PV but no storage. The tie lines remain open and the system remains radial rather than networked. The load profile in Figure 4.6 appears similar to that of the base case. There has also been a small improvement in the load factor and a slight reduction of the peak.

Figure 4.7 is the oneline at 3 pm. The demand D-LMP is listed next to each bus and the contouring is based on the D-LMP, with darker color indicating higher prices. The highest price is seen at bus 19 and the lowest price is at the feeder. The losses in the system are causing an 18% increase in price at bus 19. This is a 1% improvement over the base case.

Table 4.12 lists the hourly D-LMPs for a load at every bus. The maximum price occurs at 1:00 PM on bus 19, with a value of $0.300/kWh. The PV reduces the peak D-LMP by a negligible amount. This case has DG, thus the D-LMPs at the generators differ from the loads because of the renewable component in Equation (2.3). The largest generation D-LMP is $329.51/MWh and the largest renewable component is $0.029/kWh. This would mean the generator is paid a premium of 2.9 cents/kWh in addition to the real-time price of electricity. Table 4.14 lists the per unit voltages at each bus for the 24 hour time period. The highest voltage is 1.00 pu and the lowest is 0.91 pu, similar to Case 2. The lower value is a modest improvement yet is still near the threshold of a low voltage situation.

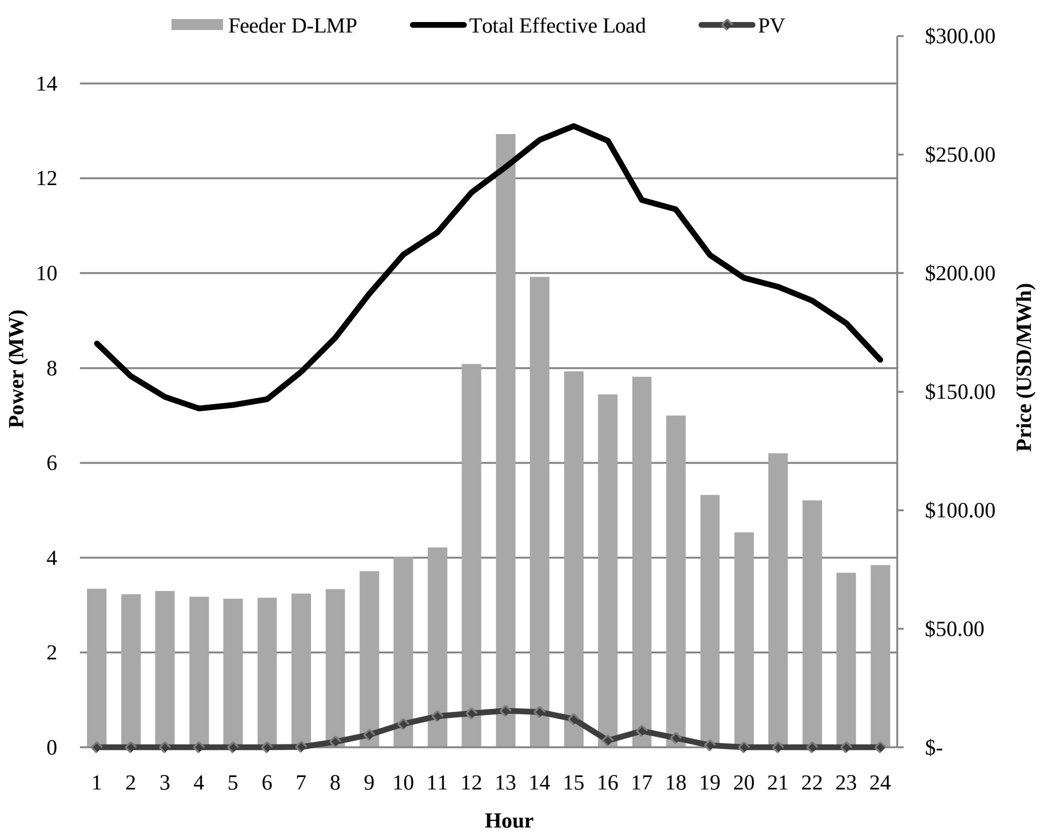

Figure 4.6 - Case 3 System Data

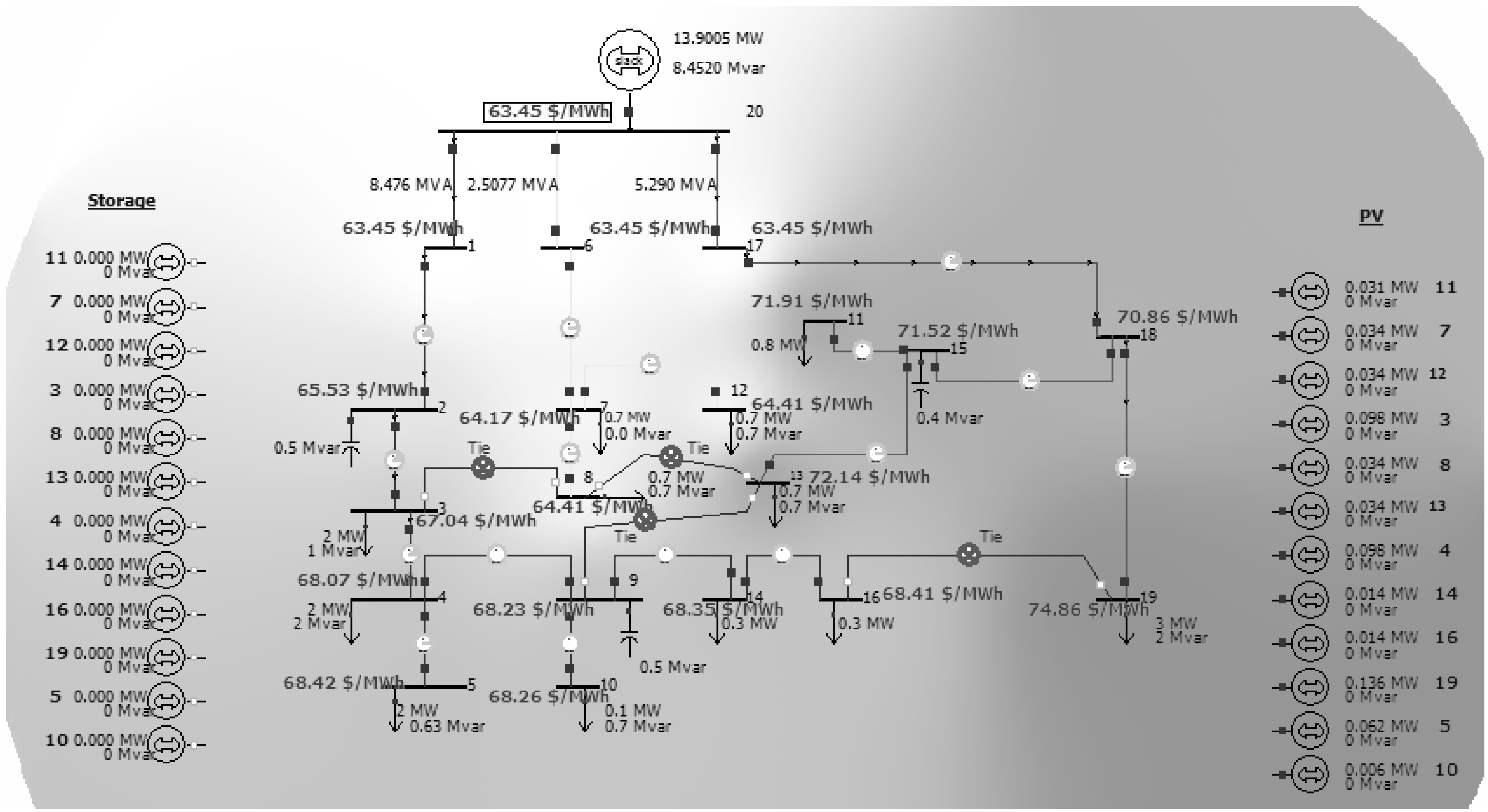

Figure 4.7 – Case 3 Oneline at Peak Demand

Table 4.12 – Case 3 Load D-LMP Prices

	Cost of Energy	Load DLMP (USD/kWh)																			
Hour	(USD/MWh)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	0.06685	0.06815	0.06908	0.0697	0.06985	0.06685	0.06738	0.06755	0.0698	0.06983	0.07208	0.06755	0.0723	0.06988	0.0719	0.06993	0.06685	0.07153	0.07413	0.06685
2:00:00 AM	64.65	0.06465	0.06588	0.06675	0.0673	0.06745	0.06465	0.06508	0.06523	0.0674	0.06743	0.06893	0.06523	0.0691	0.06748	0.06878	0.0675	0.06465	0.06848	0.07055	0.06465
3:00:00 AM	66.00	0.066	0.06723	0.06808	0.06865	0.06878	0.066	0.0664	0.06653	0.06873	0.06875	0.06993	0.06653	0.07008	0.0688	0.06978	0.06883	0.066	0.06948	0.07135	0.066
4:00:00 AM	63.55	0.06355	0.06473	0.06555	0.06608	0.0662	0.06355	0.0639	0.06403	0.06615	0.06618	0.06703	0.06403	0.06715	0.0662	0.0669	0.06625	0.06355	0.06665	0.06828	0.06355
5:00:00 AM	62.725	0.06273	0.06388	0.0647	0.06523	0.06535	0.06273	0.06308	0.0632	0.0653	0.06533	0.06618	0.0632	0.0663	0.06535	0.06603	0.06538	0.06273	0.06578	0.0674	0.06273
6:00:00 AM	63.175	0.06318	0.06445	0.06535	0.06593	0.06608	0.06318	0.0635	0.0636	0.066	0.06603	0.0665	0.0636	0.06658	0.06605	0.06633	0.06608	0.06318	0.06608	0.06755	0.06318
7:00:00 AM	64.875	0.06488	0.0663	0.0673	0.06795	0.06813	0.06488	0.06523	0.06535	0.06803	0.06805	0.0686	0.06535	0.0687	0.0681	0.06843	0.06813	0.06488	0.06813	0.0698	0.06488
8:00:00 AM	66.70	0.0667	0.0683	0.06945	0.07018	0.07038	0.0667	0.0671	0.06723	0.07025	0.07028	0.071	0.06723	0.0711	0.07033	0.07078	0.07035	0.0667	0.07045	0.07233	0.0667
9:00:00 AM	74.30	0.0743	0.0763	0.07773	0.07865	0.07893	0.0743	0.07478	0.07495	0.07875	0.07878	0.07975	0.07495	0.07985	0.07883	0.07948	0.07888	0.0743	0.07903	0.08138	0.0743
10:00:00 AM	80.275	0.08028	0.0826	0.08428	0.08538	0.08575	0.08028	0.08085	0.08105	0.08553	0.08555	0.08703	0.08105	0.08713	0.08563	0.08665	0.08568	0.08028	0.0861	0.08898	0.08028
11:00:00 AM	84.30	0.0843	0.0868	0.08863	0.08983	0.09023	0.0843	0.08495	0.08518	0.08998	0.09	0.092	0.08518	0.09213	0.0901	0.0916	0.09015	0.0843	0.09095	0.0943	0.0843
12:00:00 PM	161.675	0.16168	0.1667	0.17033	0.17275	0.17353	0.16168	0.16315	0.16365	0.1731	0.17315	0.17873	0.16365	0.17913	0.17335	0.1779	0.17348	0.16168	0.17653	0.18428	0.16168
1:00:00 PM	258.70	0.2587	0.2668	0.27268	0.27663	0.2779	0.2587	0.2613	0.26218	0.2772	0.27733	0.2891	0.26218	0.28993	0.27765	0.2877	0.27788	0.2587	0.28533	0.29953	0.2587
2:00:00 PM	198.375	0.19838	0.20473	0.20935	0.21248	0.2135	0.19838	0.20055	0.20128	0.21295	0.21305	0.22393	0.20128	0.22468	0.21333	0.2228	0.21353	0.19838	0.22083	0.233	0.19838
3:00:00 PM	158.625	0.15863	0.1637	0.1674	0.1699	0.17073	0.15863	0.16035	0.16095	0.1703	0.17035	0.17905	0.16095	0.17965	0.1706	0.17815	0.17075	0.15863	0.17658	0.18633	0.15863
4:00:00 PM	148.90	0.1489	0.1536	0.157	0.1593	0.16005	0.1489	0.15055	0.1511	0.15968	0.15975	0.16818	0.1511	0.16878	0.15995	0.16733	0.1601	0.1489	0.16585	0.17513	0.1489
5:00:00 PM	156.25	0.15625	0.16073	0.16395	0.1661	0.16678	0.15625	0.1578	0.1583	0.16645	0.16653	0.17353	0.1583	0.1741	0.1667	0.1728	0.16685	0.15625	0.1715	0.17975	0.15625
6:00:00 PM	140.00	0.14	0.14375	0.14648	0.14828	0.14878	0.14	0.14145	0.14193	0.14858	0.14863	0.15568	0.14193	0.15633	0.1488	0.1551	0.14893	0.14	0.15398	0.16178	0.14
7:00:00 PM	106.50	0.1065	0.10913	0.111	0.11223	0.11255	0.1065	0.1075	0.10783	0.11243	0.11248	0.11688	0.10783	0.11735	0.1126	0.11653	0.11268	0.1065	0.1158	0.121	0.1065
8:00:00 PM	90.625	0.09063	0.09285	0.09445	0.0955	0.09578	0.09063	0.09148	0.09175	0.09568	0.0957	0.09945	0.09175	0.09985	0.09583	0.09915	0.09588	0.09063	0.09853	0.10298	0.09063
9:00:00 PM	124.025	0.12403	0.1268	0.1288	0.1301	0.13045	0.12403	0.12513	0.1255	0.13033	0.13038	0.13535	0.1255	0.13588	0.1305	0.13498	0.1306	0.12403	0.13418	0.13988	0.12403
10:00:00 PM	104.10	0.1041	0.10645	0.10813	0.1092	0.1095	0.1041	0.10503	0.10535	0.1094	0.10943	0.1136	0.10535	0.11405	0.10955	0.11328	0.10963	0.1041	0.11263	0.1174	0.1041
11:00:00 PM	73.70	0.0737	0.07528	0.07638	0.0771	0.07728	0.0737	0.07428	0.07448	0.07723	0.07725	0.07955	0.07448	0.07983	0.07733	0.07938	0.07738	0.0737	0.07895	0.08188	0.0737
12:00:00 AM	76.90	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table 4.13 – Case 3 Generation D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Gen DLMPs (USD/MWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.15	69.08	69.70	69.85	66.85	67.38	67.55	69.80	69.83	72.08	67.55	72.30	69.88	71.90	69.93	66.85	71.53	74.13	66.85
2:00:00 AM	64.65	64.65	65.88	66.75	67.30	67.45	64.65	65.08	65.23	67.40	67.43	68.93	65.23	69.10	67.48	68.78	67.50	64.65	68.48	70.55	64.65
3:00:00 AM	66.00	66.00	67.23	68.08	68.65	68.78	66.00	66.40	66.53	68.73	68.75	69.93	66.53	70.08	68.80	69.78	68.83	66.00	69.48	71.35	66.00
4:00:00 AM	63.55	63.55	64.73	65.55	66.08	66.20	63.55	63.90	64.03	66.15	66.18	67.03	64.03	67.15	66.20	66.90	66.25	63.55	66.65	68.28	63.55
5:00:00 AM	62.73	62.73	63.88	64.70	65.23	65.35	62.73	63.08	63.20	65.30	65.33	66.18	63.20	66.30	65.35	66.03	65.38	62.73	65.78	67.40	62.73
6:00:00 AM	63.18	63.18	64.45	65.35	65.93	66.08	63.18	63.50	63.60	66.00	66.03	66.50	63.60	66.58	66.05	66.33	66.08	63.18	66.08	67.55	63.18
7:00:00 AM	64.88	64.88	66.30	67.63	68.28	68.33	64.88	65.34	65.46	68.03	68.07	68.70	65.46	68.81	68.15	68.43	68.17	64.88	68.13	70.25	64.88
8:00:00 AM	66.70	66.70	68.30	73.32	74.05	72.86	66.70	68.47	68.59	70.25	70.51	72.25	68.59	72.47	70.87	70.78	70.90	66.70	70.45	77.68	66.70
9:00:00 AM	74.30	74.30	76.30	86.02	86.95	84.29	74.30	77.74	77.92	78.75	79.29	82.47	77.92	82.82	80.02	79.48	80.07	74.30	79.03	92.75	74.30
10:00:00 AM	80.28	80.28	82.60	99.24	100.34	95.55	80.28	86.33	86.53	85.53	86.51	92.05	86.53	92.60	87.85	86.65	87.90	80.28	86.10	109.22	80.28
11:00:00 AM	84.30	84.30	86.80	108.20	109.40	103.15	84.30	92.23	92.45	89.98	91.29	98.68	92.45	99.40	93.08	91.60	93.13	84.30	90.95	120.55	84.30
12:00:00 PM	161.68	161.68	166.70	191.43	193.86	187.50	161.68	171.04	171.54	173.10	174.55	185.97	171.54	187.02	176.58	177.90	176.71	161.68	176.53	212.50	161.68
1:00:00 PM	258.70	258.70	266.80	295.15	299.10	292.82	258.70	269.75	270.62	277.20	278.83	296.85	270.62	298.37	281.12	287.70	281.34	258.70	285.33	329.51	258.70
2:00:00 PM	198.38	198.38	204.73	231.19	234.31	227.98	198.38	208.74	209.46	212.95	214.51	231.44	209.46	232.86	216.68	222.80	216.88	198.38	220.83	262.16	198.38
3:00:00 PM	158.63	158.63	163.70	185.17	187.67	182.42	158.63	166.92	167.52	170.30	171.51	185.07	167.52	186.22	173.28	178.15	173.43	158.63	176.58	210.24	158.63
4:00:00 PM	148.90	148.90	153.60	161.65	163.95	163.03	148.90	152.19	152.74	159.68	160.03	169.68	152.74	170.42	160.61	167.33	160.76	148.90	165.85	181.54	148.90
5:00:00 PM	156.25	156.25	160.73	174.81	176.96	173.83	156.25	161.72	162.22	166.45	167.21	177.12	162.22	178.02	168.29	172.80	168.44	156.25	171.50	194.56	156.25
6:00:00 PM	140.00	140.00	143.75	152.68	154.48	152.77	140.00	143.66	144.13	148.58	149.01	157.69	144.13	158.53	149.69	155.10	149.81	140.00	153.98	170.31	140.00
7:00:00 PM	106.50	106.50	109.13	112.38	113.61	113.43	106.50	107.98	108.31	112.43	112.56	117.32	108.31	117.83	112.79	116.53	112.87	106.50	115.80	122.92	106.50
8:00:00 PM	90.63	90.63	92.85	94.45	95.50	95.78	90.63	91.48	91.75	95.68	95.70	99.45	91.75	99.85	95.83	99.15	95.88	90.63	98.53	102.98	90.63
9:00:00 PM	124.03	124.03	126.80	128.80	130.10	130.45	124.03	125.13	125.50	130.33	130.38	135.35	125.50	135.88	130.50	134.98	130.60	124.03	134.18	139.88	124.03
10:00:00 PM	104.10	104.10	106.45	108.13	109.20	109.50	104.10	105.03	105.35	109.40	109.43	113.60	105.35	114.05	109.55	113.28	109.63	104.10	112.63	117.40	104.10
11:00:00 PM	73.70	73.70	75.28	76.38	77.10	77.28	73.70	74.28	74.48	77.23	77.25	79.55	74.48	79.83	77.33	79.38	77.38	73.70	78.95	81.88	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table 4.14 – Case 3 Per Unit Voltage

	Voltage (PU)																			
Hour	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.96	0.94	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.97	0.97	1.00	0.97	0.95	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
6:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
7:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
8:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	1.00	0.99	0.96	0.96	0.97	0.99	0.96	0.96	0.97	0.96	1.00	0.97	0.95	1.00
9:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.97	0.95	1.00
10:00:00 AM	1.00	0.98	0.97	0.96	0.95	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.95	0.96	0.96	0.96	1.00	0.96	0.94	1.00
11:00:00 AM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.96	0.95	0.95	0.99	0.95	0.95	0.95	0.95	1.00	0.96	0.93	1.00
12:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.94	0.99	0.94	0.95	0.95	0.95	1.00	0.95	0.92	1.00
1:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.94	0.99	0.94	0.95	0.94	0.95	1.00	0.95	0.92	1.00
2:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.93	0.99	0.93	0.95	0.94	0.95	1.00	0.94	0.91	1.00
3:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.93	0.99	0.93	0.95	0.94	0.95	1.00	0.94	0.91	1.00
4:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.93	0.99	0.93	0.95	0.94	0.95	1.00	0.94	0.91	1.00
5:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.95	0.92	1.00
6:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.95	0.92	1.00
7:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
8:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
9:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
10:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.96	0.99	0.95	0.97	0.96	0.97	1.00	0.96	0.94	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

Table 4.15 highlights the key economics of Case 3. D-LMP revenue is slightly less than the base case due to the PV reducing losses. The base case and Case 3 energy revenues are the same but the Case 3 losses revenue is slightly less. PV has a positive effect on the system like that of storage. It has been shown to lower cost slightly, decrease line flows, decrease losses, increase load factor, and shave the peak load. The DG payments are smaller than the loss revenue, thus the utility is still making a net profit on the arrangement. Case 3 demonstrates PV is beneficial and higher penetrations may continue this trend.

Table 4.15 – Revenue Streams for Case 3

Cost Stream	Cost (USD)
D-LMP Revenue	$29,705.08
Energy	$27,723.90
Losses	$1,981.18
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	N/A
DG Payments	$923.72

4.6 Simulation Result: Case 4

Case 4 uses 10% PV with storage in place. The tie lines remain open and the system remains radial rather than networked. The load profile in Figure 4.8 is similar to that of Case 2; it is largely dominated by the effects of the storage. The load factor has been improved, largely because of the storage. The smallest load peak thus far is seen. It is 10% less than the base case.

Figure 4.9 is the oneline at 3 pm. The demand D-LMP is listed next to each bus and the contouring is based on the D-LMP, with darker color indicating higher prices. The highest price is seen at bus 19 and the lowest price is at the feeder. The losses in the system are causing an 8.6% increase in price at bus 19. This reduction from the base case is largely due to the use of storage.

Table 4.16 lists the hourly D-LMPs for a load at every bus. The maximum price occurs at 1:00 PM on bus 19, with a value of \$0.284/kWh. The PV reduces the peak D-LMP by a negligible amount and it is primarily lowered by storage. The largest generation D-LMP is \$314.38/MWh and the largest renewable component is still \$0.029/kWh. Compared to Case 3, the generation D-LMP is not as large. This is because the storage also lowered the cost of losses, which in turn reduces the D-LMP. Table 4.18 lists the per unit voltages at each bus for the 24 hour time period. The highest voltage is 1.00 pu and the lowest is 0.91 pu, similar to Case 2 and Case 3. The lower value is a modest improvement over the base case yet is still near the threshold of a low voltage situation.

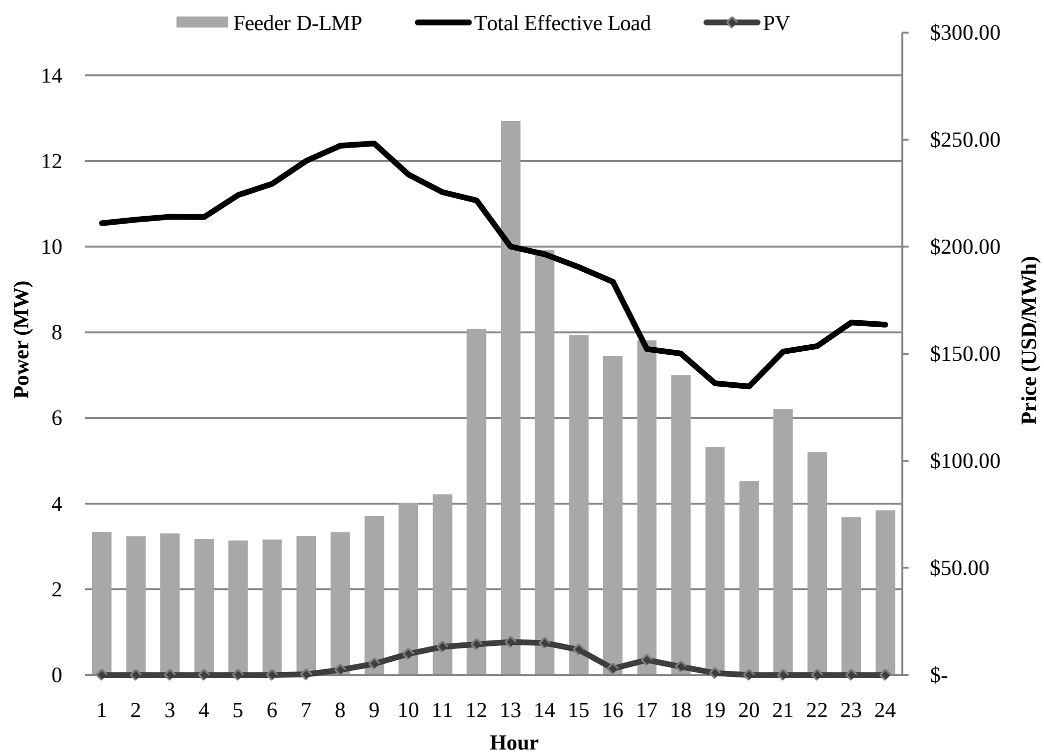

Figure 4.8 - Case 4 System Data

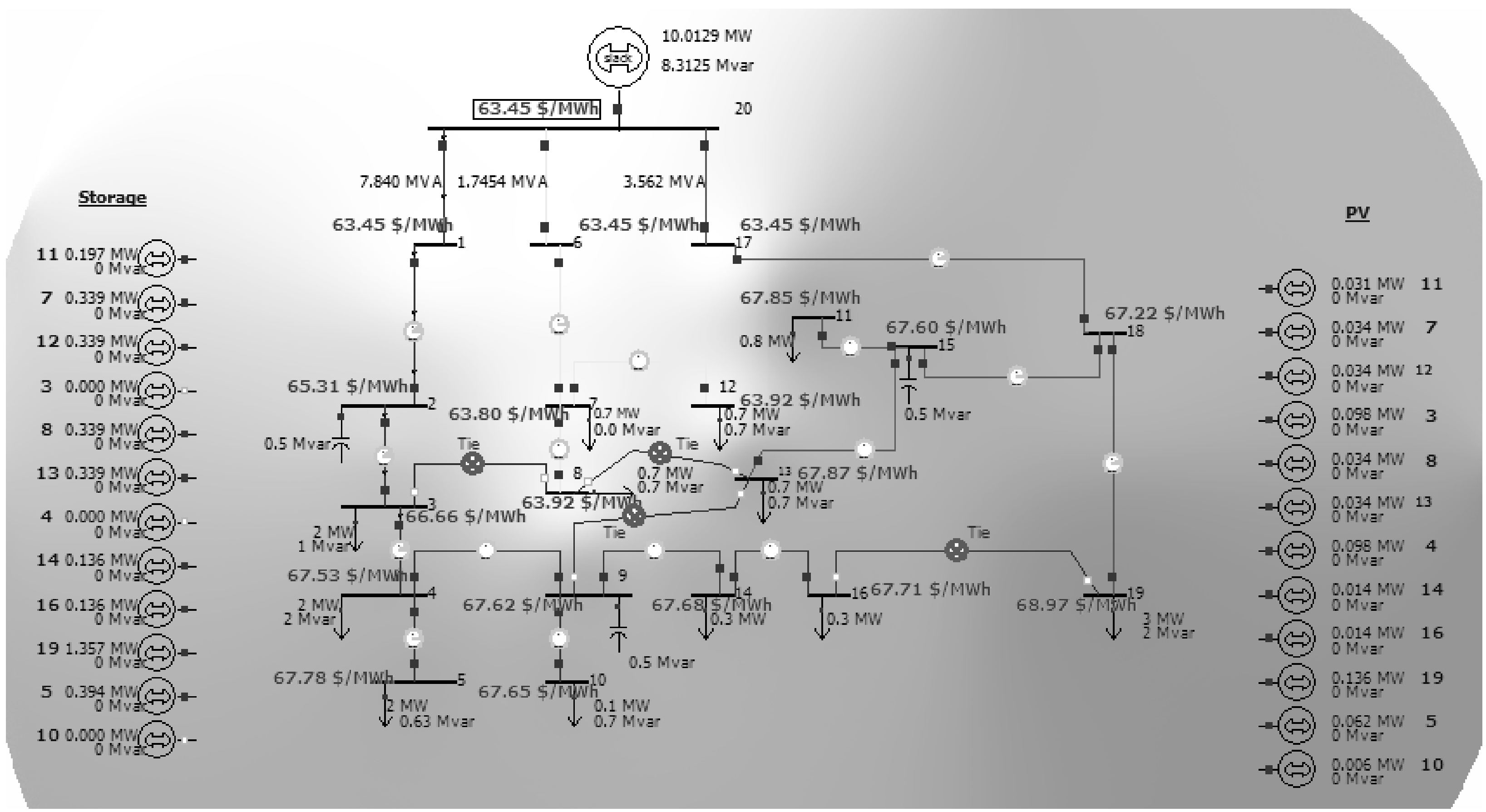

Figure 4.9 – Case 4 Oneline at Peak Demand

Table 4.16 – Case 4 Load D-LMP Prices

	Cost of Energy	Load DLMP (USD/kWh)																			
Hour	(USD/MWh)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	0.06685	0.0683	0.06935	0.07008	0.07033	0.06685	0.06758	0.0678	0.0702	0.07023	0.0744	0.0678	0.07473	0.07033	0.07413	0.07038	0.06685	0.07358	0.07738	0.06685
2:00:00 AM	64.65	0.06465	0.06605	0.06708	0.06778	0.068	0.06465	0.06535	0.06558	0.0679	0.06793	0.072	0.06558	0.0723	0.06803	0.07173	0.06808	0.06465	0.0712	0.0749	0.06465
3:00:00 AM	66.00	0.066	0.06743	0.06843	0.06913	0.06935	0.066	0.06673	0.06698	0.06928	0.0693	0.07363	0.06698	0.07398	0.0694	0.07338	0.06945	0.066	0.07283	0.07673	0.066
4:00:00 AM	63.55	0.06355	0.06493	0.0659	0.06658	0.06678	0.06355	0.06425	0.0645	0.0667	0.06673	0.0709	0.0645	0.07123	0.0668	0.07065	0.06688	0.06355	0.07013	0.07388	0.06355
5:00:00 AM	62.725	0.06273	0.0641	0.06508	0.06575	0.06595	0.06273	0.06348	0.06375	0.06588	0.0659	0.07048	0.06375	0.0709	0.066	0.07025	0.06608	0.06273	0.06973	0.07383	0.06273
6:00:00 AM	63.175	0.06318	0.06463	0.06568	0.06638	0.06658	0.06318	0.06395	0.0642	0.06653	0.06655	0.071	0.0642	0.07143	0.06665	0.07078	0.0667	0.06318	0.07023	0.07438	0.06318
7:00:00 AM	64.875	0.06488	0.06648	0.06763	0.0684	0.0686	0.06488	0.0657	0.06598	0.06855	0.06858	0.07328	0.06598	0.07373	0.06868	0.07303	0.06875	0.06488	0.07245	0.0769	0.06488
8:00:00 AM	66.70	0.0667	0.06845	0.06973	0.07058	0.07083	0.0667	0.06753	0.06783	0.07073	0.07075	0.07545	0.06783	0.07588	0.07088	0.07518	0.07095	0.0667	0.07455	0.07913	0.0667
9:00:00 AM	74.30	0.0743	0.07643	0.07795	0.079	0.0793	0.0743	0.07515	0.07545	0.07915	0.07918	0.08358	0.07545	0.08395	0.0793	0.08323	0.07938	0.0743	0.08255	0.0872	0.0743
10:00:00 AM	80.275	0.08028	0.08265	0.08438	0.08553	0.0859	0.08028	0.08105	0.0813	0.0857	0.08573	0.08888	0.0813	0.08913	0.08583	0.0885	0.0859	0.08028	0.08783	0.09183	0.08028
11:00:00 AM	84.30	0.0843	0.0868	0.08863	0.08983	0.0902	0.0843	0.08503	0.08528	0.09	0.09003	0.09268	0.08528	0.09288	0.09013	0.09228	0.09018	0.0843	0.0916	0.0954	0.0843
12:00:00 PM	161.675	0.16168	0.16658	0.17013	0.17248	0.1732	0.16168	0.163	0.16343	0.17278	0.17285	0.17693	0.16343	0.17725	0.173	0.17618	0.17313	0.16168	0.17495	0.18175	0.16168
1:00:00 PM	258.70	0.2587	0.2663	0.2718	0.27538	0.27643	0.2587	0.26038	0.26093	0.27578	0.2759	0.2788	0.26093	0.27903	0.27608	0.2777	0.2762	0.2587	0.27603	0.2844	0.2587
2:00:00 PM	198.375	0.19838	0.20418	0.20838	0.21108	0.21185	0.19838	0.1996	0.20003	0.2114	0.21148	0.21323	0.20003	0.2134	0.2116	0.21243	0.2117	0.19838	0.2112	0.2174	0.19838
3:00:00 PM	158.625	0.15863	0.16328	0.16665	0.16883	0.16945	0.15863	0.1595	0.1598	0.16905	0.16913	0.16963	0.1598	0.16968	0.1692	0.169	0.16928	0.15863	0.16805	0.17243	0.15863
4:00:00 PM	148.90	0.1489	0.15308	0.1561	0.15803	0.15855	0.1489	0.1497	0.14998	0.15825	0.15833	0.15865	0.14998	0.15875	0.15838	0.15813	0.15845	0.1489	0.1573	0.16133	0.1489
5:00:00 PM	156.25	0.15625	0.1602	0.16305	0.16483	0.16528	0.15625	0.1568	0.15698	0.165	0.16505	0.16328	0.15698	0.16325	0.16508	0.16283	0.16513	0.15625	0.1622	0.16478	0.15625
6:00:00 PM	140.00	0.14	0.14335	0.14575	0.14723	0.14758	0.14	0.14055	0.14073	0.14738	0.14743	0.1466	0.14073	0.14665	0.14745	0.14623	0.1475	0.14	0.14568	0.14828	0.14
7:00:00 PM	106.50	0.1065	0.10885	0.11053	0.11155	0.11178	0.1065	0.10685	0.10698	0.11165	0.11168	0.11068	0.10698	0.11073	0.1117	0.11045	0.11173	0.1065	0.1101	0.11175	0.1065
8:00:00 PM	90.625	0.09063	0.09263	0.09405	0.09493	0.09513	0.09063	0.09093	0.09103	0.095	0.09503	0.09418	0.09103	0.0942	0.09505	0.09398	0.09508	0.09063	0.0937	0.0951	0.09063
9:00:00 PM	124.025	0.12403	0.12665	0.12853	0.12973	0.13003	0.12403	0.12465	0.12488	0.12985	0.1299	0.13085	0.12488	0.13103	0.12998	0.13055	0.13003	0.12403	0.13	0.13303	0.12403
10:00:00 PM	104.10	0.1041	0.1063	0.10788	0.10888	0.10913	0.1041	0.10463	0.1048	0.109	0.10903	0.10983	0.1048	0.10998	0.10908	0.10958	0.10913	0.1041	0.10913	0.11165	0.1041
11:00:00 PM	73.70	0.0737	0.07525	0.07635	0.07705	0.07723	0.0737	0.07418	0.07435	0.07715	0.07718	0.07868	0.07435	0.07885	0.07723	0.07848	0.07728	0.0737	0.07813	0.08048	0.0737
12:00:00 AM	76.90	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table 4.17 – Case 4 Generation D-LMP Prices

	Cost of Energy	Gen DLMPs (USD/MWh)																			
Hour	(USD/MWh)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.30	69.35	70.08	70.33	66.85	67.58	67.80	70.20	70.23	74.40	67.80	74.73	70.33	74.13	70.38	66.85	73.58	77.38	66.85
2:00:00 AM	64.65	64.65	66.05	67.08	67.78	68.00	64.65	65.35	65.58	67.90	67.93	72.00	65.58	72.30	68.03	71.73	68.08	64.65	71.20	74.90	64.65
3:00:00 AM	66.00	66.00	67.43	68.43	69.13	69.35	66.00	66.73	66.98	69.28	69.30	73.63	66.98	73.98	69.40	73.38	69.45	66.00	72.83	76.73	66.00
4:00:00 AM	63.55	63.55	64.93	65.90	66.58	66.78	63.55	64.25	64.50	66.70	66.73	70.90	64.50	71.23	66.80	70.65	66.88	63.55	70.13	73.88	63.55
5:00:00 AM	62.73	62.73	64.10	65.08	65.75	65.95	62.73	63.48	63.75	65.88	65.90	70.48	63.75	70.90	66.00	70.25	66.08	62.73	69.73	73.83	62.73
6:00:00 AM	63.18	63.18	64.63	65.68	66.38	66.58	63.18	63.95	64.20	66.53	66.55	71.00	64.20	71.43	66.65	70.78	66.70	63.18	70.23	74.38	63.18
7:00:00 AM	64.88	64.88	66.48	67.95	68.73	68.81	64.88	65.81	66.09	68.55	68.59	73.38	66.09	73.84	68.72	73.03	68.80	64.88	72.45	77.35	64.88
8:00:00 AM	66.70	66.70	68.45	73.60	74.45	73.31	66.70	68.89	69.19	70.73	70.99	76.70	69.19	77.24	71.42	75.18	71.50	66.70	74.55	84.48	66.70
9:00:00 AM	74.30	74.30	76.43	86.25	87.30	84.67	74.30	78.12	78.42	79.15	79.69	86.29	78.42	86.92	80.50	83.23	80.57	74.30	82.55	98.57	74.30
10:00:00 AM	80.28	80.28	82.65	99.34	100.49	95.70	80.28	86.53	86.78	85.70	86.69	93.90	86.78	94.60	88.05	88.50	88.13	80.28	87.83	112.07	80.28
11:00:00 AM	84.30	84.30	86.80	108.20	109.40	103.13	84.30	92.30	92.55	90.00	91.31	99.35	92.55	100.15	93.10	92.28	93.15	84.30	91.60	121.65	84.30
12:00:00 PM	161.68	161.68	166.58	191.23	193.58	187.18	161.68	170.89	171.32	172.78	174.25	184.17	171.32	185.14	176.23	176.18	176.36	161.68	174.95	209.98	161.68
1:00:00 PM	258.70	258.70	266.30	294.28	297.85	291.35	258.70	268.82	269.37	275.78	277.40	286.55	269.37	287.47	279.54	277.70	279.67	258.70	276.03	314.38	258.70
2:00:00 PM	198.38	198.38	204.18	230.21	232.91	226.33	198.38	207.79	208.21	211.40	212.93	220.74	208.21	221.59	214.96	212.43	215.06	198.38	211.20	246.56	198.38
3:00:00 PM	158.63	158.63	163.28	184.42	186.60	181.15	158.63	166.07	166.37	169.05	170.28	175.65	166.37	176.24	171.88	169.00	171.96	158.63	168.05	196.34	158.63
4:00:00 PM	148.90	148.90	153.08	160.75	162.67	161.53	148.90	151.34	151.62	158.25	158.61	160.15	151.62	160.39	159.04	158.13	159.11	148.90	157.30	167.74	148.90
5:00:00 PM	156.25	156.25	160.20	173.91	175.68	172.33	156.25	160.72	160.89	165.00	165.73	166.87	160.89	167.17	166.66	162.83	166.71	156.25	162.20	179.58	156.25
6:00:00 PM	140.00	140.00	143.35	151.96	153.43	151.57	140.00	142.76	142.93	147.38	147.81	148.62	142.93	148.86	148.34	146.23	148.39	140.00	145.68	156.81	140.00
7:00:00 PM	106.50	106.50	108.85	111.91	112.93	112.66	106.50	107.33	107.46	111.65	111.76	111.12	107.46	111.21	111.89	110.45	111.92	106.50	110.10	113.67	106.50
8:00:00 PM	90.63	90.63	92.63	94.05	94.93	95.13	90.63	90.93	91.03	95.00	95.03	94.18	91.03	94.20	95.05	93.98	95.08	90.63	93.70	95.10	90.63
9:00:00 PM	124.03	124.03	126.65	128.53	129.73	130.03	124.03	124.65	124.88	129.85	129.90	130.85	124.88	131.03	129.98	130.55	130.03	124.03	130.00	133.03	124.03
10:00:00 PM	104.10	104.10	106.30	107.88	108.88	109.13	104.10	104.63	104.80	109.00	109.03	109.83	104.80	109.98	109.08	109.58	109.13	104.10	109.13	111.65	104.10
11:00:00 PM	73.70	73.70	75.25	76.35	77.05	77.23	73.70	74.18	74.35	77.15	77.18	78.68	74.35	78.85	77.23	78.48	77.28	73.70	78.13	80.48	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table 4.18 – Case 4 Per Unit Voltage

	Voltage (PU)																			
Hour	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
6:00:00 AM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
7:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.94	0.91	1.00
8:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.93	0.96	0.94	0.96	1.00	0.94	0.91	1.00
9:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.95	0.92	1.00
10:00:00 AM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.96	0.95	0.95	0.99	0.94	0.95	0.95	0.95	1.00	0.95	0.93	1.00
11:00:00 AM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.96	0.95	0.95	0.99	0.95	0.95	0.95	0.95	1.00	0.95	0.93	1.00
12:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.95	0.99	0.95	0.95	0.95	0.95	1.00	0.95	0.93	1.00
1:00:00 PM	1.00	0.98	0.97	0.96	0.95	1.00	1.00	0.99	0.95	0.95	0.96	0.99	0.95	0.95	0.96	0.95	1.00	0.96	0.94	1.00
2:00:00 PM	1.00	0.98	0.97	0.96	0.95	1.00	1.00	0.99	0.95	0.95	0.96	0.99	0.95	0.95	0.96	0.95	1.00	0.96	0.94	1.00
3:00:00 PM	1.00	0.98	0.97	0.96	0.95	1.00	1.00	0.99	0.95	0.95	0.96	0.99	0.96	0.95	0.96	0.95	1.00	0.96	0.94	1.00
4:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.96	0.95	1.00
5:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.97	1.00	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
6:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.97	1.00	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
7:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.98	0.96	1.00
8:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.98	0.96	1.00
9:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
10:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

Table 4.15 highlights the key economics of Case 4. D-LMP revenue is less than the base case due to the PV and storage reducing losses. The residential sector actually pays 3% less than the flat-rate price in this scenario, although other sectors still pay more than flat-rate pricing. PV and storage has been shown to slightly lower cost, decrease line flows, decrease losses, increase load factor, and shave the peak load. The DG payments are smaller than the loss revenue, thus the utility is still making a net profit on the arrangement. Case 4 demonstrates that PV and storage can work in conjunction and further improve the system.

Table 4.19 – Revenue Streams for Case 4

Cost Stream	Cost (USD)
D-LMP Revenue	$26,764.95
Energy	$25,161.36
Losses	$1,603.59
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	$2,587.81
DG Payments	$909.60

4.7 Simulation Results: Cases 5-8

Please see Appendix D for results from Cases 5 through 8. Note that these cases are included in the summary section at the end of the chapter.

4.8 Simulation Result: Case 9

Case 9 uses 100% PV penetration without any storage systems. The tie lines remain open and the system remains radial rather than networked. The load profile of Figure 4.10 is now dominated by the PV. The reduction of PV output at 16:00 also creates an abrupt spike in the total effective load, perhaps hindering operability. Nonetheless, the smallest peak load is seen in this case.

Figure 4.11 is the oneline at 3 pm. The demand D-LMP is listed next to each bus and the contouring is based on the D-LMP, with darker color indicating higher prices. The highest price is seen at bus 19 and the lowest price is at the feeder. The losses in the system are causing a 9.2% increase in price at bus 19. The PV is having an appreciable effect on losses.

Table 4.20 lists the hourly D-LMPs for a load at every bus. The maximum price occurs at 1:00 PM on bus 19, with a value of $0.272/kWh. After high penetration, the PV begins to reduce the peak D-LMP by an appreciable amount. The largest generation D-LMP is $399.98/MWh and the largest renewable component is still $0.127/kWh. Table 4.22 lists the per unit voltages at each bus for the 24 hour time period. The highest voltage is 1.00 pu and the lowest is 0.93 pu, a marked improvement over the base case.

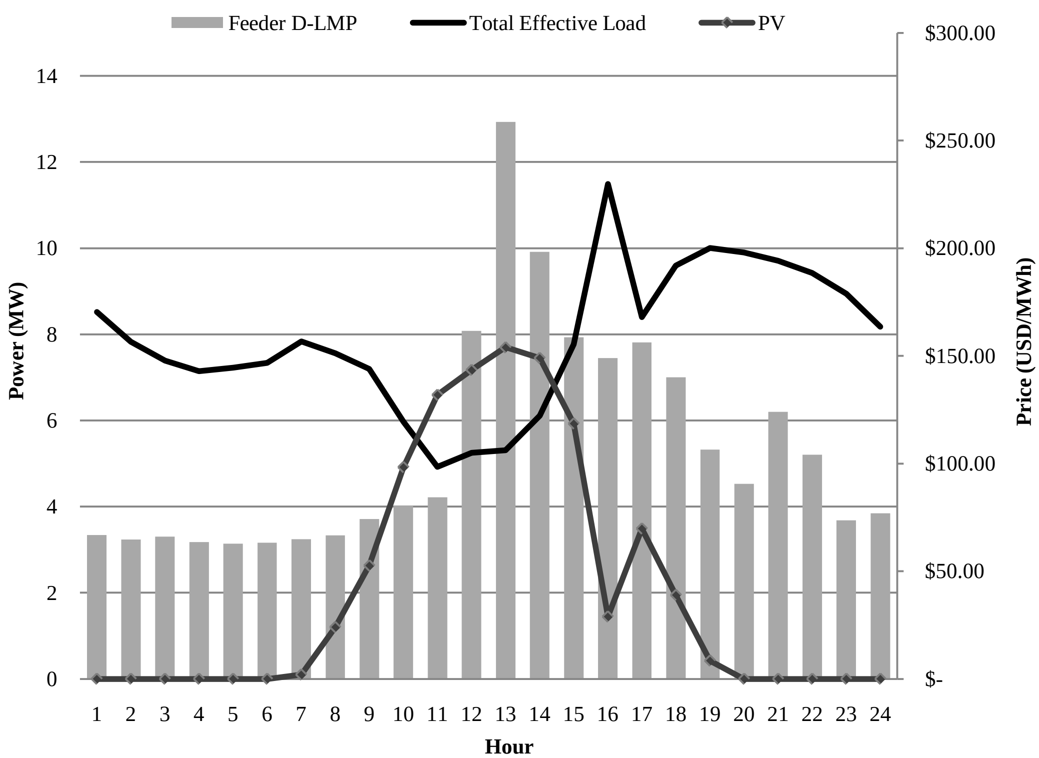

Figure 4.10 - Case 9 System Data

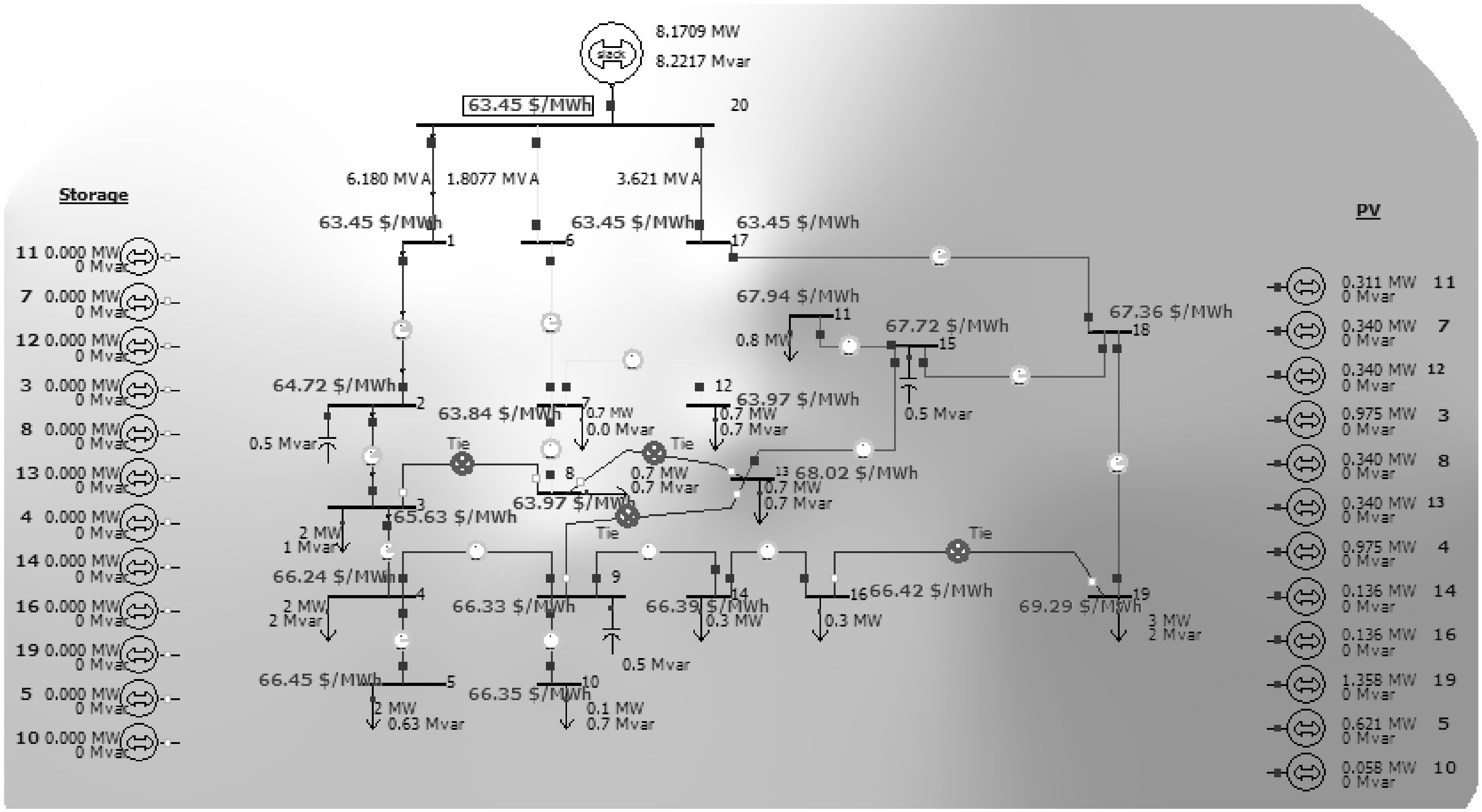

Figure 4.11 – Case 9 Oneline at Peak Demand

Table 4.20 – Case 9 Load D-LMP Prices

	Cost of Energy	Load DLMP (USD/kWh)																			
Hour	(USD/MWh)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	0.06685	0.06815	0.06908	0.0697	0.06985	0.06685	0.06738	0.06755	0.0698	0.06983	0.07208	0.06755	0.0723	0.06988	0.0719	0.06993	0.06685	0.07153	0.07413	0.06685
2:00:00 AM	64.65	0.06465	0.06588	0.06675	0.0673	0.06745	0.06465	0.06508	0.06523	0.0674	0.06743	0.06893	0.06523	0.0691	0.06748	0.06878	0.0675	0.06465	0.06848	0.07055	0.06465
3:00:00 AM	66.00	0.066	0.06723	0.06808	0.06865	0.06878	0.066	0.0664	0.06653	0.06873	0.06875	0.06993	0.06653	0.07008	0.0688	0.06978	0.06883	0.066	0.06948	0.07135	0.066
4:00:00 AM	63.55	0.06355	0.06473	0.06555	0.06608	0.0662	0.06355	0.0639	0.06403	0.06615	0.06618	0.06703	0.06403	0.06715	0.0662	0.0669	0.06625	0.06355	0.06665	0.06828	0.06355
5:00:00 AM	62.725	0.06273	0.06388	0.0647	0.06523	0.06535	0.06273	0.06308	0.0632	0.0653	0.06533	0.06618	0.0632	0.0663	0.06535	0.06603	0.06538	0.06273	0.06578	0.0674	0.06273
6:00:00 AM	63.175	0.06318	0.06445	0.06535	0.06593	0.06608	0.06318	0.0635	0.0636	0.066	0.06603	0.0665	0.0636	0.06658	0.06605	0.06633	0.06608	0.06318	0.06608	0.06755	0.06318
7:00:00 AM	64.875	0.06488	0.06628	0.0673	0.06793	0.0681	0.06488	0.06523	0.06535	0.068	0.06803	0.06855	0.06535	0.06863	0.06805	0.06838	0.0681	0.06488	0.06808	0.0697	0.06488
8:00:00 AM	66.70	0.0667	0.06813	0.06915	0.0698	0.06998	0.0667	0.06703	0.06715	0.06988	0.06988	0.07028	0.06715	0.07033	0.06993	0.0701	0.06995	0.0667	0.0698	0.07133	0.0667
9:00:00 AM	74.30	0.0743	0.07588	0.077	0.07773	0.07793	0.0743	0.07463	0.07473	0.0778	0.0778	0.07795	0.07473	0.07798	0.07785	0.07775	0.07788	0.0743	0.07743	0.0789	0.0743
10:00:00 AM	80.275	0.08028	0.08178	0.08283	0.0835	0.08373	0.08028	0.08053	0.0806	0.08358	0.0836	0.0834	0.0806	0.08338	0.0836	0.0832	0.08363	0.08028	0.0829	0.08403	0.08028
11:00:00 AM	84.30	0.0843	0.08565	0.0866	0.0872	0.0874	0.0843	0.0845	0.08455	0.08725	0.08728	0.08693	0.08455	0.08685	0.08728	0.08673	0.0873	0.0843	0.08648	0.08733	0.0843
12:00:00 PM	161.675	0.16168	0.16425	0.16608	0.16725	0.16763	0.16168	0.16215	0.16233	0.16738	0.1674	0.1677	0.16233	0.16768	0.16745	0.16733	0.16748	0.16168	0.1668	0.16905	0.16168
1:00:00 PM	258.70	0.2587	0.26263	0.2654	0.2672	0.26775	0.2587	0.2596	0.2599	0.2674	0.26745	0.26955	0.2599	0.26965	0.26755	0.26898	0.26763	0.2587	0.26808	0.27235	0.2587
2:00:00 PM	198.375	0.19838	0.20163	0.20393	0.20543	0.2059	0.19838	0.19928	0.19958	0.20563	0.20568	0.20885	0.19958	0.20903	0.20578	0.20835	0.20585	0.19838	0.20753	0.2119	0.19838
3:00:00 PM	158.625	0.15863	0.1618	0.16405	0.16558	0.16608	0.15863	0.15958	0.1599	0.16578	0.16583	0.16975	0.1599	0.16995	0.16595	0.1692	0.16603	0.15863	0.16833	0.1731	0.15863
4:00:00 PM	148.90	0.1489	0.15313	0.15618	0.15825	0.15893	0.1489	0.15038	0.15088	0.15858	0.15865	0.16568	0.15088	0.16618	0.15883	0.16493	0.15895	0.1489	0.16365	0.17158	0.1489
5:00:00 PM	156.25	0.15625	0.15958	0.16195	0.16353	0.16398	0.15625	0.15733	0.1577	0.16375	0.1638	0.1679	0.1577	0.16825	0.16393	0.1674	0.16403	0.15625	0.16653	0.17185	0.15625
6:00:00 PM	140.00	0.14	0.14318	0.14548	0.14698	0.1474	0.14	0.1412	0.14163	0.14723	0.14725	0.1528	0.14163	0.15333	0.14743	0.15233	0.1475	0.14	0.1514	0.15768	0.14
7:00:00 PM	106.50	0.1065	0.10903	0.11085	0.11203	0.11233	0.1065	0.10745	0.10778	0.1122	0.11225	0.11643	0.10778	0.11685	0.11238	0.11608	0.11245	0.1065	0.11538	0.12035	0.1065
8:00:00 PM	90.625	0.09063	0.09278	0.09433	0.09533	0.09558	0.09063	0.09145	0.09173	0.09548	0.0955	0.09908	0.09173	0.09945	0.09563	0.09878	0.09568	0.09063	0.09818	0.1024	0.09063
9:00:00 PM	124.025	0.12403	0.1268	0.1288	0.1301	0.13045	0.12403	0.12513	0.1255	0.13033	0.13038	0.13535	0.1255	0.13588	0.1305	0.13498	0.1306	0.12403	0.13418	0.13988	0.12403
10:00:00 PM	104.10	0.1041	0.10645	0.10813	0.1092	0.1095	0.1041	0.10503	0.10535	0.1094	0.10943	0.1136	0.10535	0.11405	0.10955	0.11328	0.10963	0.1041	0.11263	0.1174	0.1041
11:00:00 PM	73.70	0.0737	0.07528	0.07638	0.0771	0.07728	0.0737	0.07428	0.07448	0.07723	0.07725	0.07955	0.07448	0.07983	0.07733	0.07938	0.07738	0.0737	0.07895	0.08188	0.0737
12:00:00 AM	76.90	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table 4.21 – Case 9 Generation D-LMP Prices

	Cost of Energy	Gen DLMPs (USD/MWh)																			
Hour	(USD/MWh)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.15	69.08	69.70	69.85	66.85	67.38	67.55	69.80	69.83	72.08	67.55	72.30	69.88	71.90	69.93	66.85	71.53	74.13	66.85
2:00:00 AM	64.65	64.65	65.88	66.75	67.30	67.45	64.65	65.08	65.23	67.40	67.43	68.93	65.23	69.10	67.48	68.78	67.50	64.65	68.48	70.55	64.65
3:00:00 AM	66.00	66.00	67.23	68.08	68.65	68.78	66.00	66.40	66.53	68.73	68.75	69.93	66.53	70.08	68.80	69.78	68.83	66.00	69.48	71.35	66.00
4:00:00 AM	63.55	63.55	64.73	65.55	66.08	66.20	63.55	63.90	64.03	66.15	66.18	67.03	64.03	67.15	66.20	66.90	66.25	63.55	66.65	68.28	63.55
5:00:00 AM	62.73	62.73	63.88	64.70	65.23	65.35	62.73	63.08	63.20	65.30	65.33	66.18	63.20	66.30	65.35	66.03	65.38	62.73	65.78	67.40	62.73
6:00:00 AM	63.18	63.18	64.45	65.35	65.93	66.08	63.18	63.50	63.60	66.00	66.03	66.50	63.60	66.58	66.05	66.33	66.08	63.18	66.08	67.55	63.18
7:00:00 AM	64.88	64.88	66.28	70.52	71.15	70.16	64.88	66.36	66.48	68.00	68.22	69.59	66.48	69.76	68.50	68.38	68.55	64.88	68.08	74.16	64.88
8:00:00 AM	66.70	66.70	68.13	102.14	102.79	92.32	66.70	79.89	80.02	69.88	72.21	82.11	80.02	83.19	75.28	70.10	75.30	66.70	69.80	114.47	66.70
9:00:00 AM	74.30	74.30	75.88	137.42	138.14	121.14	74.30	100.82	100.92	77.80	82.85	102.18	100.92	104.17	89.22	77.75	89.25	74.30	77.43	154.12	74.30
10:00:00 AM	80.28	80.28	81.78	172.25	172.93	151.72	80.28	124.47	124.54	83.58	92.83	124.36	124.54	127.32	103.85	83.20	103.87	80.28	82.90	189.97	80.28
11:00:00 AM	84.30	84.30	85.65	190.67	191.27	169.12	84.30	139.34	139.39	87.25	99.46	138.28	139.39	141.69	113.53	86.73	113.55	84.30	86.48	207.68	84.30
12:00:00 PM	161.68	161.68	164.25	274.33	275.51	253.44	161.68	220.39	220.57	167.38	180.58	222.32	220.57	225.92	195.68	167.33	195.70	161.68	166.80	293.39	161.68
1:00:00 PM	258.70	258.70	262.63	377.15	378.95	357.03	258.70	320.80	321.10	267.40	281.53	327.02	321.10	330.85	297.53	268.98	297.61	258.70	268.08	399.98	258.70
2:00:00 PM	198.38	198.38	201.63	314.06	315.56	293.58	198.38	259.10	259.40	205.63	219.33	264.99	259.40	268.85	234.94	208.35	235.01	198.38	207.53	338.02	198.38
3:00:00 PM	158.63	158.63	161.80	262.80	264.33	242.70	158.63	210.28	210.60	165.78	176.85	217.14	210.60	220.65	189.87	169.20	189.94	158.63	168.33	288.30	158.63
4:00:00 PM	148.90	148.90	153.13	194.60	196.68	185.23	148.90	165.67	166.17	158.58	161.45	179.76	166.17	181.47	165.24	164.93	165.36	148.90	163.65	221.34	148.90
5:00:00 PM	156.25	156.25	159.58	234.89	236.47	217.52	156.25	190.64	191.02	163.75	170.44	198.81	191.02	201.57	178.73	167.40	178.83	156.25	166.53	260.71	156.25
6:00:00 PM	140.00	140.00	143.18	193.98	195.48	181.27	140.00	161.26	161.69	147.23	151.01	171.30	161.69	173.39	155.96	152.33	156.04	140.00	151.40	219.36	140.00
7:00:00 PM	106.50	106.50	109.03	123.87	125.04	120.81	106.50	112.18	112.51	112.20	113.08	120.76	112.51	121.58	114.30	116.08	114.37	106.50	115.38	138.03	106.50
8:00:00 PM	90.63	90.63	92.78	94.33	95.33	95.58	90.63	91.45	91.73	95.48	95.50	99.08	91.73	99.45	95.63	98.78	95.68	90.63	98.18	102.40	90.63
9:00:00 PM	124.03	124.03	126.80	128.80	130.10	130.45	124.03	125.13	125.50	130.33	130.38	135.35	125.50	135.88	130.50	134.98	130.60	124.03	134.18	139.88	124.03
10:00:00 PM	104.10	104.10	106.45	108.13	109.20	109.50	104.10	105.03	105.35	109.40	109.43	113.60	105.35	114.05	109.55	113.28	109.63	104.10	112.63	117.40	104.10
11:00:00 PM	73.70	73.70	75.28	76.38	77.10	77.28	73.70	74.28	74.48	77.23	77.25	79.55	74.48	79.83	77.33	79.38	77.38	73.70	78.95	81.88	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table 4.22 – Case 9 Per Unit Voltage

	Voltage (PU)																			
Hour	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.96	0.94	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.97	0.97	1.00	0.97	0.95	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
6:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
7:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
8:00:00 AM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
9:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
10:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.98	1.00	0.97	0.97	0.98	0.97	1.00	0.98	0.97	1.00
11:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.98	1.00	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
12:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.98	0.97	1.00	0.98	0.96	1.00
1:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
2:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.96	0.97	0.97	0.97	1.00	0.97	0.95	1.00
3:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.96	0.94	1.00
4:00:00 PM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.95	1.00	0.95	0.92	1.00
5:00:00 PM	1.00	0.98	0.97	0.97	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.95	0.96	0.96	0.96	1.00	0.96	0.94	1.00
6:00:00 PM	1.00	0.98	0.97	0.97	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
7:00:00 PM	1.00	0.98	0.97	0.97	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
8:00:00 PM	1.00	0.98	0.97	0.97	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
9:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
10:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.96	0.99	0.95	0.97	0.96	0.97	1.00	0.96	0.94	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

Table 4.23 highlights the key economics of Case 9. D-LMP revenue is less than the base case due to the PV reducing losses. The renewable premium is becoming quite large and constitutes over a third of the total D-LMP revenue. PV has been shown to slightly lower cost, decrease line flows, decrease losses, and shave the peak load. Case 9 demonstrates the benefits and some perils of high penetration PV.

Table 4.23 – Revenue Streams for Case 9

Cost Stream	Cost (USD)
D-LMP Revenue	$29,065.29
Energy	$27,723.90
Losses	$1,341.39
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	N/A
DG Payments	$12,181.05

4.9 Simulation Result: Case 10

Case 10 uses 100% PV penetration in conjunction with storage systems. The tie lines remain open and the system remains radial rather than networked. The load profile of Figure 4.12 looks very little like the original base case. The combination of storage and PV has shifted the peak by 12 hours and has induced much more volatility into the load profile.

Figure 4.13 is the oneline at 3 pm. The demand D-LMP is listed next to each bus and the contouring is based on the D-LMP, with darker color indicating higher prices. The highest price is seen at bus 5 and the lowest price is at the feeder. For comparison, the losses in the system are causing a 1.7% increase in price at bus 19. The PV and storage nearly eliminate line losses at bus 19. The oneline shading is beginning to shift and look differently.

Table 4.24 lists the hourly D-LMPs for a load at every bus. The maximum price occurs at 1:00 PM on bus 5, with a value of $0.266/kWh. The presence of storage and high PV penetration is changing the patterns and flow of the system. The largest generation D-LMP is $388.38/MWh and the largest renewable component is still $0.127/kWh. Table 4.26 lists the per unit voltages at each bus for the 24 hour time period. The highest voltage is 1.00 pu and the lowest is 0.91 pu. The low voltage is from high storage charging load in the early morning.

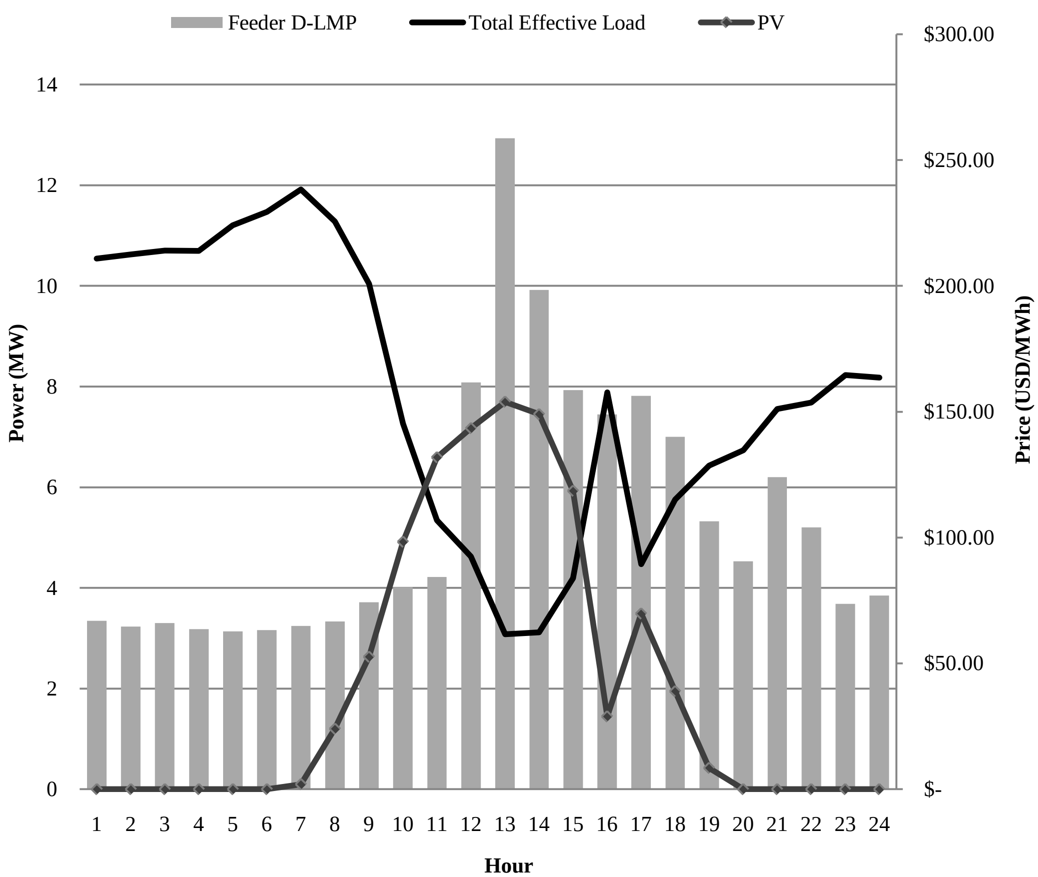

Figure 4.12 - Case 10 System Data

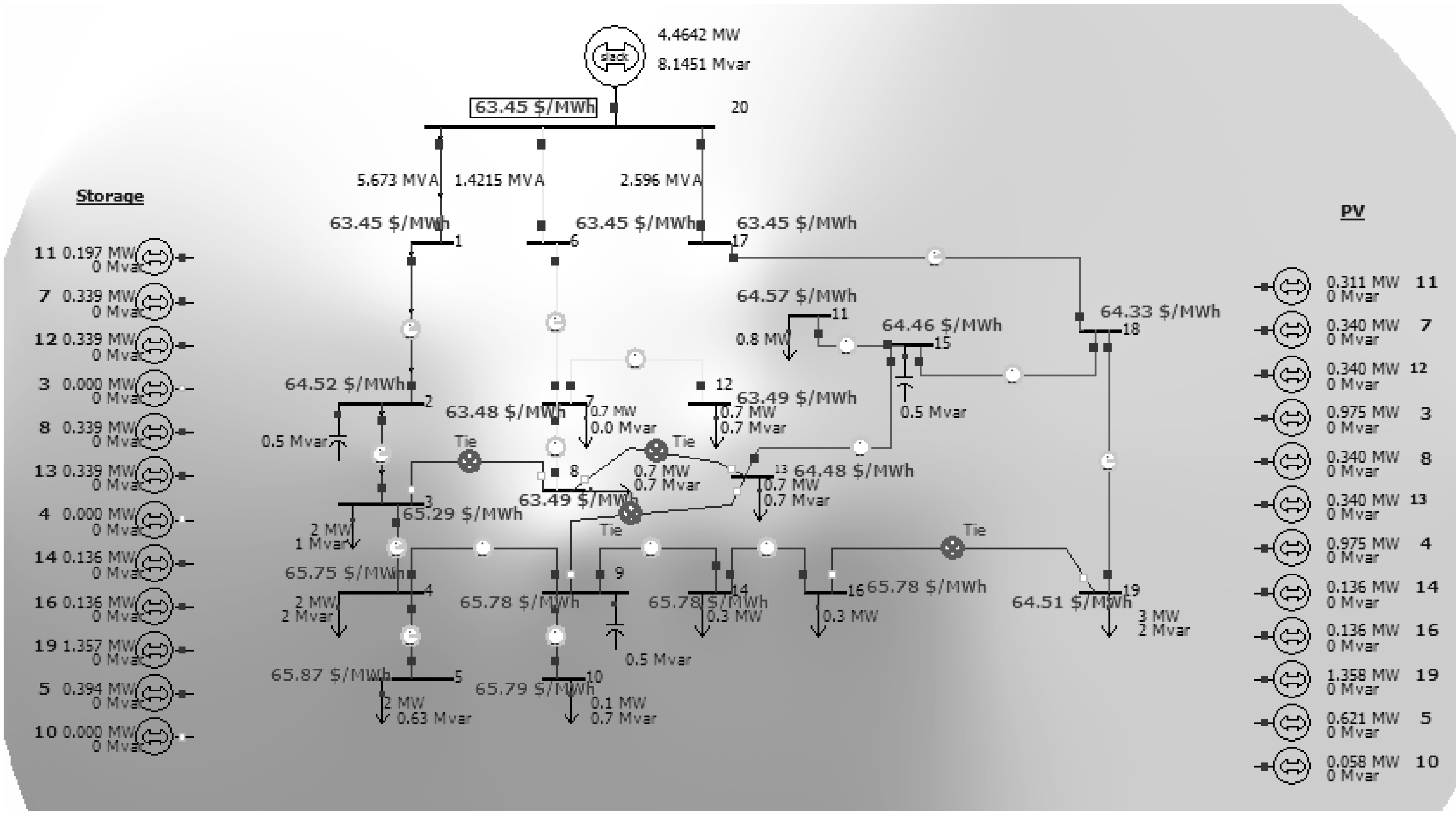

Figure 4.13 – Case 10 Oneline at Peak Demand

Table 4.24 – Case 10 Load D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Load DLMP (USD/kWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	0.06685	0.0683	0.06935	0.07008	0.07033	0.06685	0.06758	0.0678	0.0702	0.07023	0.0744	0.0678	0.07473	0.07033	0.07413	0.07038	0.06685	0.07358	0.07738	0.06685
2:00:00 AM	64.65	0.06465	0.06605	0.06708	0.06778	0.068	0.06465	0.06535	0.06558	0.0679	0.06793	0.072	0.06558	0.0723	0.06803	0.07173	0.06808	0.06465	0.0712	0.0749	0.06465
3:00:00 AM	66.00	0.066	0.06743	0.06843	0.06913	0.06935	0.066	0.06673	0.06698	0.06928	0.0693	0.07363	0.06698	0.07398	0.0694	0.07338	0.06945	0.066	0.07283	0.07673	0.066
4:00:00 AM	63.55	0.06355	0.06493	0.0659	0.06658	0.06678	0.06355	0.06425	0.0645	0.0667	0.06673	0.0709	0.0645	0.07123	0.0668	0.07065	0.06688	0.06355	0.07013	0.07388	0.06355
5:00:00 AM	62.725	0.06273	0.0641	0.06508	0.06575	0.06595	0.06273	0.06348	0.06375	0.06588	0.0659	0.07048	0.06375	0.0709	0.066	0.07025	0.06608	0.06273	0.06973	0.07383	0.06273
6:00:00 AM	63.175	0.06318	0.06463	0.06568	0.06638	0.06658	0.06318	0.06395	0.0642	0.06653	0.06655	0.071	0.0642	0.07143	0.06665	0.07078	0.0667	0.06318	0.07023	0.07438	0.06318
7:00:00 AM	64.875	0.06488	0.06645	0.0676	0.06835	0.06858	0.06488	0.06568	0.06595	0.06853	0.06853	0.0732	0.06595	0.07365	0.06865	0.07295	0.06873	0.06488	0.0724	0.0768	0.06488
8:00:00 AM	66.70	0.0667	0.06828	0.06943	0.0702	0.07043	0.0667	0.06748	0.06773	0.07033	0.07035	0.07455	0.06773	0.07493	0.07045	0.0743	0.07053	0.0667	0.07375	0.07783	0.0667
9:00:00 AM	74.30	0.0743	0.076	0.07723	0.07805	0.0783	0.0743	0.075	0.07523	0.07818	0.0782	0.08145	0.07523	0.08175	0.0783	0.0812	0.07835	0.0743	0.08068	0.0842	0.0743
10:00:00 AM	80.275	0.08028	0.08183	0.08293	0.08365	0.08388	0.08028	0.0807	0.08085	0.08375	0.08378	0.08498	0.08085	0.08508	0.08383	0.08475	0.08385	0.08028	0.08438	0.0864	0.08028
11:00:00 AM	84.30	0.0843	0.08565	0.0866	0.0872	0.0874	0.0843	0.08458	0.08465	0.08728	0.08728	0.08745	0.08465	0.08745	0.08733	0.08725	0.08733	0.0843	0.08698	0.08818	0.0843
12:00:00 PM	161.675	0.16168	0.16415	0.1659	0.167	0.16733	0.16168	0.162	0.16213	0.1671	0.16713	0.16625	0.16213	0.16618	0.16715	0.16595	0.16718	0.16168	0.16553	0.16705	0.16168
1:00:00 PM	258.70	0.2587	0.26218	0.2646	0.26608	0.26645	0.2587	0.2587	0.25868	0.26613	0.2662	0.26145	0.25868	0.26108	0.26613	0.26108	0.26613	0.2587	0.26073	0.26075	0.2587
2:00:00 PM	198.375	0.19838	0.2011	0.20303	0.20418	0.20443	0.19838	0.19835	0.19835	0.20423	0.20425	0.2004	0.19835	0.20013	0.2042	0.20015	0.2042	0.19838	0.1999	0.19993	0.19838
3:00:00 PM	158.625	0.15863	0.1613	0.16323	0.16438	0.16468	0.15863	0.1587	0.15873	0.16445	0.16448	0.16143	0.15873	0.1612	0.16445	0.16115	0.16445	0.15863	0.16083	0.16128	0.15863
4:00:00 PM	148.90	0.1489	0.15263	0.1553	0.157	0.15745	0.1489	0.14953	0.14975	0.15718	0.15725	0.15663	0.14975	0.15665	0.15728	0.15618	0.15733	0.1489	0.15553	0.15853	0.1489
5:00:00 PM	156.25	0.15625	0.15908	0.1611	0.1623	0.16255	0.15625	0.15635	0.15638	0.16238	0.16243	0.15873	0.15638	0.15853	0.16238	0.15848	0.16238	0.15625	0.15818	0.1586	0.15625
6:00:00 PM	140.00	0.14	0.14278	0.14475	0.14595	0.14623	0.14	0.14033	0.14043	0.14605	0.1461	0.14425	0.14043	0.14423	0.1461	0.14398	0.14613	0.14	0.14363	0.1451	0.14
7:00:00 PM	106.50	0.1065	0.10875	0.11038	0.11135	0.11155	0.1065	0.10683	0.10693	0.11143	0.11145	0.1103	0.10693	0.11033	0.11148	0.11008	0.1115	0.1065	0.10975	0.11123	0.1065
8:00:00 PM	90.625	0.09063	0.09255	0.09393	0.09475	0.09495	0.09063	0.09095	0.09105	0.09485	0.09488	0.0943	0.09105	0.09435	0.0949	0.0941	0.09493	0.09063	0.0938	0.09528	0.09063
9:00:00 PM	124.025	0.12403	0.12665	0.12855	0.12973	0.13003	0.12403	0.12465	0.12488	0.12988	0.1299	0.13085	0.12488	0.13103	0.12998	0.13055	0.13003	0.12403	0.13003	0.13303	0.12403
10:00:00 PM	104.10	0.1041	0.1063	0.1079	0.10888	0.10913	0.1041	0.10463	0.1048	0.109	0.10903	0.10983	0.1048	0.10998	0.10908	0.10958	0.10913	0.1041	0.10913	0.11165	0.1041
11:00:00 PM	73.70	0.0737	0.07525	0.07635	0.07705	0.07723	0.0737	0.07418	0.07435	0.07715	0.07718	0.07865	0.07435	0.07885	0.07723	0.07848	0.07728	0.0737	0.0781	0.08048	0.0737
12:00:00 AM	76.90	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table 4.25 – Case 10 Generation D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Gen DLMPs (USD/MWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.30	69.35	70.08	70.33	66.85	67.58	67.80	70.20	70.23	74.40	67.80	74.73	70.33	74.13	70.38	66.85	73.58	77.38	66.85
2:00:00 AM	64.65	64.65	66.05	67.08	67.78	68.00	64.65	65.35	65.58	67.90	67.93	72.00	65.58	72.30	68.03	71.73	68.08	64.65	71.20	74.90	64.65
3:00:00 AM	66.00	66.00	67.43	68.43	69.13	69.35	66.00	66.73	66.98	69.28	69.30	73.63	66.98	73.98	69.40	73.38	69.45	66.00	72.83	76.73	66.00
4:00:00 AM	63.55	63.55	64.93	65.90	66.58	66.78	63.55	64.25	64.50	66.70	66.73	70.90	64.50	71.23	66.80	70.65	66.88	63.55	70.13	73.88	63.55
5:00:00 AM	62.73	62.73	64.10	65.08	65.75	65.95	62.73	63.48	63.75	65.88	65.90	70.48	63.75	70.90	66.00	70.25	66.08	62.73	69.73	73.83	62.73
6:00:00 AM	63.18	63.18	64.63	65.68	66.38	66.58	63.18	63.95	64.20	66.53	66.55	71.00	64.20	71.43	66.65	70.78	66.70	63.18	70.23	74.38	63.18
7:00:00 AM	64.88	64.88	66.45	70.82	71.57	70.64	64.88	66.81	67.08	68.53	68.72	74.24	67.08	74.78	69.10	72.95	69.18	64.88	72.40	81.26	64.88
8:00:00 AM	66.70	66.70	68.28	102.41	103.19	92.77	66.70	80.34	80.59	70.33	72.68	86.38	80.59	87.79	75.80	74.30	75.88	66.70	73.75	120.97	66.70
9:00:00 AM	74.30	74.30	76.00	137.64	138.47	121.52	74.30	101.19	101.42	78.18	83.25	105.68	101.42	107.94	89.67	81.20	89.72	74.30	80.68	159.42	74.30
10:00:00 AM	80.28	80.28	81.83	172.35	173.08	151.87	80.28	124.64	124.79	83.75	93.00	125.93	124.79	129.02	104.07	84.75	104.10	80.28	84.38	192.34	80.28
11:00:00 AM	84.30	84.30	85.65	190.67	191.27	169.12	84.30	139.41	139.49	87.28	99.46	138.80	139.49	142.29	113.58	87.25	113.58	84.30	86.98	208.53	84.30
12:00:00 PM	161.68	161.68	164.15	274.16	275.26	253.14	161.68	220.24	220.37	167.10	180.31	220.87	220.37	224.42	195.38	165.95	195.40	161.68	165.53	291.39	161.68
1:00:00 PM	258.70	258.70	262.18	376.35	377.83	355.73	258.70	319.90	319.87	266.13	280.28	318.92	319.87	322.27	296.11	261.08	296.11	258.70	260.73	388.38	258.70
2:00:00 PM	198.38	198.38	201.10	313.16	314.31	292.10	198.38	258.17	258.17	204.23	217.91	256.54	258.17	259.95	233.36	200.15	233.36	198.38	199.90	326.04	198.38
3:00:00 PM	158.63	158.63	161.30	261.98	263.13	241.30	158.63	209.40	209.43	164.45	175.50	208.82	209.43	211.90	188.37	161.15	188.37	158.63	160.83	276.47	158.63
4:00:00 PM	148.90	148.90	152.63	193.73	195.43	183.76	148.90	164.82	165.05	157.18	160.05	170.71	165.05	171.95	163.69	156.18	163.74	148.90	155.53	208.29	148.90
5:00:00 PM	156.25	156.25	159.08	234.04	235.24	216.10	156.25	189.67	189.69	162.38	169.06	189.64	189.69	191.84	177.18	158.48	177.18	156.25	158.18	247.46	156.25
6:00:00 PM	140.00	140.00	142.78	193.26	194.46	180.10	140.00	160.39	160.49	146.05	149.86	162.75	160.49	164.29	154.64	143.98	154.66	140.00	143.63	206.78	140.00
7:00:00 PM	106.50	106.50	108.75	123.39	124.37	120.04	106.50	111.56	111.66	111.43	112.28	114.64	111.66	115.06	113.40	110.08	113.42	106.50	109.75	128.90	106.50
8:00:00 PM	90.63	90.63	92.55	93.93	94.75	94.95	90.63	90.95	91.05	94.85	94.88	94.30	91.05	94.35	94.90	94.10	94.93	90.63	93.80	95.28	90.63
9:00:00 PM	124.03	124.03	126.65	128.55	129.73	130.03	124.03	124.65	124.88	129.88	129.90	130.85	124.88	131.03	129.98	130.55	130.03	124.03	130.03	133.03	124.03
10:00:00 PM	104.10	104.10	106.30	107.90	108.88	109.13	104.10	104.63	104.80	109.00	109.03	109.83	104.80	109.98	109.08	109.58	109.13	104.10	109.13	111.65	104.10
11:00:00 PM	73.70	73.70	75.25	76.35	77.05	77.23	73.70	74.18	74.35	77.15	77.18	78.65	74.35	78.85	77.23	78.48	77.28	73.70	78.10	80.48	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table 4.26 – Case 10 Per Unit Voltage

Hour	Voltage (PU)																			
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
6:00:00 AM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
7:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.95	0.91	1.00
8:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.95	0.96	1.00	0.95	0.92	1.00
9:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.96	0.93	1.00
10:00:00 AM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.96	0.97	0.97	0.97	1.00	0.97	0.95	1.00
11:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.98	1.00	0.97	0.97	0.98	0.97	1.00	0.98	0.97	1.00
12:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.98	1.00	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
1:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.99	1.00	0.98	0.97	0.99	0.97	1.00	0.99	0.98	1.00
2:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.98	1.00	0.98	0.97	0.99	0.97	1.00	0.99	0.98	1.00
3:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.98	1.00	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
4:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.97	0.99	0.96	0.96	0.97	0.96	1.00	0.97	0.95	1.00
5:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.98	1.00	0.98	0.97	0.98	0.97	1.00	0.99	0.98	1.00
6:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.98	1.00	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
7:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.98	1.00	0.97	0.97	0.98	0.97	1.00	0.98	0.97	1.00
8:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.98	0.96	1.00
9:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.96	0.97	0.97	0.97	1.00	0.97	0.95	1.00
10:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.96	0.97	0.97	0.97	1.00	0.97	0.95	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

Table 4.27 highlights the key economics of Case 10. D-LMP revenue is less than Case 2 due to the PV reducing losses. The renewable premium is becoming quite large and constitutes nearly a half of the total D-LMP revenue. Case 10 demonstrates the benefits and some of perils of high penetration PV even with storage present.

Table 4.27 – Revenue Streams for Case 10

Cost Stream	Cost (USD)
D-LMP Revenue	$26,278.97
Energy	$25,161.36
Losses	$1,117.61
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	$2481.33
DG Payments	$12,062.65

4.10 Simulation Result: Case 11

Case 11 uses 100% PV penetration in conjunction with storage systems. Case 11 is a special case because tie lines are *closed* and the system becomes networked. The load profile of Figure 4.14 looks much like Case 10. The combination of storage and PV has induced much more volatility into the load profile.

Figure 4.15 is the oneline at 3 pm. The demand D-LMP is listed next to each bus and the contouring is based on the D-LMP, with darker color indicating higher prices. The highest price is seen at bus 5 and the lowest price is at the feeder. Networking the system has made the highest price only 3.6% higher than the feeder. The prices are more homogenous across the network, which can also be seen in the oneline contouring.

Table 4.28 lists the hourly D-LMPs for a load at every bus. The maximum price occurs at 1:00 PM on bus 5, with a value of $0.263/kWh. Networking the system made the D-LMPs much more homogenous. The largest generation D-LMP is $389.76/MWh and the largest renewable component is \$0.127/kWh. Table 4.30 lists the per unit voltages at each bus for the 24 hour time period. The highest voltage is 1.00 pu and the lowest is 0.96 pu, a substantial improvement.

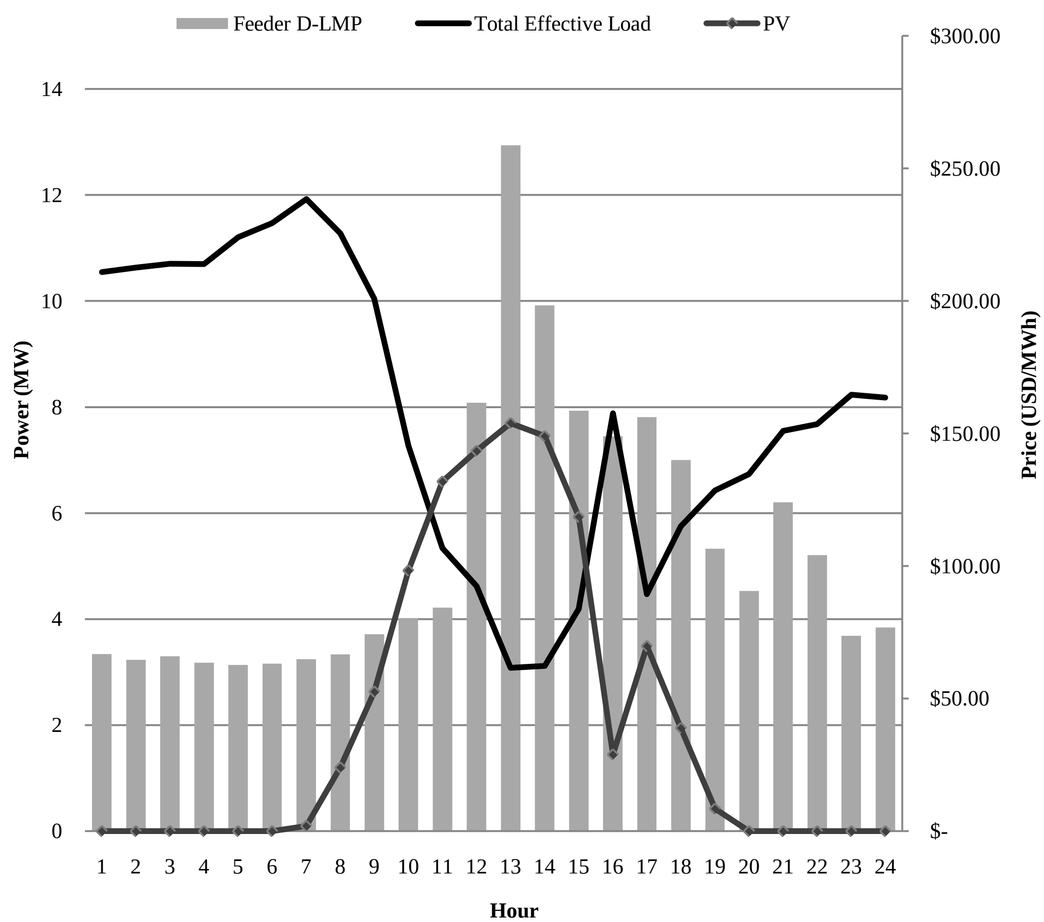

Figure 4.14 - Case 11 System Data

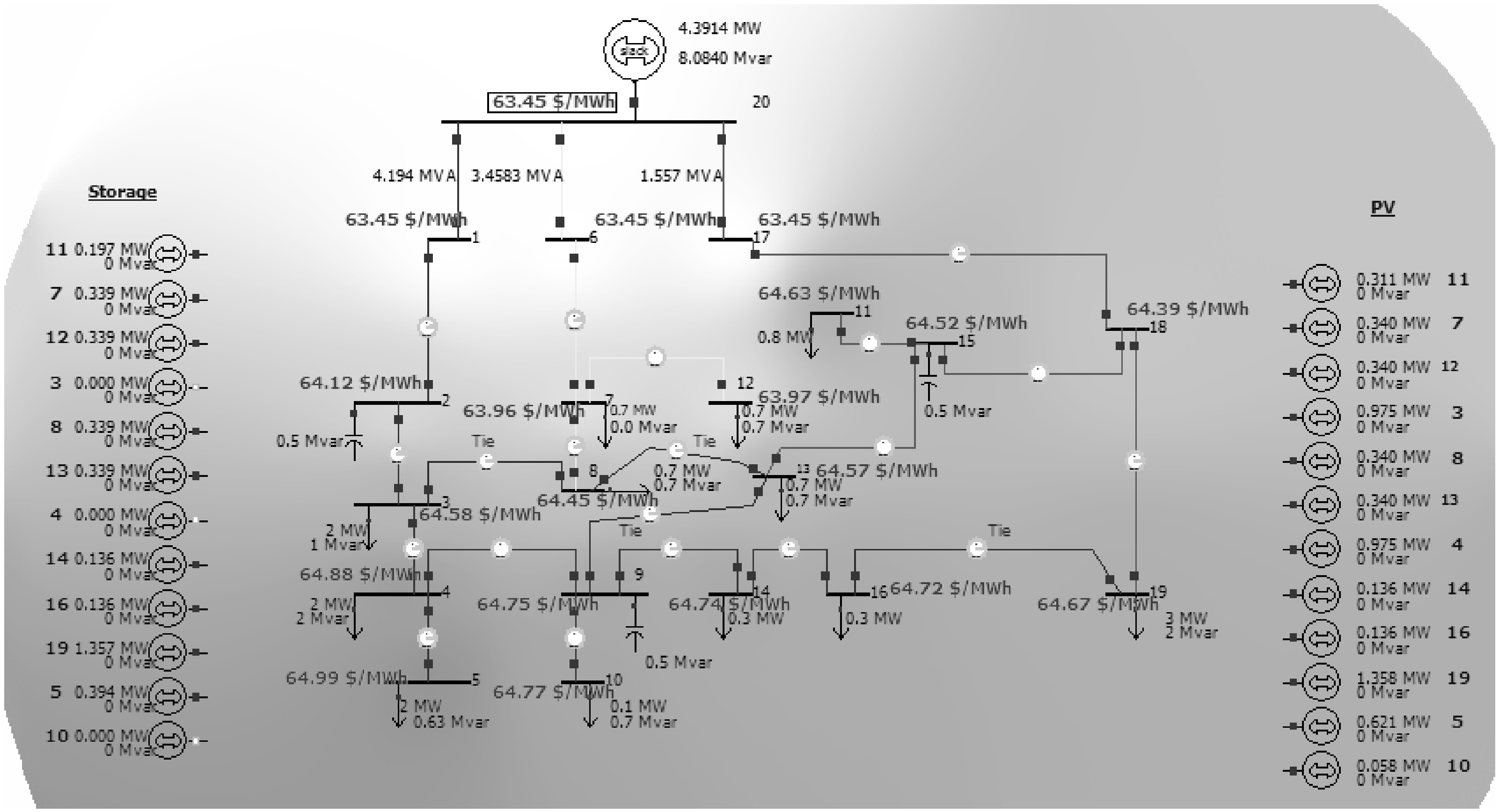

Figure 4.15 – Case 11 Oneline at Peak Demand

Table 4.28 – Case 11 Load D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Load DLMP (USD/kWh)																			
		Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	0.06685	0.06833	0.0694	0.07013	0.07035	0.06685	0.06838	0.06943	0.07025	0.07028	0.0702	0.0686	0.06985	0.07065	0.06995	0.07098	0.06685	0.06978	0.07155	0.06685
2:00:00 AM	64.65	0.06465	0.0661	0.06713	0.06783	0.06805	0.06465	0.06613	0.06715	0.06795	0.06798	0.0679	0.06638	0.06758	0.06835	0.06768	0.06868	0.06465	0.0675	0.06923	0.06465
3:00:00 AM	66.00	0.066	0.06748	0.06853	0.06925	0.06948	0.066	0.06753	0.06858	0.0694	0.06943	0.06933	0.06778	0.069	0.0698	0.0691	0.07015	0.066	0.06893	0.07075	0.066
4:00:00 AM	63.55	0.06355	0.06498	0.066	0.06668	0.0669	0.06355	0.06503	0.06603	0.06683	0.06685	0.06675	0.06525	0.06645	0.06723	0.06653	0.06755	0.06355	0.06638	0.06813	0.06355
5:00:00 AM	62.725	0.06273	0.0642	0.06525	0.06595	0.06615	0.06273	0.06425	0.06528	0.0661	0.06613	0.066	0.06453	0.06573	0.06653	0.0658	0.0669	0.06273	0.06565	0.06753	0.06273
6:00:00 AM	63.175	0.06318	0.0647	0.06578	0.0665	0.0667	0.06318	0.06475	0.06583	0.06668	0.0667	0.06655	0.065	0.06628	0.0671	0.06635	0.06748	0.06318	0.06618	0.0681	0.06318
7:00:00 AM	64.875	0.06488	0.0665	0.06768	0.06845	0.06868	0.06488	0.06655	0.0677	0.06863	0.06865	0.06848	0.06683	0.0682	0.06908	0.06825	0.06948	0.06488	0.0681	0.07013	0.06488
8:00:00 AM	66.70	0.0667	0.0683	0.06943	0.0702	0.07043	0.0667	0.06833	0.06945	0.07033	0.07035	0.0702	0.06858	0.06993	0.07075	0.06998	0.07113	0.0667	0.0698	0.07173	0.0667
9:00:00 AM	74.30	0.0743	0.0759	0.07705	0.0778	0.07805	0.0743	0.07588	0.07703	0.0779	0.0779	0.07778	0.07613	0.07748	0.07825	0.07753	0.07858	0.0743	0.07733	0.0791	0.0743
10:00:00 AM	80.275	0.08028	0.08155	0.08248	0.08308	0.0833	0.08028	0.08148	0.0824	0.08305	0.08308	0.08298	0.08163	0.08273	0.08328	0.08275	0.08345	0.08028	0.08255	0.08373	0.08028
11:00:00 AM	84.30	0.0843	0.08533	0.08603	0.0865	0.0867	0.0843	0.0852	0.08595	0.08645	0.08645	0.08635	0.0853	0.08618	0.08655	0.08618	0.08665	0.0843	0.086	0.0868	0.0843
12:00:00 PM	161.675	0.16168	0.16343	0.16465	0.16545	0.16575	0.16168	0.16318	0.16443	0.16528	0.1653	0.16508	0.16328	0.1648	0.16538	0.16475	0.16548	0.16168	0.16445	0.1656	0.16168
1:00:00 PM	258.70	0.2587	0.26075	0.26218	0.26308	0.26345	0.2587	0.26023	0.26173	0.26263	0.26268	0.26225	0.2602	0.26208	0.2625	0.2619	0.26238	0.2587	0.26145	0.26213	0.2587
2:00:00 PM	198.375	0.19838	0.2	0.2011	0.2018	0.20205	0.19838	0.19955	0.20073	0.20143	0.20148	0.20108	0.19955	0.201	0.20133	0.20083	0.20123	0.19838	0.2005	0.20103	0.19838
3:00:00 PM	158.625	0.15863	0.1603	0.16145	0.1622	0.16248	0.15863	0.1599	0.16113	0.16188	0.16193	0.16158	0.15993	0.16143	0.16185	0.1613	0.1618	0.15863	0.16098	0.16168	0.15863
4:00:00 PM	148.90	0.1489	0.15163	0.15355	0.15483	0.15525	0.1489	0.15128	0.15325	0.1546	0.15468	0.15418	0.1515	0.15388	0.15488	0.15375	0.15508	0.1489	0.15333	0.15538	0.1489
5:00:00 PM	156.25	0.15625	0.15798	0.1592	0.15995	0.1602	0.15625	0.15758	0.15885	0.15963	0.15968	0.15923	0.1576	0.15915	0.15958	0.15895	0.15953	0.15625	0.15863	0.15938	0.15625
6:00:00 PM	140.00	0.14	0.1419	0.14325	0.14408	0.14435	0.14	0.14158	0.14295	0.14385	0.1439	0.14345	0.1417	0.14335	0.14395	0.1432	0.144	0.14	0.14288	0.1441	0.14
7:00:00 PM	106.50	0.1065	0.10808	0.1092	0.10993	0.11013	0.1065	0.10785	0.109	0.10975	0.10978	0.1094	0.10795	0.10933	0.10985	0.1092	0.10995	0.1065	0.10895	0.11005	0.1065
8:00:00 PM	90.625	0.09063	0.09203	0.093	0.09363	0.09383	0.09063	0.09183	0.09285	0.09353	0.09355	0.09325	0.09195	0.09315	0.09365	0.09305	0.09373	0.09063	0.09285	0.09388	0.09063
9:00:00 PM	124.025	0.12403	0.1261	0.1276	0.12855	0.12885	0.12403	0.12593	0.12743	0.12848	0.12853	0.12815	0.12615	0.12793	0.12878	0.12788	0.129	0.12403	0.12758	0.12938	0.12403
10:00:00 PM	104.10	0.1041	0.10585	0.1071	0.1079	0.10815	0.1041	0.1057	0.10695	0.10785	0.10788	0.10758	0.10588	0.10738	0.10808	0.10733	0.10828	0.1041	0.10708	0.1086	0.1041
11:00:00 PM	73.70	0.0737	0.07503	0.07595	0.07658	0.07675	0.0737	0.07495	0.0759	0.07658	0.0766	0.0764	0.07513	0.07623	0.07683	0.07623	0.07703	0.0737	0.07605	0.07735	0.0737
12:00:00 AM	76.90	0.0769	0.07825	0.07923	0.07983	0.07998	0.0769	0.0782	0.07915	0.07988	0.0799	0.07965	0.0784	0.07953	0.08015	0.0795	0.08038	0.0769	0.07935	0.08075	0.0769

Table 4.29 – Case 11 Generation D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Gen DLMPs (USD/MWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.33	69.40	70.13	70.35	66.85	68.38	69.43	70.25	70.28	70.20	68.60	69.85	70.65	69.95	70.98	66.85	69.78	71.55	66.85
2:00:00 AM	64.65	64.65	66.10	67.13	67.83	68.05	64.65	66.13	67.15	67.95	67.98	67.90	66.38	67.58	68.35	67.68	68.68	64.65	67.50	69.23	64.65
3:00:00 AM	66.00	66.00	67.48	68.53	69.25	69.48	66.00	67.53	68.58	69.40	69.43	69.33	67.78	69.00	69.80	69.10	70.15	66.00	68.93	70.75	66.00
4:00:00 AM	63.55	63.55	64.98	66.00	66.68	66.90	63.55	65.03	66.03	66.83	66.85	66.75	65.25	66.45	67.23	66.53	67.55	63.55	66.38	68.13	63.55
5:00:00 AM	62.73	62.73	64.20	65.25	65.95	66.15	62.73	64.25	65.28	66.10	66.13	66.00	64.53	65.73	66.53	65.80	66.90	62.73	65.65	67.53	62.73
6:00:00 AM	63.18	63.18	64.70	65.78	66.50	66.70	63.18	64.75	65.83	66.68	66.70	66.55	65.00	66.28	67.10	66.35	67.48	63.18	66.18	68.10	63.18
7:00:00 AM	64.88	64.88	66.50	70.90	71.67	70.74	64.88	67.68	68.83	68.63	68.85	69.51	67.96	69.33	69.53	68.25	69.93	64.88	68.10	74.58	64.88
8:00:00 AM	66.70	66.70	68.30	102.41	103.19	92.77	66.70	81.19	82.32	70.33	72.68	82.03	81.44	82.79	76.10	69.98	76.48	66.70	69.80	114.87	66.70
9:00:00 AM	74.30	74.30	75.90	137.47	138.22	121.27	74.30	102.07	103.22	77.90	82.95	102.00	102.32	103.67	89.62	77.53	89.95	74.30	77.33	154.32	74.30
10:00:00 AM	80.28	80.28	81.55	171.90	172.50	151.29	80.28	125.42	126.34	83.05	92.30	123.93	125.57	126.67	103.52	82.75	103.70	80.28	82.55	189.67	80.28
11:00:00 AM	84.30	84.30	85.33	190.10	190.57	168.42	84.30	140.04	140.79	86.45	98.64	137.70	140.14	141.01	112.80	86.18	112.90	84.30	86.00	207.15	84.30
12:00:00 PM	161.68	161.68	163.43	272.91	273.71	251.56	161.68	221.42	222.67	165.28	178.48	219.70	221.52	223.04	193.60	164.75	193.70	161.68	164.45	289.94	161.68
1:00:00 PM	258.70	258.70	260.75	373.93	374.83	352.73	258.70	321.42	322.92	262.63	276.75	319.72	321.40	323.27	292.48	261.90	292.36	258.70	261.45	389.76	258.70
2:00:00 PM	198.38	198.38	200.00	311.24	311.94	289.73	198.38	259.37	260.55	201.43	215.13	257.22	259.37	260.82	230.49	200.83	230.39	198.38	200.50	327.14	198.38
3:00:00 PM	158.63	158.63	160.30	260.20	260.95	239.10	158.63	210.60	211.83	161.88	172.95	208.97	210.63	212.13	185.77	161.30	185.72	158.63	160.98	276.87	158.63
4:00:00 PM	148.90	148.90	151.63	191.98	193.25	181.56	148.90	166.57	168.55	154.60	157.48	168.26	166.80	169.17	161.29	153.75	161.49	148.90	153.33	205.14	148.90
5:00:00 PM	156.25	156.25	157.98	232.14	232.89	213.75	156.25	190.89	192.17	159.63	166.31	190.14	190.92	192.47	174.38	158.95	174.33	156.25	158.63	248.24	156.25
6:00:00 PM	140.00	140.00	141.90	191.76	192.58	178.22	140.00	161.64	163.01	143.85	147.66	161.95	161.76	163.41	152.49	143.20	152.54	140.00	142.88	205.78	140.00
7:00:00 PM	106.50	106.50	108.08	122.22	122.94	118.61	106.50	112.58	113.73	109.75	110.60	113.74	112.68	114.06	111.77	109.20	111.87	106.50	108.95	127.73	106.50
8:00:00 PM	90.63	90.63	92.03	93.00	93.63	93.83	90.63	91.83	92.85	93.53	93.55	93.25	91.95	93.15	93.65	93.05	93.73	90.63	92.85	93.88	90.63
9:00:00 PM	124.03	124.03	126.10	127.60	128.55	128.85	124.03	125.93	127.43	128.48	128.53	128.15	126.15	127.93	128.78	127.88	129.00	124.03	127.58	129.38	124.03
10:00:00 PM	104.10	104.10	105.85	107.10	107.90	108.15	104.10	105.70	106.95	107.85	107.88	107.58	105.88	107.38	108.08	107.33	108.28	104.10	107.08	108.60	104.10
11:00:00 PM	73.70	73.70	75.03	75.95	76.58	76.75	73.70	74.95	75.90	76.58	76.60	76.40	75.13	76.23	76.83	76.23	77.03	73.70	76.05	77.35	73.70
12:00:00 AM	76.90	76.90	78.25	79.23	79.83	79.98	76.90	78.20	79.15	79.88	79.90	79.65	78.40	79.53	80.15	79.50	80.38	76.90	79.35	80.75	76.90

Table 4.30 – Case 11 Per Unit Voltage

	Voltage (PU)																			
Hour	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.97	0.96	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.98	0.96	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.98	0.96	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.98	0.96	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.97	0.96	1.00
6:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.97	0.96	1.00
7:00:00 AM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
8:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
9:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.97	1.00	0.98	0.96	1.00
10:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.98	0.97	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
11:00:00 AM	1.00	0.99	0.98	0.98	0.98	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	1.00	0.98	0.98	1.00
12:00:00 PM	1.00	0.99	0.98	0.98	0.98	1.00	0.99	0.99	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	1.00	0.99	0.98	1.00
1:00:00 PM	1.00	0.99	0.99	0.98	0.98	1.00	0.99	0.99	0.98	0.98	0.99	0.99	0.99	0.98	0.99	0.98	1.00	0.99	0.98	1.00
2:00:00 PM	1.00	0.99	0.99	0.98	0.98	1.00	0.99	0.99	0.98	0.98	0.99	0.99	0.98	0.98	0.99	0.98	1.00	0.99	0.98	1.00
3:00:00 PM	1.00	0.99	0.98	0.98	0.98	1.00	0.99	0.99	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	1.00	0.99	0.98	1.00
4:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
5:00:00 PM	1.00	0.99	0.98	0.98	0.98	1.00	0.99	0.99	0.98	0.98	0.98	0.99	0.98	0.98	0.99	0.98	1.00	0.99	0.98	1.00
6:00:00 PM	1.00	0.99	0.98	0.98	0.98	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	1.00	0.98	0.97	1.00
7:00:00 PM	1.00	0.99	0.98	0.98	0.98	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	1.00	0.98	0.97	1.00
8:00:00 PM	1.00	0.99	0.98	0.98	0.98	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	1.00	0.98	0.97	1.00
9:00:00 PM	1.00	0.99	0.98	0.98	0.97	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
10:00:00 PM	1.00	0.99	0.98	0.98	0.97	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
12:00:00 AM	1.00	0.99	0.98	0.98	0.97	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00

Table 4.31 highlights the key economics of Case 11. D-LMP revenue is the lowest of the present cases. The renewable premium is large and constitutes nearly half of the total D-LMP revenue. Networking the system substantially reduced the cost of losses in the system and seems to have largely bolstered the system.

Table 4.31 – Revenue Streams for Case 11

Cost Stream	Cost (USD)
D-LMP Revenue	$25,951.62
Energy	$25,161.36
Losses	$790.27
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	$2554.07
DG Payments	$12,022.14

4.11 Simulation Result: Case 12

Case 12 is a special case used to demonstrate how the D-LMP behaves when an excess of energy is generated. The case uses 200% PV penetration in conjunction with storage systems. Additionally, the tie lines are *closed* and the system becomes networked. The load profile of Figure 4.16 is entirely dominated by the PV and any change in solar output is clearly reflected in the total effective load. The combination of storage and PV has shifted the peak by 12 hours and has induced much more volatility into the load profile.

Figure 4.17 is the oneline at 3 pm. The demand D-LMP is listed next to each bus and the contouring is based on the D-LMP, with darker color indicating higher prices. The highest price is seen at the feeder and the lowest price is at bus 19. The system is now generating more energy than it consumes and thus the price across the system decreases. The coloring scheme now appears inverted compared to the base case.

Table 4.32 lists the hourly D-LMPs for a load at every bus. The maximum price occurs at 1:00 PM on bus 5, with a value of $0.259/kWh. The PV was able to drive bus 19 to more than 3% less than the feeder price. The largest generation D-LMP is $406.35/MWh and the largest renewable component is $0.156/kWh. Table 4.34 lists the per unit voltages at each bus for the 24 hour time period. The highest voltage is 1.00 pu and the lowest is 0.96 pu.

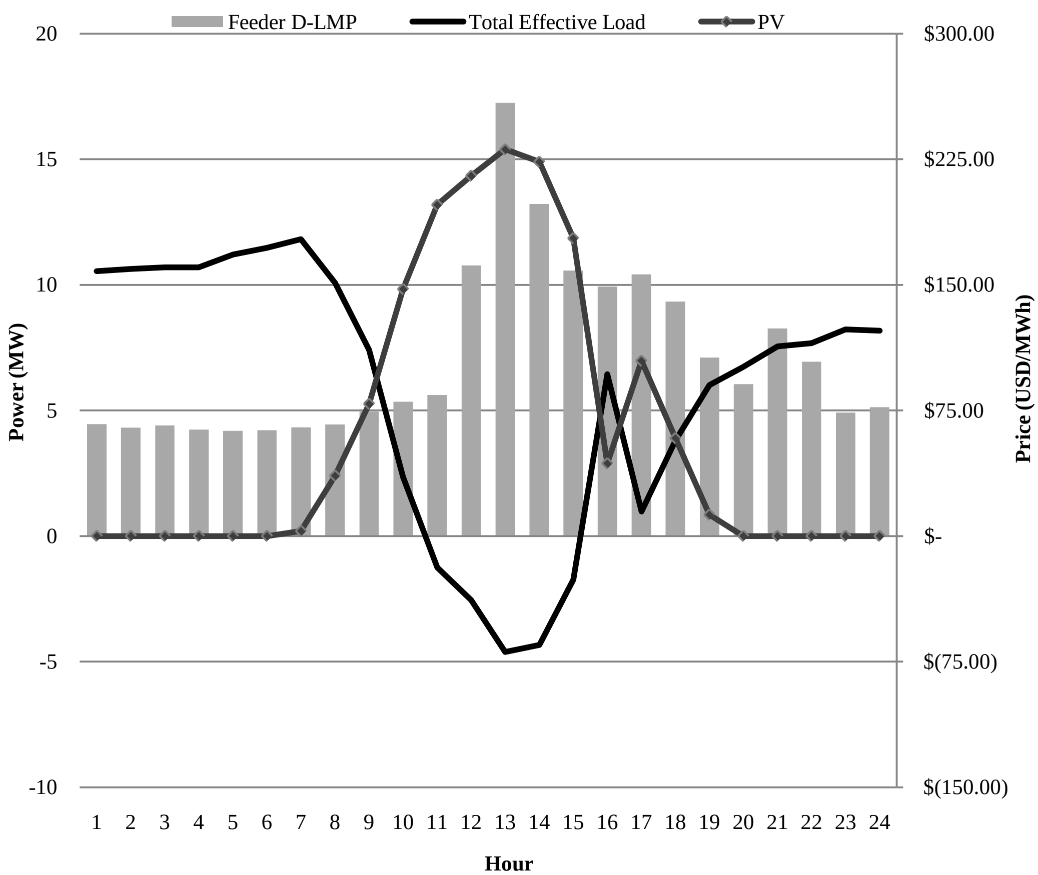

Figure 4.16 - Case 12 System Data

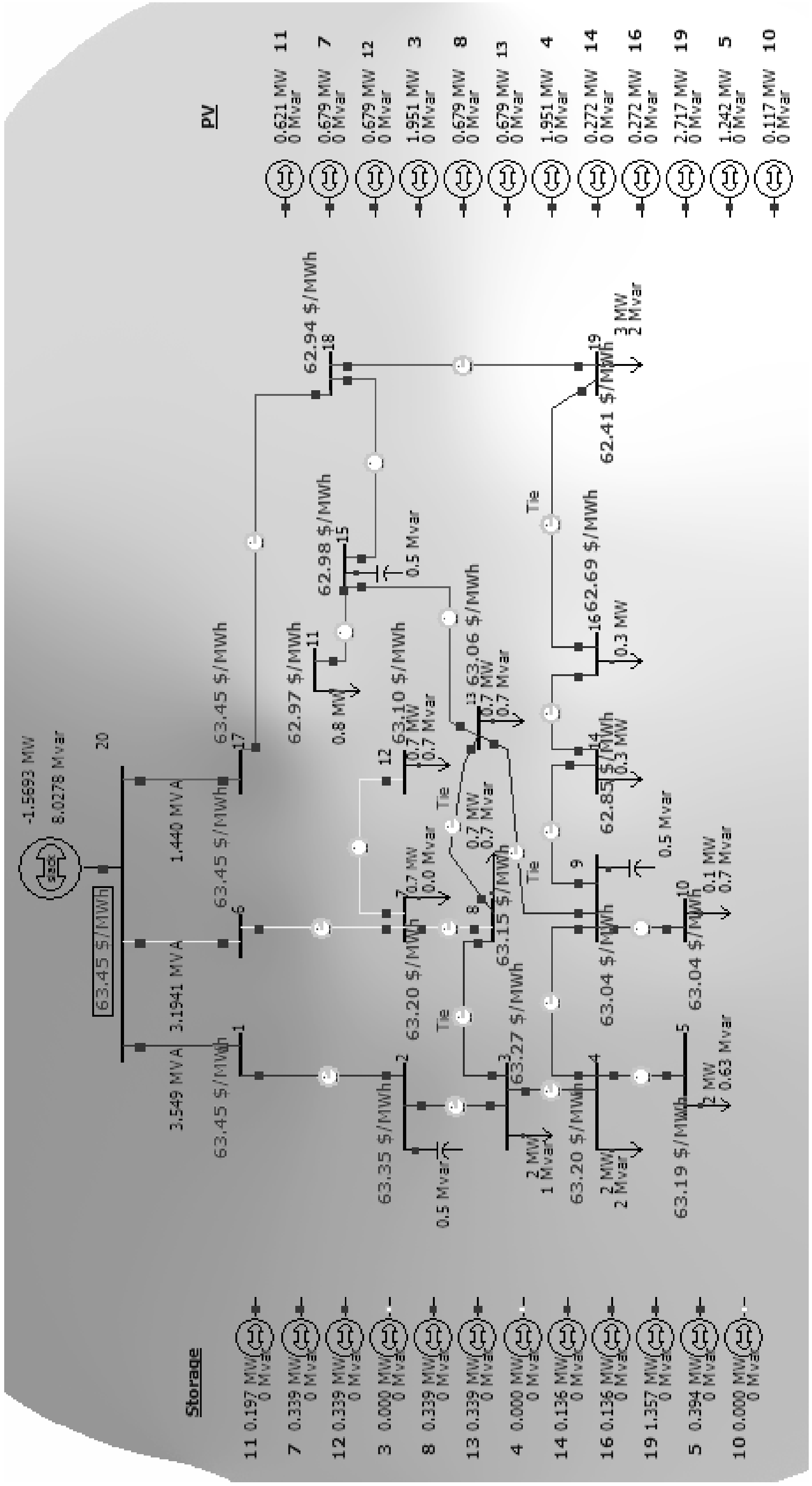

Figure 4.17 – Case 12 Oneline at Peak Demand

Table 4.32 – Case 12 Load D-LMP Prices

	Cost of Energy	Load DLMP (USD/kWh)																			
Hour	(USD/MWh)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	0.06685	0.06833	0.0694	0.07013	0.07035	0.06685	0.06838	0.06943	0.07025	0.07028	0.0702	0.0686	0.06985	0.07065	0.06995	0.07098	0.06685	0.06978	0.07155	0.06685
2:00:00 AM	64.65	0.06465	0.0661	0.06713	0.06783	0.06805	0.06465	0.06613	0.06715	0.06795	0.06798	0.0679	0.06638	0.06758	0.06835	0.06768	0.06868	0.06465	0.0675	0.06923	0.06465
3:00:00 AM	66.00	0.066	0.06748	0.06853	0.06925	0.06948	0.066	0.06753	0.06858	0.0694	0.06943	0.06933	0.06778	0.069	0.0698	0.0691	0.07015	0.066	0.06893	0.07075	0.066
4:00:00 AM	63.55	0.06355	0.06498	0.066	0.06668	0.0669	0.06355	0.06503	0.06603	0.06683	0.06685	0.06675	0.06525	0.06645	0.06723	0.06653	0.06755	0.06355	0.06638	0.06813	0.06355
5:00:00 AM	62.725	0.06273	0.0642	0.06525	0.06595	0.06615	0.06273	0.06425	0.06528	0.0661	0.06613	0.066	0.06453	0.06573	0.06653	0.0658	0.0669	0.06273	0.06565	0.06753	0.06273
6:00:00 AM	63.175	0.06318	0.0647	0.06578	0.0665	0.0667	0.06318	0.06475	0.06583	0.06668	0.0667	0.06655	0.065	0.06628	0.0671	0.06635	0.06748	0.06318	0.06618	0.0681	0.06318
7:00:00 AM	64.875	0.06488	0.0665	0.06765	0.06843	0.06865	0.06488	0.06653	0.06768	0.06858	0.0686	0.06845	0.06683	0.06815	0.06905	0.06823	0.06943	0.06488	0.06808	0.07008	0.06488
8:00:00 AM	66.70	0.0667	0.06813	0.06913	0.0698	0.06998	0.0667	0.06815	0.06915	0.06993	0.06993	0.0698	0.06838	0.06955	0.0703	0.0696	0.07063	0.0667	0.06945	0.07115	0.0667
9:00:00 AM	74.30	0.0743	0.07548	0.0763	0.07685	0.07703	0.0743	0.07545	0.07628	0.0769	0.07693	0.0768	0.07563	0.0766	0.07718	0.07663	0.0774	0.0743	0.0765	0.07775	0.0743
10:00:00 AM	80.275	0.08028	0.08073	0.08105	0.08125	0.08133	0.08028	0.08065	0.08098	0.08118	0.08118	0.08113	0.08068	0.08108	0.0812	0.08105	0.0812	0.08028	0.08098	0.0812	0.08028
11:00:00 AM	84.30	0.0843	0.08418	0.0841	0.08403	0.08403	0.0843	0.08408	0.084	0.0839	0.0839	0.08388	0.084	0.08393	0.08375	0.08388	0.08363	0.0843	0.08385	0.0834	0.0843
12:00:00 PM	161.675	0.16168	0.16108	0.16063	0.16033	0.16023	0.16168	0.16083	0.16043	0.16	0.16	0.15993	0.16058	0.16015	0.1596	0.16003	0.15925	0.16168	0.16	0.15863	0.16168
1:00:00 PM	258.70	0.2587	0.2568	0.25543	0.25445	0.25418	0.2587	0.25628	0.255	0.2538	0.2538	0.25368	0.25565	0.25428	0.25283	0.25395	0.25198	0.2587	0.254	0.25053	0.2587
2:00:00 PM	198.375	0.19838	0.19705	0.19608	0.19538	0.19515	0.19838	0.19663	0.19575	0.19488	0.19488	0.19468	0.19618	0.1952	0.19413	0.1949	0.19348	0.19838	0.19495	0.1924	0.19838
3:00:00 PM	158.625	0.15863	0.15838	0.15818	0.158	0.15798	0.15863	0.158	0.15788	0.1576	0.1576	0.15743	0.15775	0.15765	0.15713	0.15745	0.15673	0.15863	0.15735	0.15603	0.15863
4:00:00 PM	148.90	0.1489	0.15115	0.15275	0.15378	0.15413	0.1489	0.15083	0.15245	0.15355	0.1536	0.15315	0.15095	0.15293	0.15368	0.1528	0.15378	0.1489	0.15243	0.15393	0.1489
5:00:00 PM	156.25	0.15625	0.15685	0.15728	0.15748	0.15755	0.15625	0.15645	0.15693	0.1571	0.15713	0.15675	0.15633	0.15693	0.1568	0.1567	0.15653	0.15625	0.1565	0.15605	0.15625
6:00:00 PM	140.00	0.14	0.14133	0.14225	0.14283	0.14298	0.14	0.141	0.14198	0.14255	0.14258	0.14218	0.14103	0.1422	0.14253	0.14203	0.14248	0.14	0.14178	0.14238	0.14
7:00:00 PM	106.50	0.1065	0.108	0.10905	0.1097	0.1099	0.1065	0.10775	0.10883	0.10953	0.10955	0.1092	0.10785	0.10913	0.10963	0.109	0.10968	0.1065	0.10878	0.10978	0.1065
8:00:00 PM	90.625	0.09063	0.09203	0.093	0.09363	0.09383	0.09063	0.09183	0.09285	0.09353	0.09355	0.09325	0.09195	0.09315	0.09365	0.09305	0.09373	0.09063	0.09285	0.09388	0.09063
9:00:00 PM	124.025	0.12403	0.1261	0.1276	0.12855	0.12885	0.12403	0.12593	0.12743	0.12848	0.12853	0.12815	0.12615	0.12793	0.12878	0.12788	0.129	0.12403	0.12758	0.12938	0.12403
10:00:00 PM	104.10	0.1041	0.10585	0.1071	0.1079	0.10815	0.1041	0.1057	0.10695	0.10785	0.10788	0.10758	0.10588	0.10738	0.10808	0.10733	0.10828	0.1041	0.10708	0.1086	0.1041
11:00:00 PM	73.70	0.0737	0.07503	0.07595	0.07658	0.07675	0.0737	0.07495	0.0759	0.07658	0.0766	0.0764	0.07513	0.07623	0.07683	0.07623	0.07703	0.0737	0.07605	0.07735	0.0737
12:00:00 AM	76.90	0.0769	0.07825	0.07923	0.07983	0.07998	0.0769	0.0782	0.07915	0.07988	0.0799	0.07965	0.0784	0.07953	0.08015	0.0795	0.08038	0.0769	0.07935	0.08075	0.0769

Table 4.33 – Case 12 Generation D-LMP Prices

	Cost of Energy	Gen DLMPs (USD/MWh)																			
Hour	(USD/MWh)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.33	69.40	70.13	70.35	66.85	68.38	69.43	70.25	70.28	70.20	68.60	69.85	70.65	69.95	70.98	66.85	69.78	71.55	66.85
2:00:00 AM	64.65	64.65	66.10	67.13	67.83	68.05	64.65	66.13	67.15	67.95	67.98	67.90	66.38	67.58	68.35	67.68	68.68	64.65	67.50	69.23	64.65
3:00:00 AM	66.00	66.00	67.48	68.53	69.25	69.48	66.00	67.53	68.58	69.40	69.43	69.33	67.78	69.00	69.80	69.10	70.15	66.00	68.93	70.75	66.00
4:00:00 AM	63.55	63.55	64.98	66.00	66.68	66.90	63.55	65.03	66.03	66.83	66.85	66.75	65.25	66.45	67.23	66.53	67.55	63.55	66.38	68.13	63.55
5:00:00 AM	62.73	62.73	64.20	65.25	65.95	66.15	62.73	64.25	65.28	66.10	66.13	66.00	64.53	65.73	66.53	65.80	66.90	62.73	65.65	67.53	62.73
6:00:00 AM	63.18	63.18	64.70	65.78	66.50	66.70	63.18	64.75	65.83	66.68	66.70	66.55	65.00	66.28	67.10	66.35	67.48	63.18	66.18	68.10	63.18
7:00:00 AM	64.88	64.88	66.50	73.99	74.77	72.73	64.88	68.78	69.93	68.58	68.99	70.51	69.08	70.40	69.96	68.23	70.33	64.88	68.08	78.80	64.88
8:00:00 AM	66.70	66.70	68.13	125.76	126.43	110.17	66.70	92.33	93.33	69.93	74.54	92.15	92.56	93.73	80.73	69.60	81.05	66.70	69.45	142.13	66.70
9:00:00 AM	74.30	74.30	75.48	169.10	169.65	148.10	74.30	121.77	122.60	76.90	86.77	120.02	121.95	122.92	98.69	76.63	98.92	74.30	76.50	187.07	74.30
10:00:00 AM	80.28	80.28	80.73	204.64	204.84	182.81	80.28	152.71	153.03	81.18	98.82	149.12	152.73	153.13	117.97	81.05	117.97	80.28	80.98	219.71	80.28
11:00:00 AM	84.30	84.30	84.18	221.01	220.93	200.06	84.30	170.15	170.07	83.90	106.87	165.60	170.07	170.00	130.16	83.88	130.04	84.30	83.85	233.67	84.30
12:00:00 PM	161.68	161.68	161.08	301.10	300.80	280.32	161.68	251.04	250.64	160.00	184.74	245.74	250.79	250.36	209.08	160.03	208.73	161.68	160.00	311.97	161.68
1:00:00 PM	258.70	258.70	256.80	398.81	397.83	377.63	258.70	349.99	348.72	253.80	280.11	342.96	349.37	347.99	304.97	253.95	304.12	258.70	254.00	406.35	258.70
2:00:00 PM	198.38	198.38	197.05	338.13	337.43	317.06	198.38	288.72	287.85	194.88	220.45	282.35	288.27	287.30	245.03	194.90	244.38	198.38	194.95	347.09	198.38
3:00:00 PM	158.63	158.63	158.38	290.39	290.22	268.78	158.63	238.89	238.77	157.60	178.49	234.05	238.64	238.54	199.85	157.45	199.45	158.63	157.35	302.21	158.63
4:00:00 PM	148.90	148.90	151.15	217.22	218.24	200.62	148.90	179.24	180.87	153.55	159.13	179.46	179.37	181.34	166.10	152.80	166.20	148.90	152.43	233.62	148.90
5:00:00 PM	156.25	156.25	156.85	264.17	264.37	242.02	156.25	213.57	214.05	157.10	169.98	210.30	213.45	214.05	184.37	156.70	184.10	156.25	156.50	279.10	156.25
6:00:00 PM	140.00	140.00	141.33	220.33	220.90	200.91	140.00	177.46	178.44	142.55	149.95	176.05	177.49	178.66	158.90	142.03	158.85	140.00	141.78	236.66	140.00
7:00:00 PM	106.50	106.50	108.00	133.49	134.14	126.19	106.50	117.00	118.07	109.53	111.20	117.69	117.10	118.37	113.43	109.00	113.48	106.50	108.78	142.26	106.50
8:00:00 PM	90.63	90.63	92.03	93.00	93.63	93.83	90.63	91.83	92.85	93.53	93.55	93.25	91.95	93.15	93.65	93.05	93.73	90.63	92.85	93.88	90.63
9:00:00 PM	124.03	124.03	126.10	127.60	128.55	128.85	124.03	125.93	127.43	128.48	128.53	128.15	126.15	127.93	128.78	127.88	129.00	124.03	127.58	129.38	124.03
10:00:00 PM	104.10	104.10	105.85	107.10	107.90	108.15	104.10	105.70	106.95	107.85	107.88	107.58	105.88	107.38	108.08	107.33	108.28	104.10	107.08	108.60	104.10
11:00:00 PM	73.70	73.70	75.03	75.95	76.58	76.75	73.70	74.95	75.90	76.58	76.60	76.40	75.13	76.23	76.83	76.23	77.03	73.70	76.05	77.35	73.70
12:00:00 AM	76.90	76.90	78.25	79.23	79.83	79.98	76.90	78.20	79.15	79.88	79.90	79.65	78.40	79.53	80.15	79.50	80.38	76.90	79.35	80.75	76.90

Table 4.34 – Case 12 Per Unit Voltage

Hour	Voltage (PU)																			
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.97	0.96	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.98	0.96	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.98	0.96	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.98	0.96	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.97	0.96	1.00
6:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.96	1.00	0.97	0.96	1.00
7:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.98	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
8:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.97	0.99	0.97	0.97	0.98	0.97	1.00	0.98	0.96	1.00
9:00:00 AM	1.00	0.99	0.98	0.98	0.97	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
10:00:00 AM	1.00	0.99	0.99	0.99	0.98	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.99	0.98	1.00
11:00:00 AM	1.00	1.00	0.99	0.99	0.99	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.00	0.99	1.00	0.99	1.00	1.00	1.00	1.00
12:00:00 PM	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1:00:00 PM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2:00:00 PM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3:00:00 PM	1.00	1.00	0.99	0.99	0.99	1.00	1.00	1.00	0.99	0.99	1.00	1.00	0.99	0.99	1.00	0.99	1.00	1.00	0.99	1.00
4:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.98	0.97	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
5:00:00 PM	1.00	0.99	0.99	0.99	0.99	1.00	1.00	0.99	0.99	0.99	0.99	1.00	0.99	0.99	0.99	0.99	1.00	0.99	0.99	1.00
6:00:00 PM	1.00	0.99	0.99	0.98	0.98	1.00	0.99	0.99	0.98	0.98	0.99	0.99	0.99	0.98	0.99	0.98	1.00	0.99	0.98	1.00
7:00:00 PM	1.00	0.99	0.98	0.98	0.98	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	1.00	0.98	0.98	1.00
8:00:00 PM	1.00	0.99	0.98	0.98	0.98	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	1.00	0.98	0.97	1.00
9:00:00 PM	1.00	0.99	0.98	0.98	0.97	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
10:00:00 PM	1.00	0.99	0.98	0.98	0.97	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.98	0.97	0.97	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00
12:00:00 AM	1.00	0.99	0.98	0.98	0.97	1.00	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.97	0.98	0.97	1.00	0.98	0.97	1.00

Table 4.35 highlights the key economics of Case 12. The DG payments are now larger than the total D-LMP revenue, but the system was a net supplier for a period. Large PV injections may hinder reliability by increasing system volatility, but it brings down costs and helps reliability by improving voltage and reducing line loads.

Table 4.35 – Revenue Streams for Case 12

Cost Stream	Cost (USD)
D-LMP Revenue	$25,589.54
Energy	$25,161.36
Losses	$428.18
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	$2484.50
DG Payments	$26,657.95

4.12 Comparison and Summary of Results

Powerworld can provide measurements for nearly every component of the RYG system and in the process create a wealth of data. The behavior of the D-LMP is being investigated, and thus the trends across many cases are more important. This section seeks to determine how the D-LMP changes across the system under varying conditions and compares cases described in previous sections against the base case. Please see Table 4.3 for details on the cases.

As a reminder, Case 1 is the base case and will be used as the point of reference for comparison purposes. Table 4.36 highlights some system performance metrics across the 12 cases. With no storage or PV generation the system has a load factor of 0.73, an effective peak load of 13.7 MW, and a minimum voltage of 0.9 pu. The first case of note is Case 2 as this is the first to add storage into the system. The storage greatly improves the load factor of the system and likewise decreased the effective peak load. It also produces a slight improvement in bus voltage. On a performance basis the storage contributes quite positively.

Table 4.36 – System Performance Across Cases

	Load Factor	Effective Peak Load (MW)	Minimum System Voltage (pu)
Case 1	0.73	13.70	0.9
Case 2	0.79	12.67	0.91
Case 3	0.75	13.10	0.91
Case 4	0.79	12.41	0.91
Case 5	0.75	12.57	0.91
Case 6	0.78	12.18	0.91
Case 7	0.73	12.21	0.91
Case 8	0.75	11.97	0.91
Case 9	0.69	11.49	0.92
Case 10	0.66	11.92	0.91
Case 11	0.66	11.92	0.96
Case 12	0.58	11.82	0.96

When renewables are added as a variable, the previous findings still hold true. As renewable penetration increases, the benefits of storage diminish when comparing to similar cases without storage. At 100% renewable penetration (Cases 9 and 10) the storage begins to reduce all three metrics. The predictive optimization for the storage does not account for the energy produced by solar generation. The optimization uses the demand from a previous day. As solar power becomes a large component of the effective load, the prediction becomes less accurate and the storage schedule optimization is no longer reflective of the actual system.

By examining the renewable cases only, the effects of renewable penetration on the RYG system are observable. Comparing the base case to Case 3, the addition of 10% solar provides a favorable impact of the system. A smaller, but clear improvement also exists between 10% and 25% solar penetration. Beyond Case 5, the load factor begins to decrease despite the fact that the peak load is also decreasing. The solar is decreasing the daily power average faster than the peak is decreasing, and as a byproduct the peak load time is shifted, as seen in load graphs of the cases.

The special cases of 11 and 12 are notable with respect to system performance. The very high solar penetration of Case 12 results in a relatively low load factor and the viability of uncontrolled renewable injection comes into question. This will be of significance as intermittent and non-dispatchable renewables come into play on the electric distribution system. The networking of the system provides a great improvement in system voltage and reliability by creating more than one delivery path. Networked distribution systems could hold great potential. Each of these special cases highlights important performance aspects of advanced distribution grids.

A primary motivation for a D-LMP is an economic one, to allow the customer to interact with the real-time price of electricity. It is therefore important to compare and contrast the economics in the RYG system and compare them to the traditional approach of flat-rate pricing. Table 4.37 presents the important economics of the entire system. Two things of special mention are noted here. This date, August 10th, 2009, is one of the warmest days of the year and was in the 95% percentile for cost in 2009. Conversely, some days were much lower cost and thus it is not representative of typical or average energy cost. Secondly, and most important, the cost is ultimately a function of the weights in the D-LMP formula. The weights used here were developed to provide the utility with the same annual energy revenue as it would with flat-rate, but slightly decreased to allot for losses revenue. This was discussed in detail for the test bed development.

Table 4.37 – System-Wide Cost Comparison

	Total Energy Revenue (USD)	Percent of Total	Total Losses Revenue (USD)	Percent of Total	Storage Savings (USD)	Percent Savings	Total D-LMP Revenue (USD)	Flat-Rate, by Sector (USD)	D-LMP as Percent of Flat-rate	DG Payments (USD)	Net Cost for Customer (USD)	Percent Reduc-tion
Case 1	27723.90	93.1%	2062.62	6.9%	N/A	N/A	29786.52	21414.72	139.1%	0.00	29786.52	0.0%
Case 2	25161.36	93.8%	1662.47	6.2%	2600.97	9.9%	26823.83	21414.72	125.3%	0.00	26823.83	0.0%
Case 3	27723.90	93.3%	1981.18	6.7%	N/A	N/A	29705.08	21414.72	138.7%	923.72	28781.35	3.1%
Case 4	25161.36	94.0%	1603.59	6.0%	2587.81	9.9%	26764.95	21414.72	125.0%	909.60	25855.35	3.4%
Case 5	27723.90	93.7%	1871.85	6.3%	N/A	N/A	29595.75	21414.72	138.2%	2508.36	27087.39	8.5%
Case 6	25161.36	94.3%	1517.04	5.7%	2568.37	9.9%	26678.40	21414.72	124.6%	2473.57	24204.83	9.3%
Case 7	27723.90	94.3%	1687.16	5.7%	N/A	N/A	29411.06	21414.72	137.3%	5494.37	23916.69	18.7%
Case 8	25161.36	94.8%	1378.69	5.2%	2537.68	9.8%	26540.05	21414.72	123.9%	5428.67	21111.38	20.5%
Case 9	27723.90	95.4%	1341.39	4.6%	N/A	N/A	29065.29	21414.72	135.7%	12181.05	16884.24	41.9%
Case 10	25161.36	95.7%	1117.61	4.3%	2481.33	9.6%	26278.97	21414.72	122.7%	12062.65	14216.32	45.9%
Case 11	25161.36	97.0%	790.27	3.0%	2554.07	10.7%	25951.62	21414.72	121.2%	12022.14	13929.49	46.3%
Case 12	25161.36	98.3%	428.18	1.7%	2484.50	N/A	25589.54	21414.72	119.5%	26637.95	-1048.41	104.1%

The flat-rate cost is constant across all cases by definition. Because this day is higher cost than average, the total D-LMP revenue is up to 40% greater than the flat-rate revenue. The D-LMP revenue can be decreased by over 20% with the use of PV to reduce losses and storage to shift load. The DGs also must be compensated with the D-LMP. The total system-wide DG payments are listed. At 10% penetration in Cases 3 and 4, the DG payments do not exceed the revenue from losses. The DG payments increase as penetration increases, in part because they produce more energy and the renewable DG component in the D-LMP formula is nonlinear. In fact, the customers make a net gain in Case 12 even though the daily total energy demand exceeds DG energy supplied. The use of PV and storage can begin to substantially reduce the retail cost under this scheme.

The D-LMP affects each customer sector differently because flat-rate prices are separated into sectors. The rates are detailed in Section 4.2. Table 4.38 provides a summary of the D-LMP costs, the flat-rate costs, and the percent difference without DG payments. The same patterns seen in Table 4.37 are also present in Table 4.38. Storage, used by residential and large commercial, is again seen to reduce cost. Although minute, storage also reduces cost for the industrial and small commercial sectors even though they do not operate any storage of their own. These sectors benefit from the reduction of losses attributed to storage. Increased renewable usage is again seen to reduce cost.

In some cases, the residential sector pays less than it otherwise would. The residential sector realizes 8% savings over flat-rate in Case 12. Although the trends are similar across all sectors, they are quite different in absolute terms. The industrial sector pays 75% more in a D-LMP pricing scheme than it would otherwise. The commercial sectors also suffer from higher rates relative to the residential sector. The economics must work not only for the customer, but it must work for the utility as well. Table 4.39 provides an economic viewpoint from the utility.

Table 4.38 – D-LMP Cost Comparison for the Customer

	ALL SECTORS			RESIDENTIAL			SMALL COMMERCIAL			LARGE COMMERCIAL			INDUSTRIAL		
	D-LMP Charges	Flat-rate	Percent Difference	D-LMP Charges	Flat-Rate	Percent Difference	D-LMP Charges	Flat-Rate	Percent Difference	D-LMP Charges	Flat-Rate	Percent Difference	D-LMP Charges	Flat-Rate	Percent Difference
Case 1	29786.52	21414.72	39.1%	13450.02	11267.52	19.4%	295.74	231.60	27.7%	4628.18	3474.00	33.2%	11412.58	6441.60	77.2%
Case 2	26823.83	21414.72	25.3%	10946.68	11267.52	-2.8%	294.79	231.60	27.3%	4195.27	3474.00	20.8%	11387.09	6441.60	76.8%
Case 3	29705.08	21414.72	38.7%	13402.71	11267.52	18.9%	295.14	231.60	27.4%	4614.02	3474.00	32.8%	11393.21	6441.60	76.9%
Case 4	26764.95	21414.72	25.0%	10917.98	11267.52	-3.1%	294.20	231.60	27.0%	4184.33	3474.00	20.4%	11368.44	6441.60	76.5%
Case 5	29595.75	21414.72	38.2%	13339.96	11267.52	18.4%	294.29	231.60	27.1%	4595.05	3474.00	32.3%	11366.45	6441.60	76.5%
Case 6	26678.40	21414.72	24.6%	10875.99	11267.52	-3.5%	293.33	231.60	26.7%	4168.32	3474.00	20.0%	11340.76	6441.60	76.1%
Case 7	29411.06	21414.72	37.3%	13234.67	11267.52	17.5%	292.87	231.60	26.5%	4562.60	3474.00	31.3%	11320.92	6441.60	75.7%
Case 8	26540.05	21414.72	23.9%	10809.43	11267.52	-4.1%	291.93	231.60	26.0%	4142.63	3474.00	19.2%	11296.06	6441.60	75.4%
Case 9	29065.29	21414.72	35.7%	13040.74	11267.52	15.7%	290.10	231.60	25.3%	4501.48	3474.00	29.6%	11232.96	6441.60	74.4%
Case 10	26278.97	21414.72	22.7%	10686.53	11267.52	-5.2%	289.21	231.60	24.9%	4094.02	3474.00	17.8%	11209.21	6441.60	74.0%
Case 11	25951.62	21414.72	21.2%	10501.55	11267.52	-6.8%	286.15	231.60	23.6%	4044.31	3474.00	16.4%	11119.61	6441.60	72.6%
Case 12	25589.54	21414.72	19.5%	10361.13	11267.52	-8.0%	281.51	231.60	21.5%	3978.08	3474.00	14.5%	10968.82	6441.60	70.3%

Table 4.39 - Cost Comparison from the Utility Perspective

	Wholesale Energy Bought (USD)	Retail Energy Sold (USD)	DG Payment w/o Renewable Premium (USD)	Premium Amount (USD)	Premium as Percent of Total DG Payment	Total DG Payments (USD)	Net Revenue (USD)	Percent Markup
Case 1	11089.56	29786.52	0.00	0.00	0.0%	0.00	18696.96	268.6%
Case 2	10064.54	26823.83	0.00	0.00	0.0%	0.00	16759.29	266.5%
Case 3	10774.33	29705.08	851.98	71.75	7.8%	923.72	18007.02	267.1%
Case 4	9749.32	26764.95	837.85	71.75	7.9%	909.60	16106.03	265.2%
Case 5	10301.49	29595.75	2115.85	392.51	15.6%	2508.36	16785.90	262.9%
Case 6	9276.48	26678.40	2081.06	392.51	15.9%	2473.57	14928.35	260.9%
Case 7	9513.43	29411.06	4184.69	1309.68	23.8%	5494.37	14403.26	251.4%
Case 8	8488.41	26540.05	4118.99	1309.68	24.1%	5428.67	12622.97	248.7%
Case 9	7937.29	29065.29	8194.73	3986.31	32.7%	12181.05	8946.95	212.7%
Case 10	6912.28	26278.97	8076.34	3986.31	33.0%	12062.65	7304.04	205.7%
Case 11	6912.28	25951.62	8035.82	3986.31	33.2%	12022.14	7017.21	201.5%
Case 12	3760.01	25589.54	15644.72	10993.23	41.3%	26637.95	-4808.42	-27.9%

The utility was to receive a 250% markup on its energy costs to recoup its investment, as reflected in the D-LMP weights. Such rates can vary from 200% to 300% for a utility. The utility matches or exceeds this value until 50% solar penetration. Even at 100% solar penetration the utility still operates at a strong margin. Case 12 is a situation when the DG payments exceed the revenue for the utility and the utility takes a net loss. In this situation the penetration is 200%, and the premium constitutes nearly half of the DG payment. This is a situation when the utility would alter the variables in the renewable component of the D-LMP equation to provide a more economically sound DG payment.

This chapter presented a realistic implementation of the D-LMP as a real-time pricing scheme using historic data. A test bed was developed and was simulated in Powerworld. Chapter 4 and Appendix D host the tables and figures of data from the system. Each test case includes a graph of the load, solar generation, feeder bus prices, a oneline of the, a table of hourly load D-LMPs at each bus, a table of hourly generation D-LMPs at each bus, a table of bus voltages at each hour, and a table of key economics.

The results present several economic and performance trends. Storage and renewables improve the system load factor, reduce peaks, and bolster voltage. High penetration renewables introduce excessive interference in the load prediction and limit the effectiveness of reducing the load factor. Storage can provide 10% cost savings to the customer as well as have some trickle down effects on other customers on the grid. Losses are decreased by storage and renewables. Networking of the system produced benefits in every metric, economic and otherwise.

Compared to flat-rate pricing, high cost is shifted to industry while residential benefits the most. This fact would be a point of concern for a practical switch to real-time pricing, unless unique D-LMP weights are assigned to each retail sector. DG payments can be made without significant loss to the utility due to increased revenue from losses. Without modification of the renewable component of the D-LMP the payments can become excessive.

CHAPTER 5

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE WORK

5.1 Conclusions

A study of the Locational Marginal Pricing and real-time pricing has shown that many benefits may be realized. Literature indicates that the LMP delivers an accurate real-time price for a given node. The electricity markets then operate most efficiency when real-time prices are used, as supply and demand can react correspondingly. Real-time pricing can also lower prices, emissions, and peak load. The utility would no longer have to incur the capital costs to build for peak demand.

A Distribution LMP equation has also been formulated. It is built upon the PJM equations for the LMP. It includes a weighted energy and loss component, but drops the congestion component. The energy component is equal to the transmission LMP at the feeder bus. A third component is added to the modified LMP to provide a premium price to renewable distributed generation. This component is nonlinear and encourages additional capacity, but its characteristics can be controlled via two variables to limit excessive payments. A node on the distribution system is either a generation node or a load node.

A D-LMP implementation would require extensive infrastructure build out. A US initiative is already underway called the Smart Grid which may address many of these infrastructure needs. The flexibility of the D-LMP allows for many different formulations that can be mixed and matched to achieve any number of outcomes for the operating LSE and customer. Backup plans and default functionality need to be addressed and understood in case of a failure in the D-LMP system. Advancing technology in the distribution system provides a wide opportunity for real-time pricing using a D-LMP.

A storage methodology was developed for use with D-LMP. Linear programming was used with Day-Ahead LMPs to determine the most economic storage schedule. Additional constraints were applied to limit degradation of load factor and system operability by using previous load data. These constraints also can be used to size the power and capacity of the storage unit. Using MATLAB, code was developed and a storage schedule for the entire year was determined.

A test bed was developed with the goal of being highly realistic. Historic data was used for accurate and matched data. The data was used for simulations in the test bed for 12 different cases. The cases tested D-LMP results under different renewable penetrations and with and without the presence of storage. Two special cases were used to test the effects of networking and high penetration of renewables.

Storage improved the system load factor, reduced load peaks, and increased voltage at buses. Renewables showed similar results but high renewable penetration introduced excessive interference in the load prediction and negatively affected the load factor. Storage can provide 10% cost savings to the customer as well as have some trickle down effects to other customers on the grid. Losses are decreased by storage and renewables and are substantially reduced via networking the system. D-LMP pricing created high cost in industry while the residences benefited the most of any sector. DG payments can be made without significant loss to the utility due to increased revenue from losses, but without modification of the renewable component of the D-LMP the payments can become excessive. The D-LMP holds strong theoretical and empirical credence to its benefits on a distribution system. This thesis presents an initial study on the subject and may not provide global conclusions for all cases, especially when including further feedback mechanisms. Table 5.1 summarizes the main contributions of this work.

Table 5.1 – Main Research Contributions

Area of Interest	Contribution
D-LMP/Power Marketing	Formulated a realistic D-LMP to introduce real-time pricing and deregulation to the distribution system
	Demonstrated the functionality of the D-LMP in a distribution system using real data
	Rendered distribution operation consistent with transmission system operation
	Demonstrated a realistic economic operating practice with regard to distributed generation
Energy Storage	Optimal scheduling of energy storage with existing capabilities.
	Demonstrated the use of energy storage in a distribution system

5.2 Recommendations and Future Work

This thesis presented a D-LMP formulation and demonstrated its use with two complementary technologies, storage and PV. There is a wide range of potential future work available for the D-LMP:

- Alternative D-LMPs can be tested and compared in reaching desired outcomes.
- Hardware and software development for the physical logistics of administrating a D-LMP market.

- Advanced storage modeling and scheduling, including adding storage nonlinearities, losses, and lifetime optimization.
- Including a solar forecast in the storage optimization.
- Modeling voltage and price feedbacks from the transmission system.
- Exploring other renewable generation sources and their interaction with a D-LMP market.
- Further system networking.
- Demand response technologies and customer reaction to price.
- Payback times on system capital costs.

This future work would create a more refined picture of the D-LMP and its prospects as a real-time pricing instrument in the electric distribution system.

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APPENDIX A

MATLAB STORAGE OPTIMIZATION CODE

```
clear W X Y Z PT PTt LMt RC NC RS feval
RTLMP = xlsread('datam2.xlsx', 'RTLMP_Data', 'B4:Y368');
DALMP = xlsread('datam2.xlsx', 'DALMP_Data', 'B4:Y368');
LoadMtx = xlsread('datam2.xlsx', 'Load_Data', 'C4:Z368');
BMtx = xlsread('datam2.xlsx', 'Load_Data', 'BF4:CY368');
Bch = xlsread('datam2.xlsx', 'Load_Data', 'BF2');
W(1:365,1:24)=0;
X(1:365,1)=0;
Y(1:365,1)=0;
Z(1:365,1)=0;
for m = 2:1:365
    Lt = 2.7*DALMP(m,:)/1000;
    L = transpose(Lt);
    %
    Pt = LoadMtx(m-1,:);
    P = transpose(Pt);
    Pavg = mean(P);
    Pb = transpose(BMtx(m-1,:));
    if (Pavg-P(1)>=0)
        Pb2 = Bch/2+(Pavg-P(1));
    elseif (Pavg-P(1)<-Bch/2)
        Pb2 = 0;
    else
        Pb2 = Bch/2-(Pavg-P(1));
    end
    %
    if (Pavg-P(24)>Bch/2)
        lb2 = 0;
    elseif (Pavg-P(24)<0)
      lb2 = -Bch/2+(Pavg-P(24));
    else
        lb2 = -Bch/2+(Pavg-P(24));
    end
    %
    [S, feval, exitflag]
=linprog(L,A2,[50000*b;Pb;Pb2],Aeq,beq,[50000*lb;lb2],1.25*Pavg*u
b-P);
    W(m,:)= S;
    X(m,:)= -feval;

end
%
 R = 2.7*RTLMP/1000;
 PT = LoadMtx+W;
 PTt= transpose(PT);
 LMt= transpose(LoadMtx);
 %
for m = 1:1:365
    Y(m,:)= mean(LoadMtx(m,:))/max(LoadMtx(m,:));
    Z(m,:)= mean(PT(m,:))/max(PT(m,:));
     %
    NC(m,1) = R(m,:)*LMt(:,m);
    RC(m,1) = R(m,:)*PTt(:,m);
end
RS = NC-RC;
```

```
%XLS
xlswrite('datam2.xlsx',W,'Sheet3','A2');
xlswrite('datam2.xlsx',X,'Sheet3','AA2');
xlswrite('datam2.xlsx',NC,'Sheet3','AC2');
xlswrite('datam2.xlsx',RC,'Sheet3','AD2');
xlswrite('datam2.xlsx',RS,'Sheet3','AE2');
xlswrite('datam2.xlsx',Y,'Sheet3','AG2');
xlswrite('datam2.xlsx',Z,'Sheet3','AH2');
xlswrite('datam2.xlsx',LoadMtx+W, 'Lnew', 'A2')
```

APPENDIX B

TEST BED DETAILS

Table B.1 – RYG System Information		
Lines	16	
Switches	4	Operated normally open
Buses	19	
Total system load	10+j3.9 MVA	
f	60 Hz	
Number of ckts	3	Denominated as red, yellow, green
Supply volts	13.8 kV	
Phases	3	
Line configuration		
Red	2/0 ACSR 0.4 m GMD	
Yellow	No 2 AWG ACSR 0.3 m GMD	
Green	No 2 AWG ACSR 0.3 m GMD	

Table B.2 – RYG Line Data						
			(km)	(ohms)	(ohms)	Mohms
Line	Start	End	length	R	X	Xcharging
1	1	2	0.707	0.3932	0.2817	-0.269
2	2	3	0.5	0.2781	0.1992	-0.3804
3	3	4	0.5	0.2781	0.1992	-0.3804
4	4	5	0.5	0.2781	0.1992	-0.3804
5	4	9	0.5	0.2781	0.1992	-0.3804
6	9	10	0.5	0.2781	0.1992	-0.3804
7	9	14	0.5	0.2781	0.1992	-0.3804
8	14	16	0.5	0.2781	0.1992	-0.3804
9	6	7	0.5	0.5125	0.2104	-0.44
10	7	8	0.5	0.5125	0.2104	-0.44
11	7	12	0.5	0.5125	0.2104	-0.44
12	17	18	2	2.05	0.8414	-0.11
13	18	15	0.5	0.5125	0.2104	-0.44
14	11	15	0.559	0.573	0.2352	-0.3936
15	13	15	1	1.025	0.4207	-0.22
16	18	19	1.5	1.5375	0.6311	-0.1467
T1	3	8	0.5	0.2781	0.1992	-0.3804
T2	8	13	0.5	0.2781	0.1992	-0.3804
T3	16	19	1	0.5562	0.3984	-0.1902
T4	13	9	0.707	0.3932	0.2817	-0.269

Table B.3 – RYG Bus Loads		
	MW	MVAr
Bus	P	Q
1	Source	
2	0	-0.5
3	2	1
4	2	2
5	1	0.4
6	Source	
7	0.5	0
8	0.5	0.5
9	0	-0.5
10	0.1	0.5
11	0.5	0
12	0.5	0.5
13	0.5	0.5
14	0.2	0
15	0	-0.5
16	0.2	0
17	Source	
18	0	0
19	1	0.8
Total demand	9	4.7

APPENDIX C

SOLAR RADIATION CALCULATIONS

This appendix explains how the photovoltaic system data was derived from the solar radiation data. The 2005 National Climate Data Center model data from National Renewable Energy Laboratory (NREL) and the National Weather Service (NWS) data provides the total (beam and diffuse) radiation on 1 m^2 horizontal surface and the diffuse radiation on a 1 m^2 horizontal surface. The beam radiation can be extracted by simply subtracting the former from the latter. The data also provides the solar zenith angle and the albedo. Albedo is a measure of the surround environments reflectivity. Drawings of the angles and coordinate systems can be found in references at the end of the appendix.

The solar angle equations first need to be computed to proceed in calculating the isolation on a tilted surface. The declination angle, δ, is the angle between the sun's ray and the equatorial plane of the earth. Declination can be calculated from,

$$\delta\ [rad] = \frac{23.45°\pi}{180} sin\left(\frac{2\pi(n + 284)}{365}\right). \quad \text{(C.1)}$$

Where n is the day of the Julian year. The solar zenith angle, Z, is provided in the data set for each hour. The zenith angle is the angle between the sun's rays and a line normal to the earth's surface at a given location. The zenith angle allows the hour angle to be calculated. The hour angle, w, is the angle between the sun and its solar noon position. The cosine of w can be found from the zenith angle,

$$\cos(w) = \frac{\cos(Z) - \sin(\varphi)\sin(\delta)}{\cos(\varphi)\cos(\delta)}. \quad \text{(C.2)}$$

Where φ is the local latitude. The solar radiation can now be formulated for a tilted surface. The tilt of the panels, β, is set equal to the latitude of their location. The global (total sum) solar radiation falling on a tilted surface is given by,

$$I_G = I_B r_b + I_D r_b + I_T r_r. \quad \text{(C.3)}$$

Where I_G is the global amount of radiation on a tilted surface, I_B is the beam radiation on a horizontal surface, I_D is the diffuse radiation on a horizontal surface, I_T is the total beam and diffuse radiation (I_B+I_D) on horizontal surface, r_b is the horizontal-to-tilt conversion factor for beam radiation, r_d is the horizontal-to-tilt conversion factor for diffuse radiation, and r_r is the horizontal-to-tilt conversion factor for reflected radiation. The values of I_B, I_D, and I_T are found or simply calculated from the data set as mentioned previously. The formulas for the horizontal-to-tilt ratios are as follows,

$$r_b = \frac{\sin(\delta)\sin(\varphi-\beta)+\cos(\delta)\cos(\varphi-\beta)\cos(w)}{\sin(\delta)\sin(\varphi)+\cos(\delta)\cos(\varphi)\cos(w)}, \tag{C.4}$$

$$r_b = \frac{1+\cos(\beta)}{2}, \tag{C.5}$$

$$r_r = \rho\left(\frac{1-\cos(\beta)}{2}\right). \tag{C.6}$$

Where ρ is the albedo, which can be found in the data set. Equation (1.1) can be simplified because the tilt is equal to the latitude, $\varphi=\beta$,

$$r_b = \frac{\cos(\delta)\cos(w)}{\sin(\delta)\sin(\varphi)+\cos(\delta)\cos(\varphi)\cos(w)}. \tag{C.7}$$

Inserting Equation (C.2) into (C.7),

$$r_b = \frac{\cos(Z)-\sin(\varphi)\sin(\delta)}{\cos(\varphi)\cos(Z)}. \tag{C.8}$$

Equation (C.3) may now be generalized as,

$$I_G = I_B\left[\frac{\cos(Z)-\sin(\varphi)\sin(\delta)}{\cos(\varphi)\cos(Z)}\right] + I_D\left[\frac{1+\cos(\beta)}{2}\right] + I_T\left[\rho\left(\frac{1-\cos(\beta)}{2}\right)\right]. \tag{C.9}$$

This finalized equation for I_G is the equation for solar radiation on a surface tilted equal to that of the latitude. This formula is used to calculate the isolation for the photo-voltaic arrays in this study. The BP 3220T solar panel was used in the array model. It has a maximum efficiency of 13.2%, and is capable of producing a peak power of 220 Watts DC. The efficiency reduction at lower irradiances was simplified and modeled as linear. The DC to AC conversion was taken to be 90% efficient. Table C.1 summarizes the nomenclature found in this appendix.

Table C.1 – Appendix C Nomenclature

δ	Solar Declination Angle
n	nth Day of the Julian Year
Z	Solar Zenith Angle
w	Solar Hour Angle
φ	Latitude
I_G	Global Solar Radiation
I_B	Solar Beam Radiation
I_D	Solar Diffuse Radiation
I_T	Solar Total Radiation (I_B+I_D)
r_b	Horizontal-to-Tilt Conversion Factor for Beam Radiation
r_d	Horizontal-to-Tilt Conversion Factor for Diffuse Radiation
r_r	Horizontal-to-Tilt Conversion Factor for Reflected Radiation
ρ	Albedo

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APPENDIX D

CONTINUATION OF DETAILED SIMULATION RESULTS

D.1 Simulation Result: Case 5

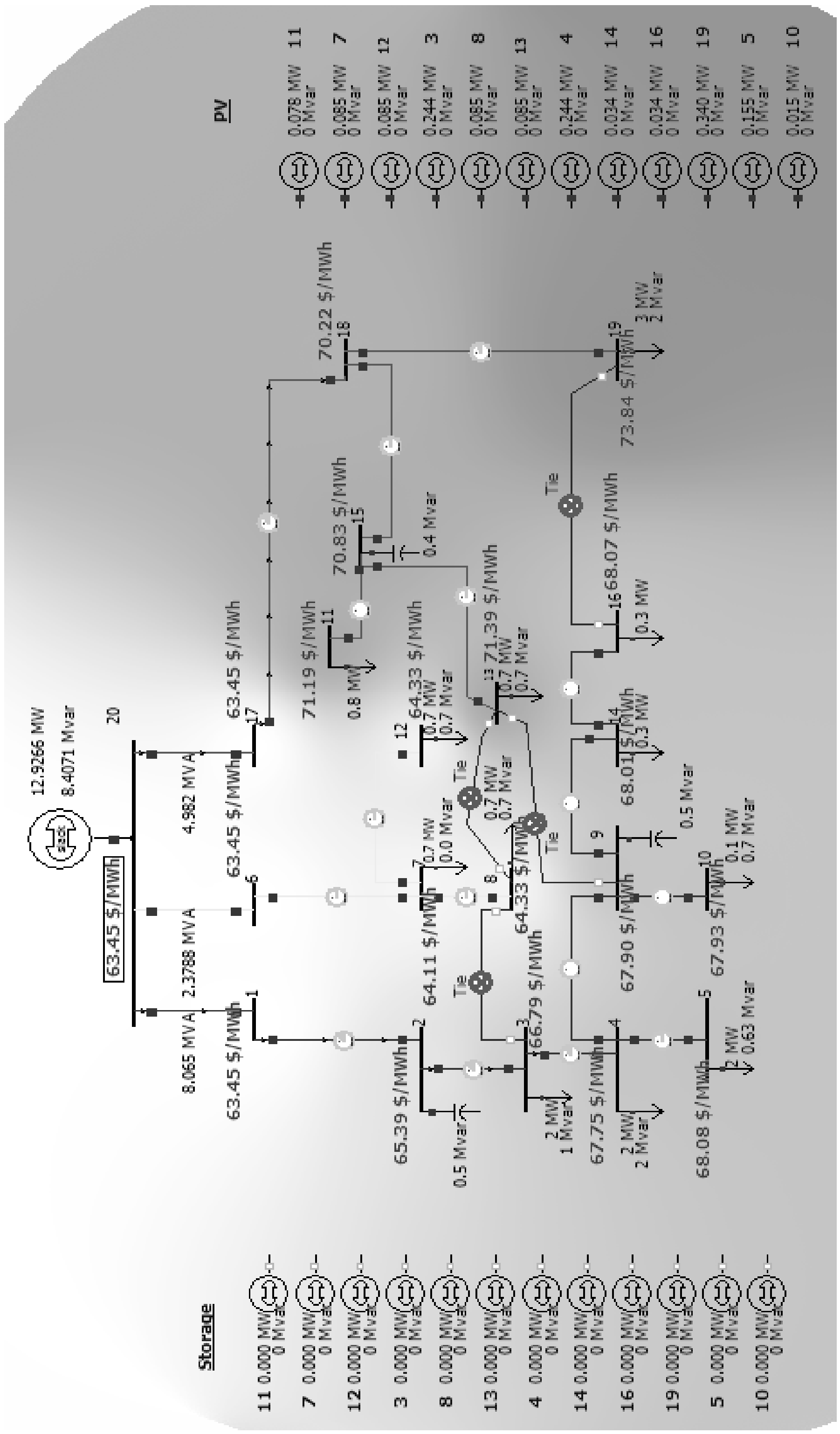

Figure D.1 – Case 5 Oneline at Peak Demand

Table D.1 – Case 5 Load D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Load DLMP (USD/kWh)																			
		Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	0.06685	0.06685	0.06815	0.06908	0.0697	0.06985	0.06685	0.06738	0.06755	0.0698	0.06983	0.07208	0.06755	0.0723	0.06988	0.0719	0.06993	0.06685	0.07153	0.07413	0.06685
2:00:00 AM	0.06465	0.06465	0.06588	0.06675	0.0673	0.06745	0.06465	0.06508	0.06523	0.0674	0.06743	0.06893	0.06523	0.0691	0.06748	0.06878	0.0675	0.06465	0.06848	0.07055	0.06465
3:00:00 AM	0.066	0.066	0.06723	0.06808	0.06865	0.06878	0.066	0.0664	0.06653	0.06873	0.06875	0.06993	0.06653	0.07008	0.0688	0.06978	0.06883	0.066	0.06948	0.07135	0.066
4:00:00 AM	0.06355	0.06355	0.06473	0.06555	0.06608	0.0662	0.06355	0.0639	0.06403	0.06615	0.06618	0.06703	0.06403	0.06715	0.0662	0.0669	0.06625	0.06355	0.06665	0.06828	0.06355
5:00:00 AM	0.06273	0.06273	0.06388	0.0647	0.06523	0.06535	0.06273	0.06308	0.0632	0.0653	0.06533	0.06618	0.0632	0.0663	0.06535	0.06603	0.06538	0.06273	0.06578	0.0674	0.06273
6:00:00 AM	0.06318	0.06318	0.06445	0.06535	0.06593	0.06608	0.06318	0.0635	0.0636	0.066	0.06603	0.0665	0.0636	0.06658	0.06605	0.06633	0.06608	0.06318	0.06608	0.06755	0.06318
7:00:00 AM	0.06488	0.06488	0.0663	0.0673	0.06795	0.06813	0.06488	0.06523	0.06535	0.06803	0.06805	0.0686	0.06535	0.06868	0.06808	0.06843	0.06813	0.06488	0.06813	0.06978	0.06488
8:00:00 AM	0.0667	0.0667	0.06828	0.0694	0.0701	0.07033	0.0667	0.0671	0.06723	0.0702	0.0702	0.07088	0.06723	0.07095	0.07025	0.07068	0.0703	0.0667	0.07033	0.07215	0.0667
9:00:00 AM	0.0743	0.0743	0.07623	0.0776	0.0785	0.07878	0.0743	0.07475	0.0749	0.0786	0.07863	0.07945	0.0749	0.07953	0.07868	0.07918	0.0787	0.0743	0.07875	0.08095	0.0743
10:00:00 AM	0.08028	0.08028	0.08245	0.08403	0.08505	0.0854	0.08028	0.0808	0.08098	0.08518	0.0852	0.0864	0.08098	0.08645	0.08528	0.08605	0.08533	0.08028	0.08553	0.0881	0.08028
11:00:00 AM	0.0843	0.0843	0.0866	0.08828	0.08938	0.08973	0.0843	0.08488	0.08508	0.0895	0.08953	0.0911	0.08508	0.09118	0.0896	0.09073	0.08965	0.0843	0.09015	0.09303	0.0843
12:00:00 PM	0.16168	0.16168	0.16628	0.1696	0.1718	0.1725	0.16168	0.16298	0.16343	0.1721	0.17215	0.1767	0.16343	0.17703	0.17233	0.17598	0.17243	0.16168	0.17475	0.18145	0.16168
1:00:00 PM	0.2587	0.2587	0.26608	0.2714	0.27498	0.27613	0.2587	0.26103	0.2618	0.2755	0.2756	0.28548	0.2618	0.28618	0.2759	0.28425	0.2761	0.2587	0.28213	0.29445	0.2587
2:00:00 PM	0.19838	0.19838	0.2042	0.2084	0.21125	0.21218	0.19838	0.20033	0.201	0.21168	0.21178	0.22113	0.201	0.22178	0.21203	0.22013	0.21218	0.19838	0.21835	0.22905	0.19838
3:00:00 PM	0.15863	0.15863	0.16348	0.16698	0.16938	0.17018	0.15863	0.16028	0.16083	0.16973	0.1698	0.17803	0.16083	0.17855	0.17003	0.17713	0.17015	0.15863	0.17563	0.1847	0.15863
4:00:00 PM	0.1489	0.1489	0.15353	0.15685	0.15913	0.15985	0.1489	0.15053	0.15108	0.15948	0.15955	0.16775	0.15108	0.16833	0.15975	0.16693	0.1599	0.1489	0.16548	0.17453	0.1489
5:00:00 PM	0.15625	0.15625	0.16053	0.1636	0.16568	0.1663	0.15625	0.15773	0.1582	0.16598	0.16605	0.17255	0.1582	0.17308	0.16623	0.17185	0.16635	0.15625	0.17063	0.17838	0.15625
6:00:00 PM	0.14	0.14	0.14365	0.1463	0.14805	0.14855	0.14	0.1414	0.14188	0.14833	0.14838	0.1552	0.14188	0.1558	0.14858	0.15463	0.14868	0.14	0.15353	0.16108	0.14
7:00:00 PM	0.1065	0.1065	0.1091	0.11098	0.1122	0.11253	0.1065	0.1075	0.10783	0.1124	0.11243	0.1168	0.10783	0.11728	0.11258	0.11645	0.11265	0.1065	0.11573	0.1209	0.1065
8:00:00 PM	0.09063	0.09063	0.09285	0.09445	0.09548	0.09575	0.09063	0.09148	0.09175	0.09565	0.09568	0.0994	0.09175	0.09978	0.09578	0.0991	0.09585	0.09063	0.09848	0.10288	0.09063
9:00:00 PM	0.12403	0.12403	0.1268	0.1288	0.1301	0.13045	0.12403	0.12513	0.1255	0.13033	0.13038	0.13535	0.1255	0.13588	0.1305	0.13498	0.1306	0.12403	0.13418	0.13988	0.12403
10:00:00 PM	0.1041	0.1041	0.10645	0.10813	0.1092	0.1095	0.1041	0.10503	0.10535	0.1094	0.10943	0.1136	0.10535	0.11405	0.10955	0.11328	0.10963	0.1041	0.11263	0.1174	0.1041
11:00:00 PM	0.0737	0.0737	0.07528	0.07638	0.0771	0.07728	0.0737	0.07428	0.07448	0.07723	0.07725	0.07955	0.07448	0.07983	0.07733	0.07938	0.07738	0.0737	0.07895	0.08188	0.0737
12:00:00 AM	0.0769	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table D.2 – Case 5 Generation D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Gen DLMPs (USD/MWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.15	69.08	69.70	69.85	66.85	67.38	67.55	69.80	69.83	72.08	67.55	72.30	69.88	71.90	69.93	66.85	71.53	74.13	66.85
2:00:00 AM	64.65	64.65	65.88	66.75	67.30	67.45	64.65	65.08	65.23	67.40	67.43	68.93	65.23	69.10	67.48	68.78	67.50	64.65	68.48	70.55	64.65
3:00:00 AM	66.00	66.00	67.23	68.08	68.65	68.78	66.00	66.40	66.53	68.73	68.75	69.93	66.53	70.08	68.80	69.78	68.83	66.00	69.48	71.35	66.00
4:00:00 AM	63.55	63.55	64.73	65.55	66.08	66.20	63.55	63.90	64.03	66.15	66.18	67.03	64.03	67.15	66.20	66.90	66.25	63.55	66.65	68.28	63.55
5:00:00 AM	62.73	62.73	63.88	64.70	65.23	65.35	62.73	63.08	63.20	65.30	65.33	66.18	63.20	66.30	65.35	66.03	65.38	62.73	65.78	67.40	62.73
6:00:00 AM	63.18	63.18	64.45	65.35	65.93	66.08	63.18	63.50	63.60	66.00	66.03	66.50	63.60	66.58	66.05	66.33	66.08	63.18	66.08	67.55	63.18
7:00:00 AM	64.88	64.88	66.30	68.12	68.77	68.64	64.88	65.51	65.63	68.03	68.10	68.86	65.63	68.96	68.19	68.43	68.24	64.88	68.13	70.91	64.88
8:00:00 AM	66.70	66.70	68.28	78.81	79.51	76.42	66.70	70.48	70.61	70.20	70.79	73.97	70.61	74.33	71.62	70.68	71.67	66.70	70.33	85.02	66.70
9:00:00 AM	74.30	74.30	76.23	97.13	98.03	91.67	74.30	82.01	82.16	78.60	79.91	86.11	82.16	86.79	81.64	79.18	81.67	74.30	78.75	107.14	74.30
10:00:00 AM	80.28	80.28	82.45	117.66	118.69	108.21	80.28	93.95	94.13	85.18	87.59	98.50	94.13	99.60	90.75	86.05	90.80	80.28	85.53	132.04	80.28
11:00:00 AM	84.30	84.30	86.60	130.95	132.05	119.18	84.30	102.13	102.33	89.50	92.72	107.00	102.33	108.43	96.88	90.73	96.93	84.30	90.15	147.86	84.30
12:00:00 PM	161.68	161.68	166.28	215.16	217.36	204.13	161.68	181.60	182.05	172.10	175.62	193.87	182.05	195.65	180.22	175.98	180.32	161.68	174.75	239.69	161.68
1:00:00 PM	258.70	258.70	266.08	319.49	323.07	309.68	258.70	280.88	281.66	275.50	279.32	303.79	281.66	306.03	284.35	284.25	284.55	258.70	282.13	355.65	258.70
2:00:00 PM	198.38	198.38	204.20	255.31	258.16	244.83	198.38	219.61	220.28	211.68	215.37	238.90	220.28	241.06	220.21	220.13	220.36	198.38	218.35	288.87	198.38
3:00:00 PM	158.63	158.63	163.48	206.18	208.58	197.06	158.63	175.93	176.48	169.73	172.67	192.43	176.48	194.20	176.59	177.13	176.72	158.63	175.63	235.40	158.63
4:00:00 PM	148.90	148.90	153.53	168.07	170.35	167.15	148.90	154.58	155.13	159.48	160.26	171.47	155.13	172.38	161.39	166.93	161.54	148.90	165.48	189.82	148.90
5:00:00 PM	156.25	156.25	160.53	188.70	190.78	183.05	156.25	167.24	167.72	165.98	167.75	181.29	167.72	182.59	170.14	171.85	170.27	156.25	170.63	211.69	156.25
6:00:00 PM	140.00	140.00	143.65	161.12	162.87	158.25	140.00	146.82	147.30	148.33	149.33	160.17	147.30	161.22	150.78	154.63	150.88	140.00	153.53	181.14	140.00
7:00:00 PM	106.50	106.50	109.10	114.40	115.62	114.72	106.50	108.70	109.03	112.40	112.63	117.90	109.03	118.48	113.06	116.45	113.13	106.50	115.73	125.63	106.50
8:00:00 PM	90.63	90.63	92.85	94.45	95.48	95.75	90.63	91.48	91.75	95.65	95.68	99.40	91.75	99.78	95.78	99.10	95.85	90.63	98.48	102.88	90.63
9:00:00 PM	124.03	124.03	126.80	128.80	130.10	130.45	124.03	125.13	125.50	130.33	130.38	135.35	125.50	135.88	130.50	134.98	130.60	124.03	134.18	139.88	124.03
10:00:00 PM	104.10	104.10	106.45	108.13	109.20	109.50	104.10	105.03	105.35	109.40	109.43	113.60	105.35	114.05	109.55	113.28	109.63	104.10	112.63	117.40	104.10
11:00:00 PM	73.70	73.70	75.28	76.38	77.10	77.28	73.70	74.28	74.48	77.23	77.25	79.55	74.48	79.83	77.33	79.38	77.38	73.70	78.95	81.88	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table D.3 – Case 5 Per Unit Voltage

	Voltage (PU)																			
Hour	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.96	0.94	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.97	0.97	1.00	0.97	0.95	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
6:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
7:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
8:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	1.00	0.99	0.97	0.96	0.97	0.99	0.96	0.96	0.97	0.96	1.00	0.97	0.95	1.00
9:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.97	0.95	1.00
10:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.96	0.94	1.00
11:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.95	0.96	0.96	0.96	1.00	0.96	0.94	1.00
12:00:00 PM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.96	0.95	0.95	0.99	0.95	0.96	0.95	0.95	1.00	0.96	0.93	1.00
1:00:00 PM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.96	0.95	0.94	0.99	0.94	0.95	0.95	0.95	1.00	0.95	0.92	1.00
2:00:00 PM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.95	0.95	0.94	0.99	0.94	0.95	0.94	0.95	1.00	0.95	0.92	1.00
3:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.94	0.99	0.93	0.95	0.94	0.95	1.00	0.94	0.91	1.00
4:00:00 PM	1.00	0.98	0.96	0.95	0.95	1.00	0.99	0.99	0.95	0.95	0.94	0.99	0.93	0.95	0.94	0.95	1.00	0.94	0.91	1.00
5:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.95	0.96	1.00	0.95	0.92	1.00
6:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.95	0.92	1.00
7:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
8:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
9:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
10:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.96	0.99	0.95	0.97	0.96	0.97	1.00	0.96	0.94	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

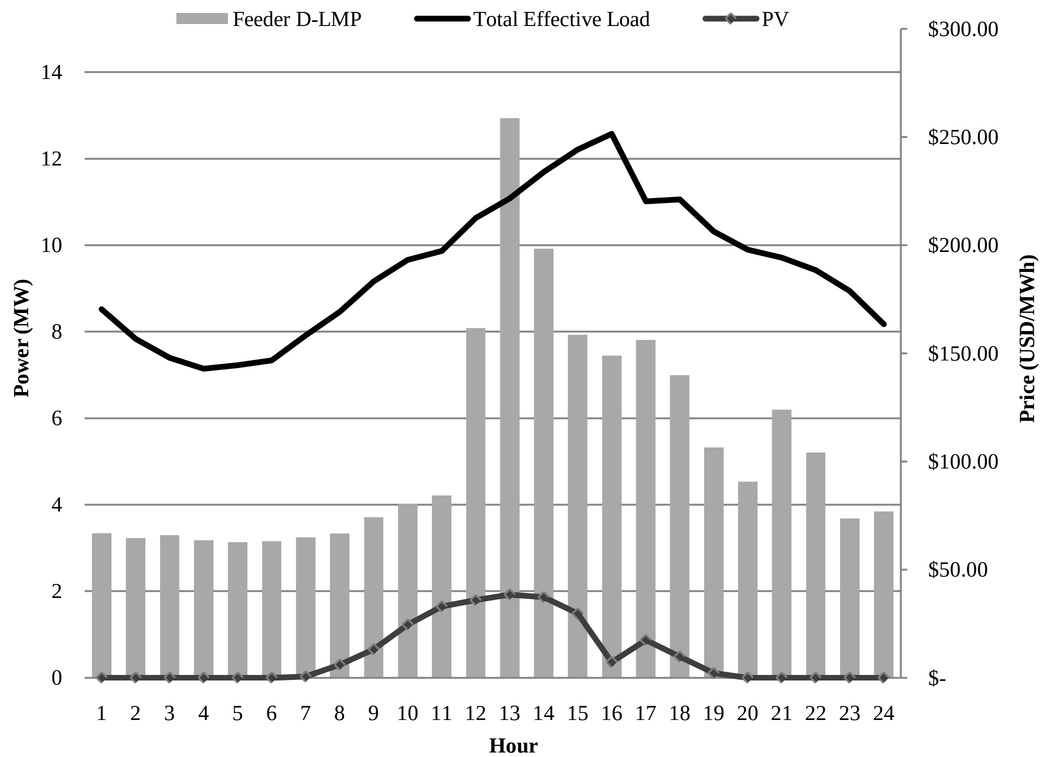

Figure D.2 – Case 5 System Data

Table D.4 – Revenue Streams for Case 5

Cost Stream	Cost (USD)
D-LMP Revenue	$29,595.75
Energy	$27,723.90
Losses	$1,871.85
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	N/A
DG Payments	$2,508.36

D.2 Simulation Result: Case 6

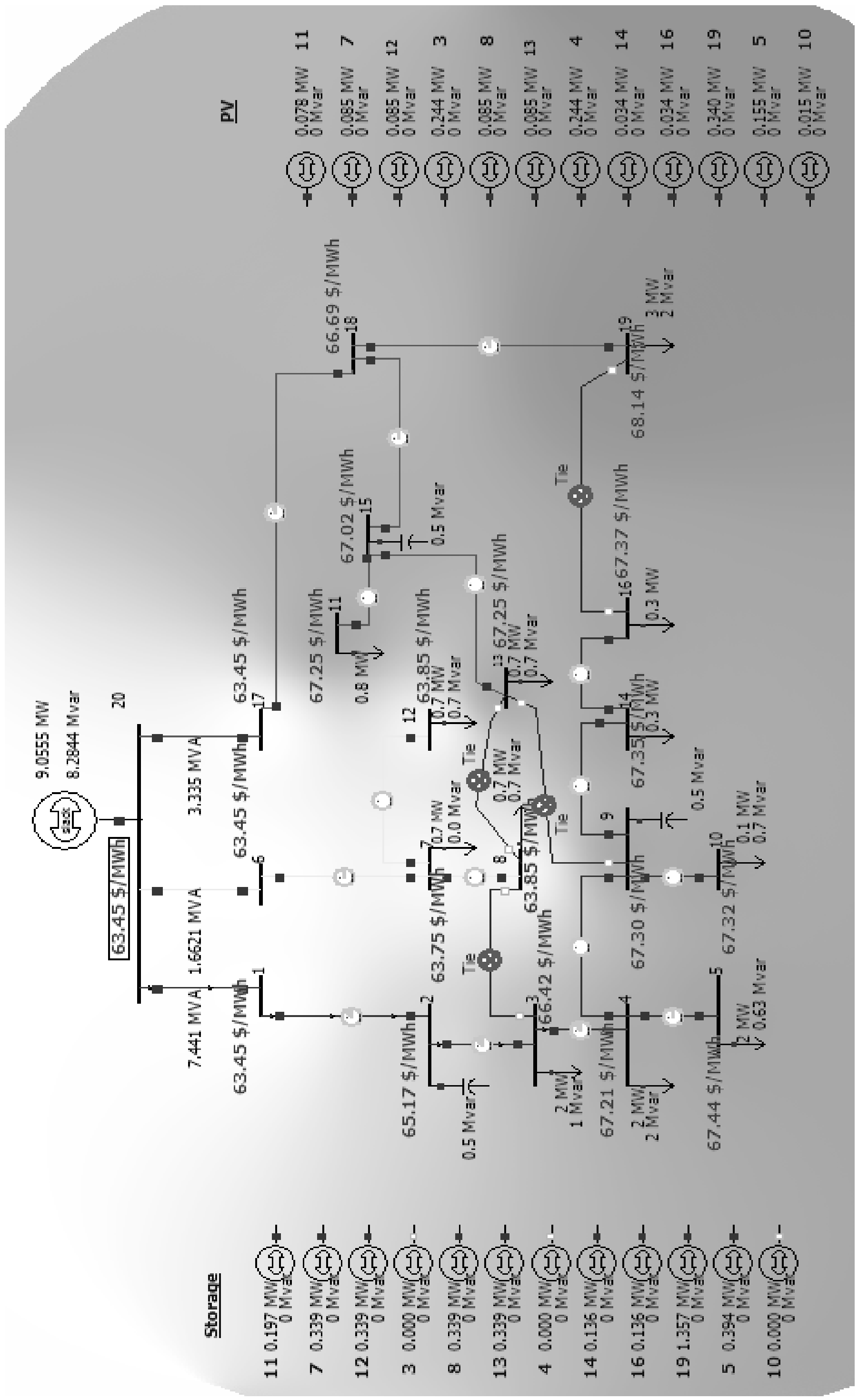

Figure D.3 – Case 6 Oneline at Peak Demand

Table D.5 – Case 6 Load D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Load DLMP (USD/kWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	0.06685	0.06685	0.0683	0.06935	0.07008	0.07033	0.06685	0.06758	0.0678	0.0702	0.07023	0.0744	0.0678	0.07473	0.07033	0.07413	0.07038	0.06685	0.07358	0.07738	0.06685
2:00:00 AM	0.06465	0.06465	0.06605	0.06708	0.06778	0.068	0.06465	0.06535	0.06558	0.0679	0.06793	0.072	0.06558	0.0723	0.06803	0.07173	0.06808	0.06465	0.0712	0.0749	0.06465
3:00:00 AM	0.066	0.066	0.06743	0.06843	0.06913	0.06935	0.066	0.06673	0.06698	0.06928	0.0693	0.07363	0.06698	0.07398	0.0694	0.07338	0.06945	0.066	0.07283	0.07673	0.066
4:00:00 AM	0.06355	0.06355	0.06493	0.0659	0.06658	0.06678	0.06355	0.06425	0.0645	0.0667	0.06673	0.0709	0.0645	0.07123	0.0668	0.07065	0.06688	0.06355	0.07013	0.07388	0.06355
5:00:00 AM	0.06273	0.06273	0.0641	0.06508	0.06575	0.06595	0.06273	0.06348	0.06375	0.06588	0.0659	0.07048	0.06375	0.0709	0.066	0.07025	0.06608	0.06273	0.06973	0.07383	0.06273
6:00:00 AM	0.06318	0.06318	0.06463	0.06568	0.06638	0.06658	0.06318	0.06395	0.0642	0.06653	0.06655	0.071	0.0642	0.07143	0.06665	0.07078	0.0667	0.06318	0.07023	0.07438	0.06318
7:00:00 AM	0.06488	0.06488	0.06648	0.0676	0.06838	0.0686	0.06488	0.0657	0.06598	0.06855	0.06855	0.07328	0.06598	0.0737	0.06868	0.07303	0.06875	0.06488	0.07245	0.0769	0.06488
8:00:00 AM	0.0667	0.0667	0.06843	0.06968	0.07053	0.07075	0.0667	0.06753	0.0678	0.07068	0.07068	0.0753	0.0678	0.07573	0.0708	0.07503	0.07088	0.0667	0.07443	0.0789	0.0667
9:00:00 AM	0.0743	0.0743	0.07635	0.07783	0.07883	0.07913	0.0743	0.07513	0.0754	0.079	0.07903	0.0832	0.0754	0.08358	0.07913	0.08288	0.0792	0.0743	0.08223	0.08668	0.0743
10:00:00 AM	0.08028	0.08028	0.08253	0.08413	0.0852	0.08555	0.08028	0.081	0.08123	0.08535	0.0854	0.0882	0.08123	0.0884	0.08548	0.08783	0.08555	0.08028	0.0872	0.09088	0.08028
11:00:00 AM	0.0843	0.0843	0.0866	0.08828	0.08938	0.08973	0.0843	0.08495	0.08518	0.08953	0.08955	0.09173	0.08518	0.09188	0.08963	0.09135	0.08968	0.0843	0.09078	0.09408	0.0843
12:00:00 PM	0.16168	0.16168	0.16615	0.1694	0.17153	0.17218	0.16168	0.16283	0.1632	0.1718	0.17185	0.17498	0.1632	0.17523	0.172	0.1743	0.17208	0.16168	0.17323	0.17903	0.16168
1:00:00 PM	0.2587	0.2587	0.26558	0.27055	0.27375	0.2747	0.2587	0.2601	0.26055	0.2741	0.2742	0.27563	0.26055	0.27573	0.27435	0.27465	0.27445	0.2587	0.27323	0.28	0.2587
2:00:00 PM	0.19838	0.19838	0.20365	0.20745	0.20988	0.21055	0.19838	0.1994	0.19973	0.21015	0.21023	0.21088	0.19973	0.21098	0.21033	0.21018	0.2104	0.19838	0.20915	0.21418	0.19838
3:00:00 PM	0.15863	0.15863	0.16293	0.16605	0.16803	0.1686	0.15863	0.15938	0.15963	0.16825	0.1683	0.16813	0.15963	0.16813	0.16838	0.16755	0.16843	0.15863	0.16673	0.17035	0.15863
4:00:00 PM	0.1489	0.1489	0.153	0.15598	0.15785	0.15835	0.1489	0.14968	0.14995	0.15805	0.15813	0.1583	0.14995	0.1584	0.1582	0.1578	0.15825	0.1489	0.157	0.16085	0.1489
5:00:00 PM	0.15625	0.15625	0.16	0.1627	0.16438	0.1648	0.15625	0.15673	0.15688	0.16455	0.1646	0.1625	0.15688	0.16243	0.16463	0.16208	0.16465	0.15625	0.1615	0.1637	0.15625
6:00:00 PM	0.14	0.14	0.14325	0.14558	0.147	0.14735	0.14	0.1405	0.14068	0.14715	0.1472	0.1462	0.14068	0.14623	0.14723	0.14585	0.14728	0.14	0.14533	0.14775	0.14
7:00:00 PM	0.1065	0.1065	0.10883	0.1105	0.11153	0.11175	0.1065	0.10685	0.10698	0.1116	0.11165	0.11063	0.10698	0.11065	0.11168	0.1104	0.1117	0.1065	0.11005	0.11165	0.1065
8:00:00 PM	0.09063	0.09063	0.0926	0.09403	0.0949	0.0951	0.09063	0.09093	0.09103	0.09498	0.095	0.09413	0.09103	0.09415	0.09503	0.09393	0.09505	0.09063	0.09365	0.09503	0.09063
9:00:00 PM	0.12403	0.12403	0.12665	0.12855	0.12973	0.13003	0.12403	0.12465	0.12488	0.12985	0.1299	0.13085	0.12488	0.13103	0.12998	0.13055	0.13003	0.12403	0.13	0.13303	0.12403
10:00:00 PM	0.1041	0.1041	0.1063	0.1079	0.10888	0.10913	0.1041	0.10463	0.1048	0.109	0.10903	0.10983	0.1048	0.10998	0.10908	0.10958	0.10913	0.1041	0.10913	0.11165	0.1041
11:00:00 PM	0.0737	0.0737	0.07525	0.07635	0.07705	0.07723	0.0737	0.07418	0.07435	0.07715	0.07718	0.07865	0.07435	0.07885	0.07723	0.07848	0.07728	0.0737	0.0781	0.08048	0.0737
12:00:00 AM	0.0769	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table D.6 – Case 6 Generation D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Gen DLMPs (USD/MWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.30	69.35	70.08	70.33	66.85	67.58	67.80	70.20	70.23	74.40	67.80	74.73	70.33	74.13	70.38	66.85	73.58	77.38	66.85
2:00:00 AM	64.65	64.65	66.05	67.08	67.78	68.00	64.65	65.35	65.58	67.90	67.93	72.00	65.58	72.30	68.03	71.73	68.08	64.65	71.20	74.90	64.65
3:00:00 AM	66.00	66.00	67.43	68.43	69.13	69.35	66.00	66.73	66.98	69.28	69.30	73.63	66.98	73.98	69.40	73.38	69.45	66.00	72.83	76.73	66.00
4:00:00 AM	63.55	63.55	64.93	65.90	66.58	66.78	63.55	64.25	64.50	66.70	66.73	70.90	64.50	71.23	66.80	70.65	66.88	63.55	70.13	73.88	63.55
5:00:00 AM	62.73	62.73	64.10	65.08	65.75	65.95	62.73	63.48	63.75	65.88	65.90	70.48	63.75	70.90	66.00	70.25	66.08	62.73	69.73	73.83	62.73
6:00:00 AM	63.18	63.18	64.63	65.68	66.38	66.58	63.18	63.95	64.20	66.53	66.55	71.00	64.20	71.43	66.65	70.78	66.70	63.18	70.23	74.38	63.18
7:00:00 AM	64.88	64.88	66.48	68.42	69.19	69.12	64.88	65.98	66.26	68.55	68.60	73.54	66.26	73.98	68.79	73.03	68.86	64.88	72.45	78.03	64.88
8:00:00 AM	66.70	66.70	68.43	79.09	79.94	76.85	66.70	70.91	71.18	70.68	71.26	78.40	71.18	79.11	72.17	75.03	72.24	66.70	74.43	91.77	66.70
9:00:00 AM	74.30	74.30	76.35	97.35	98.35	92.02	74.30	82.39	82.66	79.00	80.31	89.86	82.66	90.84	82.09	82.88	82.17	74.30	82.23	112.87	74.30
10:00:00 AM	80.28	80.28	82.53	117.76	118.84	108.36	80.28	94.15	94.38	85.35	87.79	100.30	94.38	101.55	90.95	87.83	91.03	80.28	87.20	134.82	80.28
11:00:00 AM	84.30	84.30	86.60	130.95	132.05	119.18	84.30	102.21	102.43	89.53	92.74	107.62	102.43	109.13	96.90	91.35	96.95	84.30	90.78	148.91	84.30
12:00:00 PM	161.68	161.68	166.15	214.96	217.09	203.81	161.68	181.45	181.83	171.80	175.32	192.15	181.83	193.85	179.89	174.30	179.97	161.68	173.23	237.27	161.68
1:00:00 PM	258.70	258.70	265.58	318.64	321.84	308.26	258.70	279.96	280.41	274.10	277.92	293.94	280.41	295.58	282.80	274.65	282.90	258.70	273.23	341.20	258.70
2:00:00 PM	198.38	198.38	203.65	254.36	256.78	243.21	198.38	218.68	219.01	210.15	213.82	228.65	219.01	230.26	218.51	210.18	218.59	198.38	209.15	274.00	198.38
3:00:00 PM	158.63	158.63	162.93	205.26	207.23	195.48	158.63	175.03	175.28	168.25	171.17	182.53	175.28	183.78	174.94	167.55	174.99	158.63	166.73	221.05	158.63
4:00:00 PM	148.90	148.90	153.00	167.20	169.07	165.65	148.90	153.73	154.01	158.05	158.83	162.02	154.01	162.46	159.84	157.80	159.89	148.90	157.00	176.15	148.90
5:00:00 PM	156.25	156.25	160.00	187.80	189.48	181.55	156.25	166.24	166.39	164.55	166.30	171.24	166.39	171.94	168.54	162.08	168.57	156.25	161.50	197.02	156.25
6:00:00 PM	140.00	140.00	143.25	160.40	161.82	157.05	140.00	145.92	146.10	147.15	148.15	151.17	146.10	151.65	149.43	145.85	149.48	140.00	145.33	167.81	140.00
7:00:00 PM	106.50	106.50	108.83	113.92	114.95	113.94	106.50	108.05	108.18	111.60	111.86	111.73	108.18	111.85	112.16	110.40	112.18	106.50	110.05	116.38	106.50
8:00:00 PM	90.63	90.63	92.60	94.03	94.90	95.10	90.63	90.93	91.03	94.98	95.00	94.13	91.03	94.15	95.03	93.93	95.05	90.63	93.65	95.03	90.63
9:00:00 PM	124.03	124.03	126.65	128.55	129.73	130.03	124.03	124.65	124.88	129.85	129.90	130.85	124.88	131.03	129.98	130.55	130.03	124.03	130.00	133.03	124.03
10:00:00 PM	104.10	104.10	106.30	107.90	108.88	109.13	104.10	104.63	104.80	109.00	109.03	109.83	104.80	109.98	109.08	109.58	109.13	104.10	109.13	111.65	104.10
11:00:00 PM	73.70	73.70	75.25	76.35	77.05	77.23	73.70	74.18	74.35	77.15	77.18	78.65	74.35	78.85	77.23	78.48	77.28	73.70	78.10	80.48	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table D.7 – Case 6 Per Unit Voltage

Hour	Voltage (PU)																			
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
6:00:00 AM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
7:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.94	0.91	1.00
8:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.94	0.91	1.00
9:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.95	0.92	1.00
10:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
11:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.96	0.96	1.00	0.96	0.94	1.00
12:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.96	0.96	1.00	0.96	0.94	1.00
1:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.96	0.95	1.00
2:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.96	0.95	1.00
3:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.97	0.95	1.00
4:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.97	0.95	1.00
5:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.97	1.00	0.97	0.96	0.97	0.96	1.00	0.98	0.96	1.00
6:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.97	1.00	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
7:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.98	0.96	1.00
8:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.98	0.96	1.00
9:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
10:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

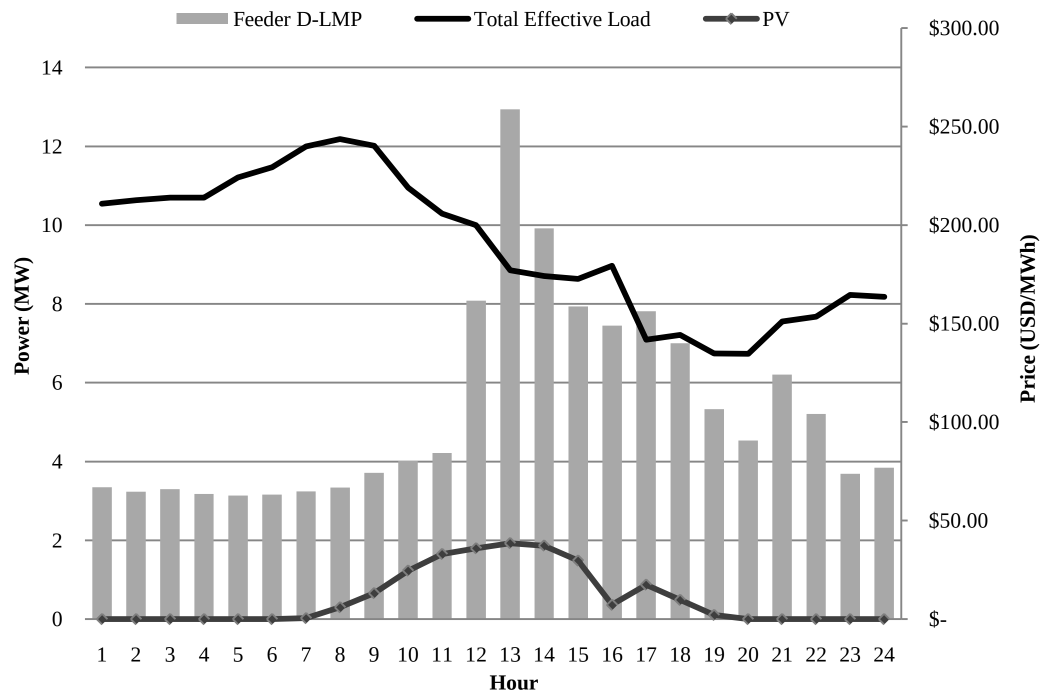

Figure D.4 – Case 6 System Data

Table D.8 – Revenue Streams for Case 6

Cost Stream	Cost (USD)
D-LMP Revenue	$26,678.40
Energy	$25,161.36
Losses	$1,517.04
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	$2,568.37
DG Payments	$2,473.57

D.3 Simulation Result: Case 7

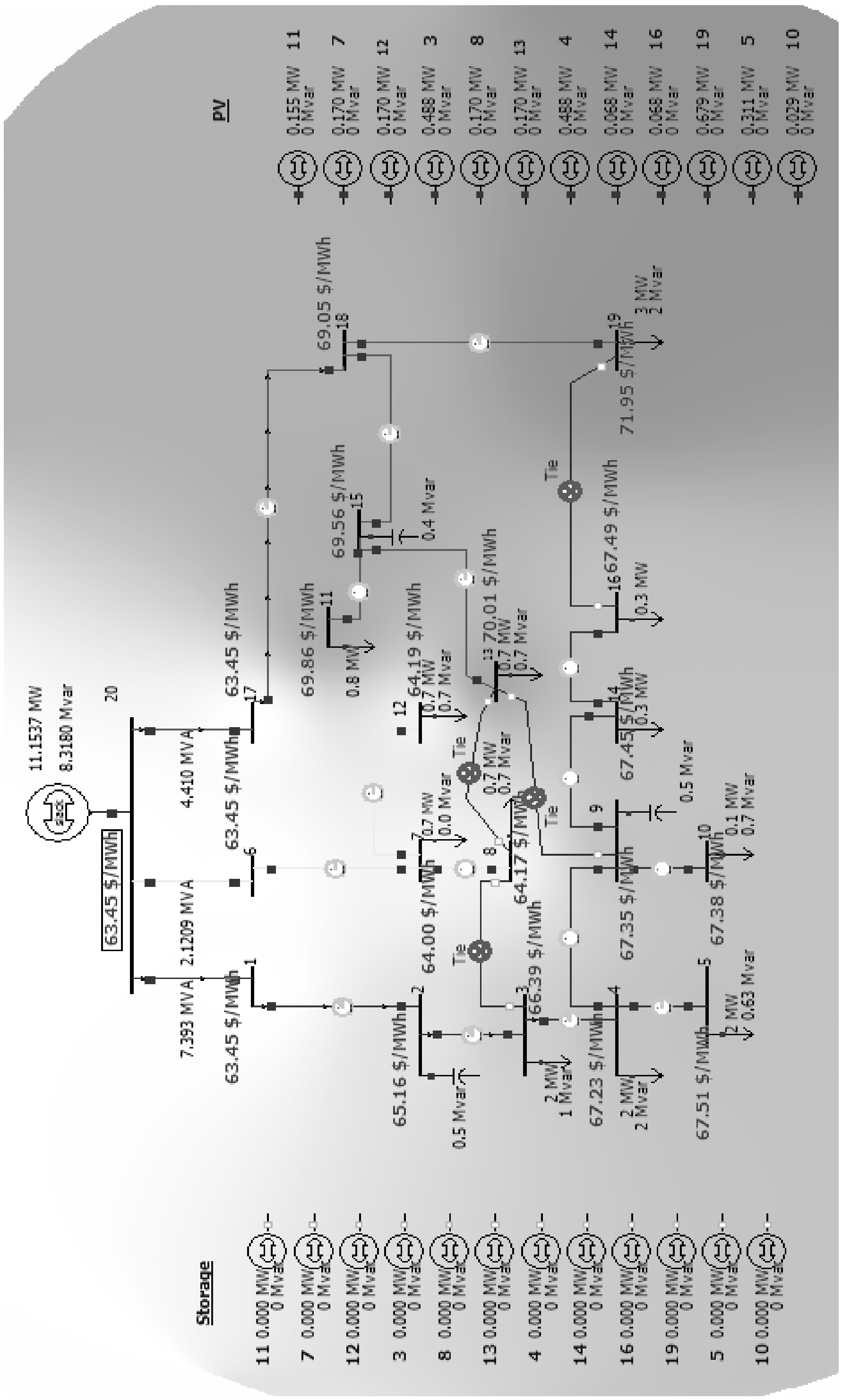

Figure D.5 – Case 7 Oneline at Peak Demand

Table D.9 – Case 7 Load D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Load DLMP (USD/kWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	0.06685	0.06685	0.06815	0.06908	0.0697	0.06985	0.06685	0.06738	0.06755	0.0698	0.06983	0.07208	0.06755	0.0723	0.06988	0.0719	0.06993	0.06685	0.07153	0.07413	0.06685
2:00:00 AM	0.06465	0.06465	0.06588	0.06675	0.0673	0.06745	0.06465	0.06508	0.06523	0.0674	0.06743	0.06893	0.06523	0.0691	0.06748	0.06878	0.0675	0.06465	0.06848	0.07055	0.06465
3:00:00 AM	0.066	0.066	0.06723	0.06808	0.06865	0.06878	0.066	0.0664	0.06653	0.06873	0.06875	0.06993	0.06653	0.07008	0.0688	0.06978	0.06883	0.066	0.06948	0.07135	0.066
4:00:00 AM	0.06355	0.06355	0.06473	0.06555	0.06608	0.0662	0.06355	0.0639	0.06403	0.06615	0.06618	0.06703	0.06403	0.06715	0.0662	0.0669	0.06625	0.06355	0.06665	0.06828	0.06355
5:00:00 AM	0.06273	0.06273	0.06388	0.0647	0.06523	0.06535	0.06273	0.06308	0.0632	0.0653	0.06533	0.06618	0.0632	0.0663	0.06535	0.06603	0.06538	0.06273	0.06578	0.0674	0.06273
6:00:00 AM	0.06318	0.06318	0.06445	0.06535	0.06593	0.06608	0.06318	0.0635	0.0636	0.066	0.06603	0.0665	0.0636	0.06658	0.06605	0.06633	0.06608	0.06318	0.06608	0.06755	0.06318
7:00:00 AM	0.06488	0.06488	0.0663	0.0673	0.06795	0.06813	0.06488	0.06523	0.06535	0.06803	0.06805	0.06858	0.06535	0.06868	0.06808	0.0684	0.0681	0.06488	0.0681	0.06975	0.06488
8:00:00 AM	0.0667	0.0667	0.06823	0.0693	0.07	0.0702	0.0667	0.06708	0.0672	0.07008	0.0701	0.07068	0.0672	0.07075	0.07015	0.07048	0.07018	0.0667	0.07015	0.07188	0.0667
9:00:00 AM	0.0743	0.0743	0.0761	0.0774	0.07823	0.07848	0.0743	0.0747	0.07485	0.07833	0.07835	0.07895	0.07485	0.079	0.0784	0.07868	0.07843	0.0743	0.0783	0.08025	0.0743
10:00:00 AM	0.08028	0.08028	0.08223	0.08363	0.08453	0.08483	0.08028	0.0807	0.08085	0.08463	0.08465	0.08535	0.08085	0.08538	0.0847	0.08505	0.08475	0.08028	0.08463	0.08668	0.08028
11:00:00 AM	0.0843	0.0843	0.08628	0.0877	0.08863	0.08893	0.0843	0.08475	0.0849	0.08873	0.08875	0.08963	0.0849	0.08965	0.0888	0.0893	0.08885	0.0843	0.08885	0.091	0.0843
12:00:00 PM	0.16168	0.16168	0.16558	0.1684	0.17025	0.17083	0.16168	0.1627	0.16305	0.17048	0.17053	0.17353	0.16305	0.17373	0.17065	0.1729	0.17073	0.16168	0.17195	0.17703	0.16168
1:00:00 PM	0.2587	0.2587	0.2649	0.26935	0.27233	0.27325	0.2587	0.26055	0.26118	0.27273	0.27283	0.27983	0.26118	0.28028	0.27303	0.2788	0.2732	0.2587	0.27713	0.2865	0.2587
2:00:00 PM	0.19838	0.19838	0.20333	0.20688	0.20925	0.21003	0.19838	0.19998	0.20053	0.2096	0.20968	0.21678	0.20053	0.21725	0.20988	0.21593	0.21003	0.19838	0.2145	0.2229	0.19838
3:00:00 PM	0.15863	0.15863	0.1629	0.166	0.16808	0.1688	0.15863	0.16003	0.1605	0.1684	0.16845	0.17515	0.1605	0.17558	0.16863	0.1744	0.16875	0.15863	0.1731	0.18065	0.15863
4:00:00 PM	0.1489	0.1489	0.15338	0.15663	0.15883	0.15953	0.1489	0.15048	0.151	0.15918	0.15925	0.16705	0.151	0.16763	0.15945	0.16628	0.15958	0.1489	0.16488	0.17355	0.1489
5:00:00 PM	0.15625	0.15625	0.1602	0.16305	0.16495	0.1655	0.15625	0.15758	0.15803	0.16523	0.1653	0.17095	0.15803	0.17143	0.16545	0.17033	0.16558	0.15625	0.1692	0.17613	0.15625
6:00:00 PM	0.14	0.14	0.1435	0.14603	0.14768	0.14815	0.14	0.14133	0.14178	0.14795	0.148	0.15438	0.14178	0.15495	0.14818	0.15385	0.1483	0.14	0.1528	0.15993	0.14
7:00:00 PM	0.1065	0.1065	0.10908	0.11093	0.11213	0.11245	0.1065	0.10748	0.1078	0.11233	0.11238	0.11668	0.1078	0.11713	0.1125	0.11633	0.11258	0.1065	0.11563	0.1207	0.1065
8:00:00 PM	0.09063	0.09063	0.09283	0.0944	0.09543	0.0957	0.09063	0.09145	0.09175	0.0956	0.09563	0.09928	0.09175	0.09968	0.09573	0.099	0.0958	0.09063	0.09838	0.10273	0.09063
9:00:00 PM	0.12403	0.12403	0.1268	0.1288	0.1301	0.13045	0.12403	0.12513	0.1255	0.13033	0.13038	0.13535	0.1255	0.13588	0.1305	0.13498	0.1306	0.12403	0.13418	0.13988	0.12403
10:00:00 PM	0.1041	0.1041	0.10645	0.10813	0.1092	0.1095	0.1041	0.10503	0.10535	0.1094	0.10943	0.1136	0.10535	0.11405	0.10955	0.11328	0.10963	0.1041	0.11263	0.1174	0.1041
11:00:00 PM	0.0737	0.0737	0.07528	0.07638	0.0771	0.07728	0.0737	0.07428	0.07448	0.07723	0.07725	0.07955	0.07448	0.07983	0.07733	0.07938	0.07738	0.0737	0.07895	0.08188	0.0737
12:00:00 AM	0.0769	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table D.10 – Case 7 Generation D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Gen DLMPs (USD/MWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.15	69.08	69.70	69.85	66.85	67.38	67.55	69.80	69.83	72.08	67.55	72.30	69.88	71.90	69.93	66.85	71.53	74.13	66.85
2:00:00 AM	64.65	64.65	65.88	66.75	67.30	67.45	64.65	65.08	65.23	67.40	67.43	68.93	65.23	69.10	67.48	68.78	67.50	64.65	68.48	70.55	64.65
3:00:00 AM	66.00	66.00	67.23	68.08	68.65	68.78	66.00	66.40	66.53	68.73	68.75	69.93	66.53	70.08	68.80	69.78	68.83	66.00	69.48	71.35	66.00
4:00:00 AM	63.55	63.55	64.73	65.55	66.08	66.20	63.55	63.90	64.03	66.15	66.18	67.03	64.03	67.15	66.20	66.90	66.25	63.55	66.65	68.28	63.55
5:00:00 AM	62.73	62.73	63.88	64.70	65.23	65.35	62.73	63.08	63.20	65.30	65.33	66.18	63.20	66.30	65.35	66.03	65.38	62.73	65.78	67.40	62.73
6:00:00 AM	63.18	63.18	64.45	65.35	65.93	66.08	63.18	63.50	63.60	66.00	66.03	66.50	63.60	66.58	66.05	66.33	66.08	63.18	66.08	67.55	63.18
7:00:00 AM	64.88	64.88	66.30	68.92	69.57	69.16	64.88	65.79	65.92	68.03	68.15	69.09	65.92	69.24	68.30	68.40	68.33	64.88	68.10	72.00	64.88
8:00:00 AM	66.70	66.70	68.23	87.28	87.98	82.03	66.70	73.72	73.85	70.08	71.27	76.77	73.85	77.40	72.86	70.48	72.89	66.70	70.15	96.06	66.70
9:00:00 AM	74.30	74.30	76.10	112.98	113.81	102.70	74.30	88.71	88.86	78.33	80.91	91.84	88.86	93.01	84.25	78.68	84.28	74.30	78.30	126.57	74.30
10:00:00 AM	80.28	80.28	82.23	141.21	142.11	125.78	80.28	105.38	105.53	84.63	89.37	108.16	105.53	110.06	95.36	85.05	95.41	80.28	84.63	158.73	80.28
11:00:00 AM	84.30	84.30	86.28	158.04	158.96	140.28	84.30	116.52	116.67	88.73	95.03	119.08	116.67	121.42	102.85	89.30	102.90	84.30	88.85	177.07	84.30
12:00:00 PM	161.68	161.68	165.58	242.62	244.47	225.45	161.68	196.78	197.13	170.48	177.34	205.16	197.13	207.81	185.84	172.90	185.91	161.68	171.95	267.24	161.68
1:00:00 PM	258.70	258.70	264.90	346.89	349.86	330.72	258.70	296.68	297.30	272.73	280.12	313.38	297.30	316.40	289.23	278.80	289.41	258.70	277.13	380.22	258.70
2:00:00 PM	198.38	198.38	203.33	282.87	285.25	266.17	198.38	235.15	235.70	209.60	216.75	249.43	235.70	252.42	225.60	215.93	225.75	198.38	214.50	315.00	198.38
3:00:00 PM	158.63	158.63	162.90	231.56	233.64	216.19	158.63	189.06	189.53	168.40	174.12	202.03	189.53	204.61	181.34	174.40	181.47	158.63	173.10	261.54	158.63
4:00:00 PM	148.90	148.90	153.38	177.88	180.08	173.61	148.90	158.43	158.95	159.18	160.66	174.35	158.95	175.58	162.71	166.28	162.83	148.90	164.88	201.97	148.90
5:00:00 PM	156.25	156.25	160.20	207.66	209.56	196.41	156.25	175.75	176.20	165.23	168.68	187.70	176.20	189.60	173.14	170.33	173.26	156.25	169.20	233.25	156.25
6:00:00 PM	140.00	140.00	143.50	173.63	175.28	166.65	140.00	151.88	152.33	147.95	149.90	164.08	152.33	165.51	152.54	153.85	152.66	140.00	152.80	196.39	140.00
7:00:00 PM	106.50	106.50	109.08	117.65	118.85	116.79	106.50	109.87	110.19	112.33	112.79	118.87	110.19	119.52	113.46	116.33	113.54	106.50	115.63	129.95	106.50
8:00:00 PM	90.63	90.63	92.83	94.40	95.43	95.70	90.63	91.45	91.75	95.60	95.63	99.28	91.75	99.68	95.73	99.00	95.80	90.63	98.38	102.73	90.63
9:00:00 PM	124.03	124.03	126.80	128.80	130.10	130.45	124.03	125.13	125.50	130.33	130.38	135.35	125.50	135.88	130.50	134.98	130.60	124.03	134.18	139.88	124.03
10:00:00 PM	104.10	104.10	106.45	108.13	109.20	109.50	104.10	105.03	105.35	109.40	109.43	113.60	105.35	114.05	109.55	113.28	109.63	104.10	112.63	117.40	104.10
11:00:00 PM	73.70	73.70	75.28	76.38	77.10	77.28	73.70	74.28	74.48	77.23	77.25	79.55	74.48	79.83	77.33	79.38	77.38	73.70	78.95	81.88	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table D.11 – Case 7 Per Unit Voltage

Hour	Voltage (PU)																			
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.96	0.94	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.97	0.97	1.00	0.97	0.95	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
6:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
7:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
8:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.97	0.96	1.00
9:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.97	0.99	0.96	0.96	0.97	0.96	1.00	0.97	0.95	1.00
10:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.97	0.96	1.00	0.97	0.95	1.00
11:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.97	0.96	1.00	0.97	0.95	1.00
12:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.96	0.94	1.00
1:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.96	0.96	1.00	0.96	0.94	1.00
2:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
3:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.95	0.96	1.00	0.95	0.92	1.00
4:00:00 PM	1.00	0.98	0.97	0.96	0.95	1.00	0.99	0.99	0.95	0.95	0.94	0.99	0.93	0.95	0.94	0.95	1.00	0.94	0.91	1.00
5:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
6:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.94	0.96	0.95	0.96	1.00	0.95	0.92	1.00
7:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
8:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.95	0.96	0.95	0.96	1.00	0.95	0.93	1.00
9:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
10:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.95	0.99	0.95	0.97	0.95	0.97	1.00	0.96	0.93	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.96	0.99	0.95	0.97	0.96	0.97	1.00	0.96	0.94	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

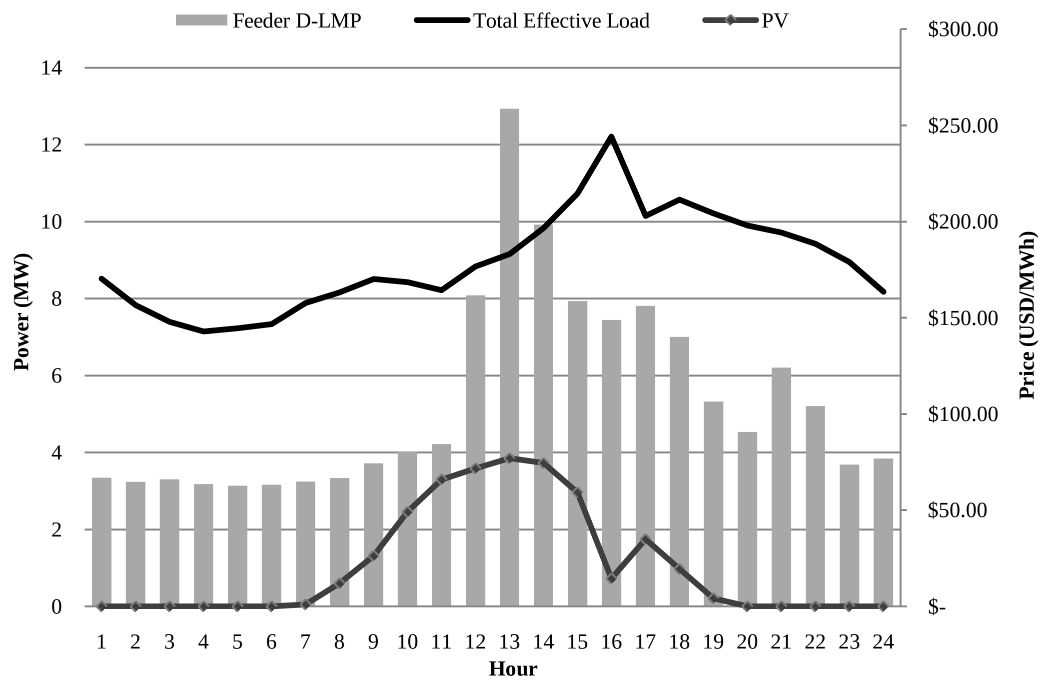

Figure D.6 – Case 7 System Data

Table D.12 – Revenue Streams for Case 7

Cost Stream	Cost (USD)
D-LMP Revenue	$29,411.06
Energy	$27,723.90
Losses	$ 1,687.16
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	N/A
DG Payments	$ 5,494.37

D.4 Simulation Result: Case 8

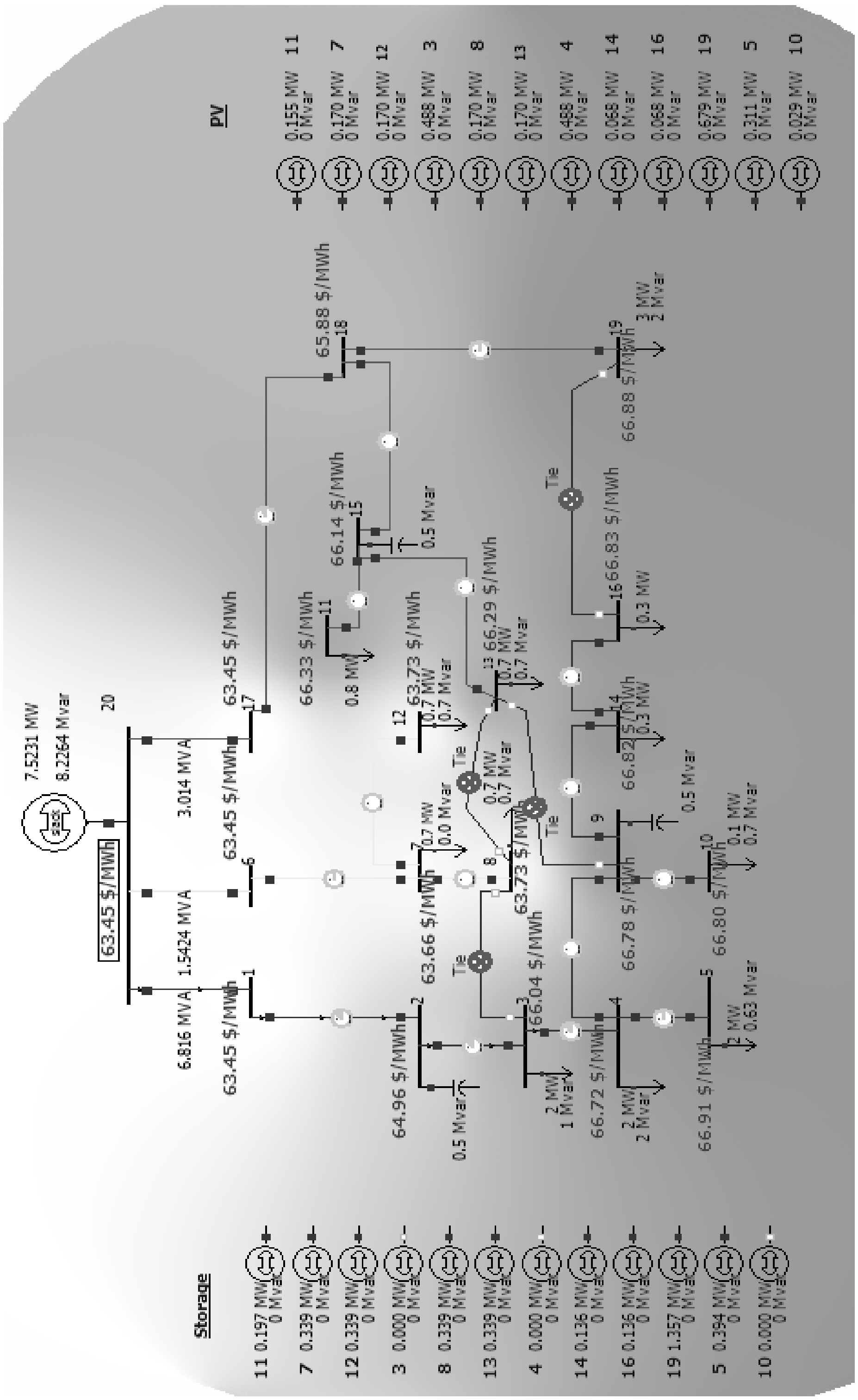

Figure D.7 – Case 8 Oneline at Peak Demand

Table D.13 – Case 8 Load D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Load DLMP (USD/kWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	0.06685	0.06685	0.0683	0.06935	0.07008	0.07033	0.06685	0.06758	0.0678	0.0702	0.07023	0.0744	0.0678	0.07473	0.07033	0.07413	0.07038	0.06685	0.07358	0.07738	0.06685
2:00:00 AM	0.06465	0.06465	0.06605	0.06708	0.06778	0.068	0.06465	0.06535	0.06558	0.0679	0.06793	0.072	0.06558	0.0723	0.06803	0.07173	0.06808	0.06465	0.0712	0.0749	0.06465
3:00:00 AM	0.066	0.066	0.06743	0.06843	0.06913	0.06935	0.066	0.06673	0.06698	0.06928	0.0693	0.07363	0.06698	0.07398	0.0694	0.07338	0.06945	0.066	0.07283	0.07673	0.066
4:00:00 AM	0.06355	0.06355	0.06493	0.0659	0.06658	0.06678	0.06355	0.06425	0.0645	0.0667	0.06673	0.0709	0.0645	0.07123	0.0668	0.07065	0.06688	0.06355	0.07013	0.07388	0.06355
5:00:00 AM	0.06273	0.06273	0.0641	0.06508	0.06575	0.06595	0.06273	0.06348	0.06375	0.06588	0.0659	0.07048	0.06375	0.0709	0.066	0.07025	0.06608	0.06273	0.06973	0.07383	0.06273
6:00:00 AM	0.06318	0.06318	0.06463	0.06568	0.06638	0.06658	0.06318	0.06395	0.0642	0.06653	0.06655	0.071	0.0642	0.07143	0.06665	0.07078	0.0667	0.06318	0.07023	0.07438	0.06318
7:00:00 AM	0.06488	0.06488	0.06648	0.0676	0.06838	0.0686	0.06488	0.0657	0.06598	0.06853	0.06855	0.07325	0.06598	0.0737	0.06868	0.073	0.06873	0.06488	0.07243	0.07688	0.06488
8:00:00 AM	0.0667	0.0667	0.06838	0.0696	0.0704	0.07065	0.0667	0.0675	0.06778	0.07055	0.07058	0.07505	0.06778	0.07545	0.07068	0.07478	0.07075	0.0667	0.0742	0.07853	0.0667
9:00:00 AM	0.0743	0.0743	0.07625	0.07763	0.07858	0.07885	0.0743	0.07508	0.07535	0.07873	0.07875	0.0826	0.07535	0.08295	0.07885	0.0823	0.07893	0.0743	0.0817	0.08583	0.0743
10:00:00 AM	0.08028	0.08028	0.08228	0.08373	0.08468	0.08498	0.08028	0.0809	0.0811	0.08483	0.08485	0.08708	0.0811	0.08725	0.08493	0.08675	0.08498	0.08028	0.08623	0.0893	0.08028
11:00:00 AM	0.0843	0.0843	0.08628	0.0877	0.08863	0.08893	0.0843	0.08483	0.085	0.08875	0.08878	0.09023	0.085	0.09033	0.08885	0.0899	0.08888	0.0843	0.08943	0.092	0.0843
12:00:00 PM	0.16168	0.16168	0.16548	0.1682	0.16998	0.17053	0.16168	0.16255	0.16285	0.1702	0.17025	0.1719	0.16285	0.17203	0.17033	0.17135	0.1704	0.16168	0.1705	0.17475	0.16168
1:00:00 PM	0.2587	0.2587	0.26443	0.26853	0.27113	0.27188	0.2587	0.25963	0.25993	0.27138	0.27145	0.2706	0.25993	0.27055	0.27153	0.26985	0.2716	0.2587	0.2688	0.27315	0.2587
2:00:00 PM	0.19838	0.19838	0.20278	0.20595	0.20793	0.20845	0.19838	0.19905	0.19928	0.20813	0.20818	0.20718	0.19928	0.20715	0.20823	0.20665	0.20828	0.19838	0.20588	0.2091	0.19838
3:00:00 PM	0.15863	0.15863	0.1624	0.1651	0.1668	0.16728	0.15863	0.15915	0.15933	0.16695	0.167	0.16583	0.15933	0.16573	0.16705	0.16535	0.16708	0.15863	0.1647	0.1672	0.15863
4:00:00 PM	0.1489	0.1489	0.15288	0.15575	0.15755	0.15805	0.1489	0.14963	0.14988	0.15775	0.15783	0.15775	0.14988	0.15783	0.15788	0.15725	0.15795	0.1489	0.15653	0.16008	0.1489
5:00:00 PM	0.15625	0.15625	0.1597	0.16218	0.16368	0.16405	0.15625	0.1566	0.1567	0.1638	0.16388	0.1612	0.1567	0.1611	0.16385	0.16085	0.1639	0.15625	0.16038	0.16195	0.15625
6:00:00 PM	0.14	0.14	0.14308	0.1453	0.14665	0.14698	0.14	0.14045	0.1406	0.14678	0.14683	0.14553	0.1406	0.14555	0.14685	0.14523	0.1469	0.14	0.14475	0.14685	0.14
7:00:00 PM	0.1065	0.1065	0.1088	0.11045	0.11145	0.11168	0.1065	0.10685	0.10695	0.11155	0.11158	0.1105	0.10695	0.11053	0.1116	0.1103	0.11163	0.1065	0.10995	0.11153	0.1065
8:00:00 PM	0.09063	0.09063	0.09258	0.094	0.09485	0.09503	0.09063	0.09093	0.091	0.09493	0.09495	0.09405	0.091	0.09405	0.09498	0.09385	0.095	0.09063	0.09355	0.0949	0.09063
9:00:00 PM	0.12403	0.12403	0.12665	0.12855	0.12973	0.13003	0.12403	0.12465	0.12488	0.12988	0.1299	0.13085	0.12488	0.13103	0.12998	0.13055	0.13003	0.12403	0.13	0.13303	0.12403
10:00:00 PM	0.1041	0.1041	0.1063	0.1079	0.10888	0.10913	0.1041	0.10463	0.1048	0.109	0.10903	0.10983	0.1048	0.10998	0.10908	0.10958	0.10913	0.1041	0.10913	0.11165	0.1041
11:00:00 PM	0.0737	0.0737	0.07525	0.07635	0.07705	0.07723	0.0737	0.07418	0.07435	0.07715	0.07718	0.07865	0.07435	0.07885	0.07723	0.07848	0.07728	0.0737	0.0781	0.08048	0.0737
12:00:00 AM	0.0769	0.0769	0.07843	0.0795	0.0802	0.08035	0.0769	0.07745	0.07763	0.0803	0.08033	0.0822	0.07763	0.08245	0.0804	0.08203	0.08045	0.0769	0.08168	0.0843	0.0769

Table D.14 – Case 8 Generation D-LMP Prices

Hour	Cost of Energy (USD/MWh)	Gen DLMPs (USD/MWh) Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	66.85	66.85	68.30	69.35	70.08	70.33	66.85	67.58	67.80	70.20	70.23	74.40	67.80	74.73	70.33	74.13	70.38	66.85	73.58	77.38	66.85
2:00:00 AM	64.65	64.65	66.05	67.08	67.78	68.00	64.65	65.35	65.58	67.90	67.93	72.00	65.58	72.30	68.03	71.73	68.08	64.65	71.20	74.90	64.65
3:00:00 AM	66.00	66.00	67.43	68.43	69.13	69.35	66.00	66.73	66.98	69.28	69.30	73.63	66.98	73.98	69.40	73.38	69.45	66.00	72.83	76.73	66.00
4:00:00 AM	63.55	63.55	64.93	65.90	66.58	66.78	63.55	64.25	64.50	66.70	66.73	70.90	64.50	71.23	66.80	70.65	66.88	63.55	70.13	73.88	63.55
5:00:00 AM	62.73	62.73	64.10	65.08	65.75	65.95	62.73	63.48	63.75	65.88	65.90	70.48	63.75	70.90	66.00	70.25	66.08	62.73	69.73	73.83	62.73
6:00:00 AM	63.18	63.18	64.63	65.68	66.38	66.58	63.18	63.95	64.20	66.53	66.55	71.00	64.20	71.43	66.65	70.78	66.70	63.18	70.23	74.38	63.18
7:00:00 AM	64.88	64.88	66.48	69.22	70.00	69.64	64.88	66.27	66.54	68.53	68.65	73.77	66.54	74.27	68.90	73.00	68.95	64.88	72.43	79.13	64.88
8:00:00 AM	66.70	66.70	68.38	87.58	88.38	82.48	66.70	74.15	74.42	70.55	71.75	81.15	74.42	82.10	73.39	74.78	73.46	66.70	74.20	102.71	66.70
9:00:00 AM	74.30	74.30	76.25	113.21	114.16	103.08	74.30	89.09	89.36	78.73	81.31	95.49	89.36	96.96	84.70	82.30	84.78	74.30	81.70	132.15	74.30
10:00:00 AM	80.28	80.28	82.28	141.31	142.26	125.93	80.28	105.58	105.78	84.83	89.57	109.89	105.78	111.93	95.59	86.75	95.64	80.28	86.23	161.36	80.28
11:00:00 AM	84.30	84.30	86.28	158.04	158.96	140.28	84.30	116.60	116.77	88.75	95.06	119.68	116.77	122.10	102.90	89.90	102.92	84.30	89.43	178.07	84.30
12:00:00 PM	161.68	161.68	165.48	242.42	244.19	225.15	161.68	196.63	196.93	170.20	177.07	203.53	196.93	206.11	185.51	171.35	185.59	161.68	170.50	264.96	161.68
1:00:00 PM	258.70	258.70	264.43	346.06	348.66	329.35	258.70	295.75	296.05	271.38	278.75	304.16	296.05	306.68	287.73	269.85	287.81	258.70	268.80	366.87	258.70
2:00:00 PM	198.38	198.38	202.78	281.95	283.92	264.59	198.38	234.22	234.45	208.13	215.25	239.83	234.45	242.32	223.95	206.65	224.00	198.38	205.88	301.20	198.38
3:00:00 PM	158.63	158.63	162.40	230.66	232.36	214.67	158.63	188.18	188.36	166.95	172.67	192.71	188.36	194.76	179.77	165.35	179.79	158.63	164.70	248.09	158.63
4:00:00 PM	148.90	148.90	152.88	177.01	178.81	172.13	148.90	157.58	157.83	157.75	159.24	165.05	157.83	165.78	161.13	157.25	161.21	148.90	156.53	188.49	148.90
5:00:00 PM	156.25	156.25	159.70	206.78	208.28	194.96	156.25	174.77	174.87	163.80	167.25	177.95	174.87	179.27	171.54	160.85	171.59	156.25	160.38	219.07	156.25
6:00:00 PM	140.00	140.00	143.08	172.90	174.25	165.48	140.00	151.01	151.16	146.78	148.72	155.23	151.16	156.11	151.21	145.23	151.26	140.00	144.75	183.31	140.00
7:00:00 PM	106.50	106.50	108.80	117.18	118.18	116.01	106.50	109.24	109.34	111.55	111.99	112.69	109.34	112.92	112.56	110.30	112.59	106.50	109.95	120.77	106.50
8:00:00 PM	90.63	90.63	92.58	94.00	94.85	95.03	90.63	90.93	91.00	94.93	94.95	94.05	91.00	94.05	94.98	93.85	95.00	90.63	93.55	94.90	90.63
9:00:00 PM	124.03	124.03	126.65	128.55	129.73	130.03	124.03	124.65	124.88	129.88	129.90	130.85	124.88	131.03	129.98	130.55	130.03	124.03	130.00	133.03	124.03
10:00:00 PM	104.10	104.10	106.30	107.90	108.88	109.13	104.10	104.63	104.80	109.00	109.03	109.83	104.80	109.98	109.08	109.58	109.13	104.10	109.13	111.65	104.10
11:00:00 PM	73.70	73.70	75.25	76.35	77.05	77.23	73.70	74.18	74.35	77.15	77.18	78.65	74.35	78.85	77.23	78.48	77.28	73.70	78.10	80.48	73.70
12:00:00 AM	76.90	76.90	78.43	79.50	80.20	80.35	76.90	77.45	77.63	80.30	80.33	82.20	77.63	82.45	80.40	82.03	80.45	76.90	81.68	84.30	76.90

Table D.15 – Case 8 Per Unit Voltage

	Voltage (PU)																			
Hour	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11	Bus 12	Bus 13	Bus 14	Bus 15	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
1:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
2:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
3:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
4:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.95	0.97	1.00	0.95	0.92	1.00
5:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
6:00:00 AM	1.00	0.99	0.97	0.97	0.97	1.00	0.99	0.99	0.97	0.97	0.94	0.99	0.94	0.97	0.94	0.97	1.00	0.95	0.92	1.00
7:00:00 AM	1.00	0.98	0.97	0.97	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.94	0.91	1.00
8:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.94	0.99	0.94	0.96	0.94	0.96	1.00	0.95	0.92	1.00
9:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	0.99	0.99	0.96	0.96	0.95	0.99	0.94	0.96	0.95	0.96	1.00	0.95	0.92	1.00
10:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.95	0.96	0.96	0.96	1.00	0.96	0.94	1.00
11:00:00 AM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.96	0.95	1.00
12:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.97	0.95	1.00
1:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.97	1.00	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
2:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.97	1.00	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
3:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.97	1.00	0.97	0.96	0.97	0.96	1.00	0.97	0.96	1.00
4:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	0.99	0.96	0.96	0.96	0.99	0.96	0.96	0.96	0.96	1.00	0.97	0.95	1.00
5:00:00 PM	1.00	0.98	0.97	0.96	0.96	1.00	1.00	1.00	0.96	0.96	0.98	1.00	0.98	0.96	0.98	0.96	1.00	0.98	0.97	1.00
6:00:00 PM	1.00	0.98	0.97	0.97	0.96	1.00	1.00	1.00	0.97	0.96	0.97	1.00	0.97	0.97	0.97	0.97	1.00	0.98	0.96	1.00
7:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.98	0.97	1.00	0.98	0.96	1.00
8:00:00 PM	1.00	0.99	0.97	0.97	0.97	1.00	1.00	1.00	0.97	0.97	0.97	1.00	0.97	0.97	0.98	0.97	1.00	0.98	0.96	1.00
9:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
10:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.97	0.99	0.97	0.97	0.97	0.97	1.00	0.97	0.95	1.00
11:00:00 PM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00
12:00:00 AM	1.00	0.99	0.98	0.97	0.97	1.00	1.00	0.99	0.97	0.97	0.96	0.99	0.96	0.97	0.96	0.97	1.00	0.97	0.95	1.00

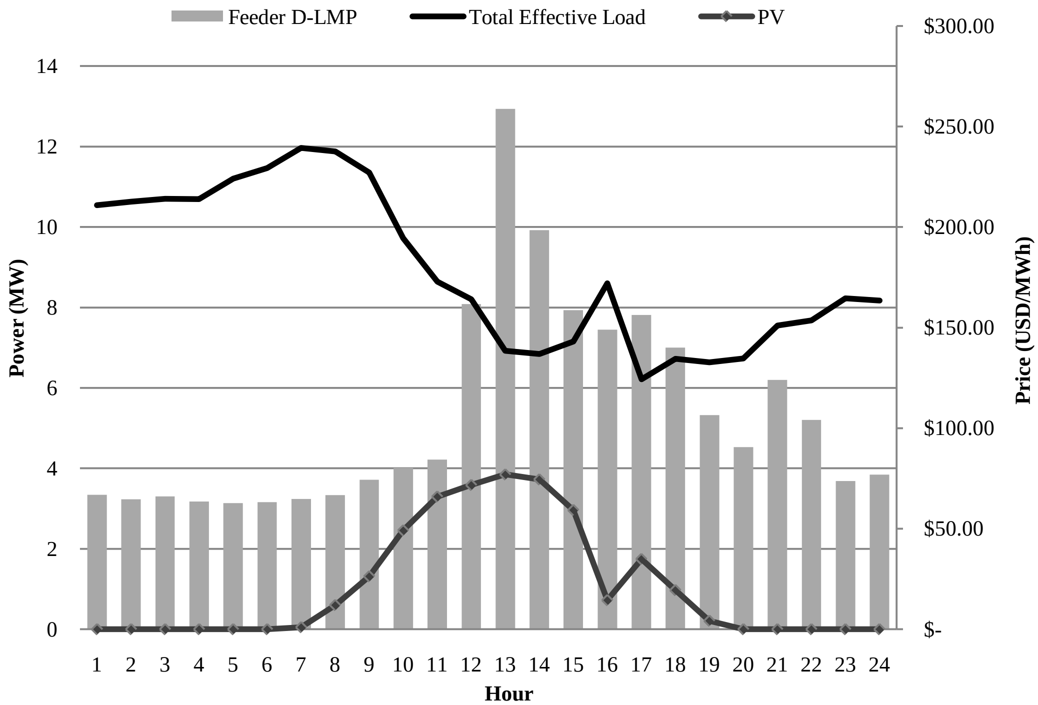

Figure D.8 – Case 8 System Data

Table D.16 – Revenue Streams for Case 8

Cost Stream	Cost (USD)
D-LMP Revenue	$26,540.05
Energy	$25,161.36
Losses	$1,378.69
Flat-Rate, by Sector Revenue	$21,414.72
System Storage Savings	$2,537.68
DG Payments	$5,428.67