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Smart Grid Technologies for Efficiency Improvement of Integrated Industrial Electric System

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Smart Grid Technologies for Efficiency Improvement of Integrated Industrial Electric System

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Science
in
Engineering Science
Electrical Engineering

by

Spandana Balani

B.Tech. Padmasri Dr. B. V. Raju Institute of Technology, 2008

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Abstract

The purpose of this research is to identify the need of Smart Grid Technologies in communication between industrial plants with co-generation capability and the electric utilities in providing the most optimum scheme for buying and selling of electricity in such a way that the fuel consumption is minimized, reliability is increased, and time to restore the system is reduced. A typical industrial plant load profile based on statistical mean and variance of industrial plants' load requirement is developed, and used in determining the minimum cost of producing the next megawatt-hours by a typical electric utility. The 24-hour load profile and optimal power flow program are used to simulate the IEEE 39 Bus Test System. The methodology for the use of smart grid technology in fuel saving is documented in the thesis. The results obtained from this research shall be extended to include several industrial plants served by electric utilities in future work by the UNO research team.

KEY WORDS:

Industrial Load Profile, Fuel Cost, Smart Grid Transaction, IEEE 39-Bus Test System, Cogeneration, MATPOWER, OPF, Economic Dispatch

1. Introduction

1.1 Background

The electric utility is the basic supplier of electrical energy; everyone does business with it and is dependent upon its product [1]. The traditional utility industry can be characterized as vertically integrated industry composed mostly of publicly regulated and protected regional monopolies, which are assigned with the right and responsibility to produce and distribute sufficient, reliable, and high quality electricity to meet consumer demand in the most economical fashion. To make it possible in the current scenario, the system has to become more efficient as we proceed in time and as reliance on availability of electricity gain ever increasing importance. The term Efficiency is sometimes so vague, because it has two meanings - one in engineering contexts and another in economic contexts. In the study, efficiency is used to refer the engineering view of the word, whereas economic efficiency can be used when dealing in economic sense. Engineering efficiency is the amount of useful work output that a process or a piece of equipment performs with a unit of energy input. A process or a machine is said to be more energy efficient than another if it uses less energy to produce the same output. For instance, a distillation column that requires 20,000 Btu to process a barrel of crude oil is more efficient than the one which requires 30,000 Btu per barrel. On the other hand, Economic efficiency emphasizes the cost performance of equipment or process. A machine or a process is said to be more economically efficient than another if it costs less by producing greater benefits. For the above considered example, the 20,000 Btu/barrel distillation column is more efficient than the 30,000 Btu/barrel column only if it processes the oil at a lower cost [1].

The efficiency of electric industry may be improved by forecasting the future demand and preferably minimizing it through comprehensive system planning and/or educating the user with new technologies and techniques. One such technique to improve efficiency is described in the thesis. And turning up to forecasting, it can be explained as an effort to predict the future, considering the results that are almost always qualified or that are based on the past patterns of behavior. The forecast process is generally determined by the means of assumptions [2]. The further details about the load profile forecast techniques that are available will be described in Chapter 3 – Industrial Load Modeling.

1.2 Integrated Industrial Electric System

The main objective of the thesis is to find an optimum solution that maximizes the profit in fuel savings by the integrated industrial electric systems which consists of both the electricity service provider and the Industrial user. While industrial plants and electric utilities follow two different business models and perhaps, benefit for one is considered as cost for the other. Our work focuses on the integrated fuel savings of the system that consists of both entities in the system. Figure 1.1 depicts the model of the integrated system consisting of one Industrial plant and an electric utility. The two-way arrows in Figure 1.1 depict the traditional flow of electricity between industrial load and electric utility without use of smart grid technology. The results of the study shall be extended to the cases where we consider more than one plant in the integrated system. Furthermore, we shall also consider special cases of the “Integrated Systems Approach” in finding the maximum benefits for only the utility or each of the industrial plants.

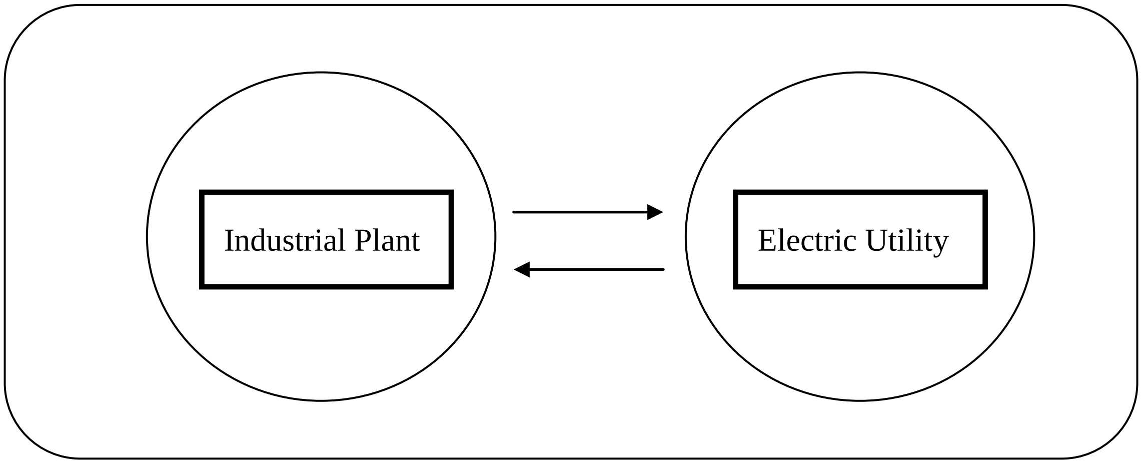


Figure 1.1 Integrated Industrial Electric System

1.2.1 Electric Utility

The electric utilities sketch the supply to meet the forecasted demand through generator dispatch which is considered as a primary function of day-to-day operations in an electric utility. The supply/generating units on the system include – customer-owned, independent power producers or utility-owned generation plants. For a dispatch arrangement, the operator considers the cost or contract requirement of each unit and groups them to – a base load, load follow, or peaking unit. The lowest-cost units are dispatched to "base load" criteria. Then, higher-cost units are dispatched as load increases during period. Other units may be required to "load follow" or for "peaking" [4]. To meet the system demand effectively and reliably, the operator utilizes the resources of the both base load and peaking units and the required total generation can be determined by – (a) forecasting the demand, and (b) collecting the information that affects the contracts to buy or sell power. The forecast process used in the study is described in Chapter 3 and the details about System Lambda (information required to buy or sell power) is presented in Chapter 3, 5. The process of deciding the units which meet the demand follow some factors which are portrayed in Figure 1.2.

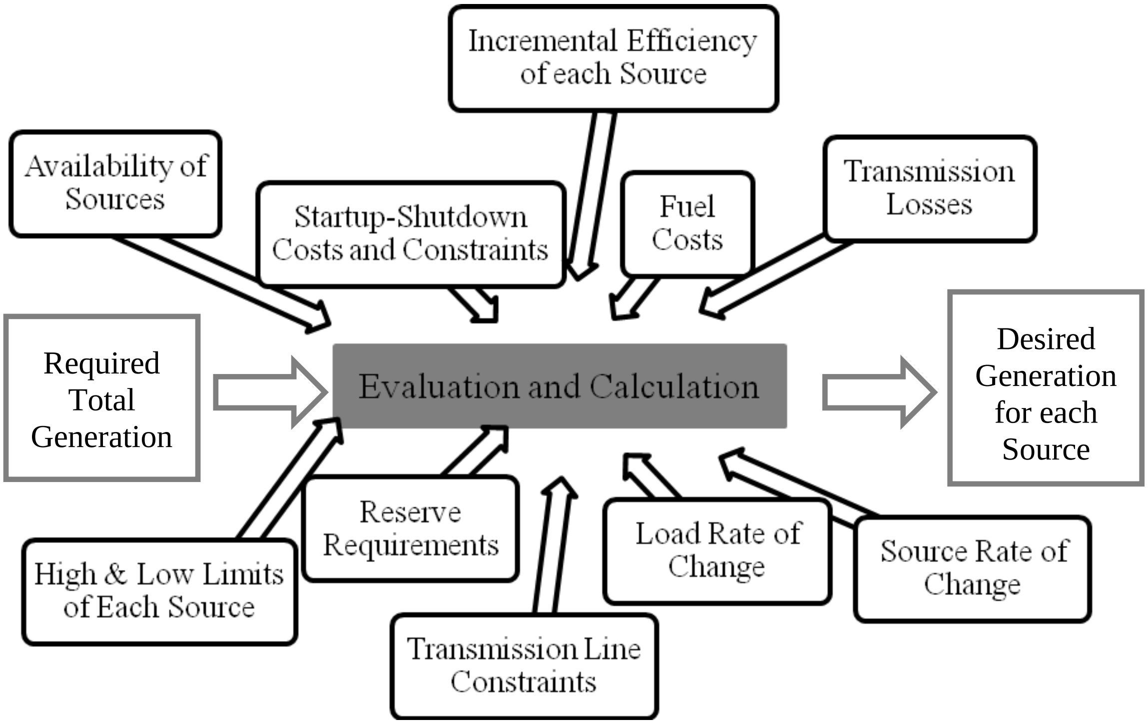


Figure 1.2 Generator dispatch factors [4]

When the supply lessens and the price increases, managing the demand to match available supply becomes a cost-effective activity, generally termed as Load Management. Load management programs are designed and implemented mostly for residential loads and customers. Industrial loads are not very often thought of as possible for load management applications though the power used in the industries is complex than that of the residential sector [2]. But, with increase in Megawatt produced by co-generation, availability of flexible AC transmission system (FACTS) devices, and the potential for the electric industry in becoming deregulated, extending load management to the industrial loads is a wise move.

When the demand is more than maximum generating capacity, the transmission system operators must either find additional supplies of energy or find ways to reduce the load, which therefore prevents the system instability and the occurrence of blackout. One way to achieve load management is to use special tariffs to attract consumers – both residential and industrial. Another is the utility's involvement in the real time. The summary of load management and the possible classification of utility load management techniques are studied under the topic industrial load management described in the third section of this chapter.

The other sophisticated techniques that are available to control use of electricity may be categorized as – those that reduce demand by increasing appliance efficiency and reducing waste, those that direct and control load to make character of demand curves match the character of supply, and end-use management. Of these the main role of managing the demand of a utility system is to reduce the peak load. Tariff during peak demand periods have induced industries to adjust scheduling for full-scale production and maintenance activities, increase level of productive off-peak periods and generate their own power from industrial by-products. The availability of excess power during off-peak periods can be sold out to neighboring utilities at lower rates, which increases the dollars for both industry and the utilities. The extreme shortfall in power availability in a grid can also be eliminated by load shedding; but, this may not be well-suited for large industrial consumers though a load-shedding cooperative (Energy Users Report 1980) organized among four large utility customers in Southern California was able to reduce its peak demand by 25 percent using electronic data processing equipment to monitor and control energy consumption in ten different buildings owned by these customers. By shedding load six times during the first year of operation, the cooperative was able to reduce utility capacity requirements by 4MW [3].

When the load cannot be reduced or the additional supply of electricity to meet the demand is not possible there is an occurrence of blackout, and a so called black start needs to be performed to bootstrap the power grid into operation. In the United States, currently there are three methods of procuring black start – (a) Cost of Service – used by California Independent System Operator (CAISO), the PJM Interconnection, and the New York Independent System Operator (NYISO). (b) Flat rate payment – used by the Independent System Operator of New England (ISO-NE). (c) Competitive procurement – used by the Electric Reliability Council of Texas (ERCOT) [9]. Utilizing the literature, the black start guidelines are proposed which increase the system efficiency and shall decrease the number of days between system collapse and its restoration. The purpose of this thesis is to make use of Smart Grid Technologies in communication, between industrial plants with co-generation capability and electric utilities in providing the most optimum scheme for buying and selling of electricity in such a way that the fuel consumption is minimized, reliability is increased, and time to restore the system is reduced. While economic consideration of “integrated systems approach” in minimizing total fuel consumption is of vital importance, reducing the “time to restore” the system is of extreme importance in Louisiana that has the largest Industrial concentration along the coast and the Mississippi river when compared to the rest of the nation. We shall address these points in subsequent sections of the thesis. An integrated system approach gives prior importance to electric utility, which is then followed by the Industrial load.

1.2.2 Industrial Load and Types of Industries

Loads may be classified broadly as residential, commercial, industrial and other. Other customers include municipalities or divisions of state and federal governments using energy for street and highway lighting. In, addition, sales to public authorities and to railroads and railways, sales for resale, and interdepartmental sales also come under the “other” classification.

The Industries in United States could be recognized in four categories. However for this research, based on the industries served by electric utilities in Louisiana, we shall focus only on certain categories.

The four major types are –

(a) Primary industry - largely raw material extraction industries such as mining and farming

(b) Secondary industry - involving refining, construction and manufacturing

(c) Tertiary industry - which deals with services and distribution of manufactured goods

(d) Quaternary industry - which focuses on technological research and development

Classes (a) and (d) are not included in this study and we mainly focus on class (b) and to a lesser degree on class (c) of the above classification. From electric utilities side of the equation, industrial loads are further classified.

1.2.2.1 Industrial Load Classification

Industrial loads are divided into two main levels, viz., Linear & Non-linear loads. [2]

Figure 1.3 depicts different classifications of load.

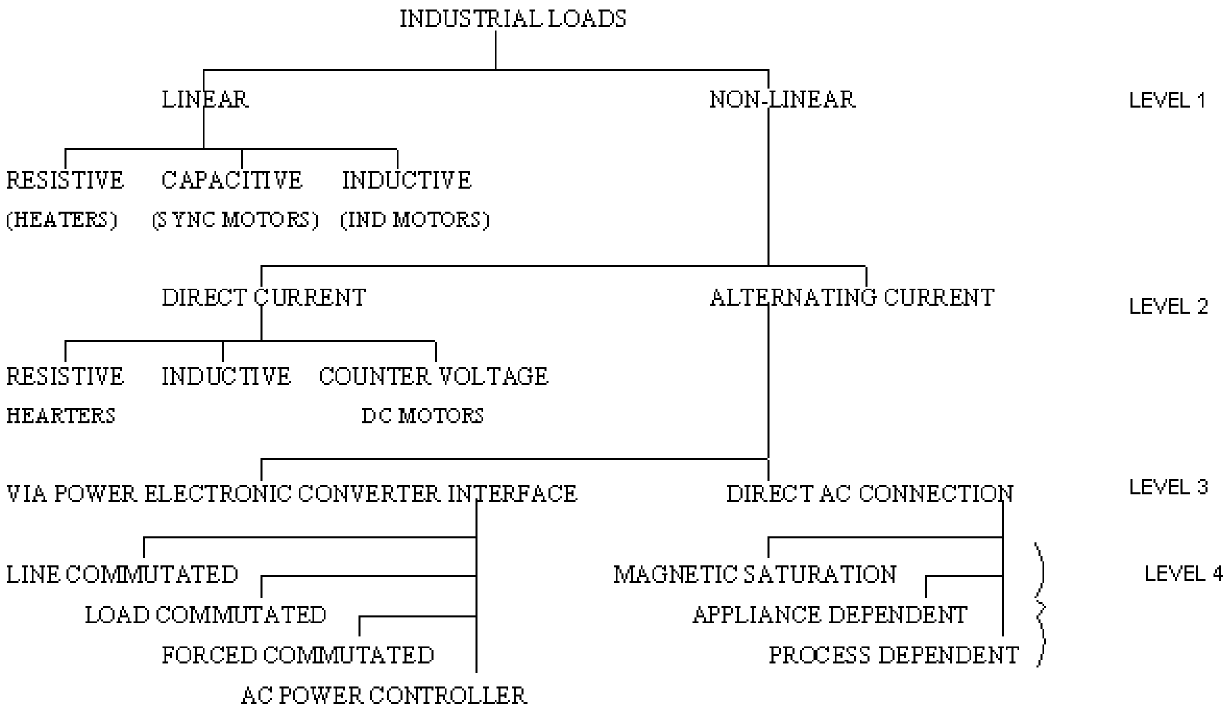


Figure 1.3 Classification of Industrial Loads [1][2]

Based on load management action, industrial loads are divided into:

a. Controllable loads—that can be subjected to any type of load management (LM) actions.

b. fixed time loads—that occur at specified time periods and cannot be controlled or subjected to LM actions (e.g., lighting load).

Controllable loads can be grouped into process independent loads, process-interlocked loads, storage constraint loads and sequential loads [2].

Load management programs are designed and implemented generally for residential loads and customers [1]. The Industrial loads are not very often thought of as possible for load management applications. The power used in the industries is more complex than that of the residential sector, because of the heavy performance. However, with increase in MW produced by co-generation, availability of flexible AC transmission system (FACTS) devices, and the potential for the electric industry in becoming deregulated, it is wise to extend load management to the industrial loads as well.

The goal of any load-management program is to maintain, as nearly as possible, a constant level of load, thereby allowing the system “load factor” to approach 100%. The important benefits of load management are reduction in maximum demand, reduction in power loss, better equipment utilization and saving through reduced maximum demand charges [5].

Load shifting, one of the simplest methods of load management, is to reduce customer demand during the peak period by shifting the use of appliances and equipment to partial peak and off-peak periods. Here no loads are being switched off, but only shifted or rescheduled, and hence the total production is not affected. Using reference [7], a summary of load Management techniques is presented in Table 1.1.

Utility Controlled		**Customer Controlled**	
Supply Side	**Demand Side**	**Backup Storage**	**End-Use Modification**
Energy Storage	Interruptible Power	On-peak self-Generation	Load Deferral
Power Pooling	Remote Control of Customer Load	Customer Energy Storage	Load Curtailment
			Under contract
			Voluntary response to incentives

Table 1.1 Possible classification of utility-load management techniques [7]

The Industrial user for the moment comprise of the utility and manufacturing plants in Louisiana. Chapter 2, 3 gives more information about Industries and the Industrial loads in Louisiana, and the best chosen option for optimizing the costs associated by the industrial plants. Knowledge about Smart Grid described in Section 1.3 is essential in order to understand the methodology development in the study for the profitable scheme that electricity provider and industrial user can follow to exchange the available electricity.

1.3 Overview of Smart Grids

To meet the increasing electricity demands, building more power plants and addition of transmission and distribution facilities have been used for several years. However, these modifications are expensive, costing up to $2,000 per kilowatt of capacity. The average home consumes around 2 kilowatts of power per hour, so building electrical facilities to serve 1,000 homes could cost $4 million. Moreover, building more power plants cannot be achieved easily due to regulatory and environmental concerns and do not seem to be an acceptable approach to the rising demand for electricity. Alternatively, revising the current power distribution network and markets to use the energy we have in a more efficient way, and harness renewable energy resources such as **wind** and **solar** power could be the best solution instead of producing more energy. This alternative and thoughtful approach should be kept in mind by those who are working on and who all are interested in implementation of **smart grid technologies**, as a viable approach for increasing residential or industrial customer efficiencies. Figure 1.4 is the text box with EISA (Energy Independence and Security Act) policy which depicts the need for smart grid.

Energy Independence and Security Act of 2007 Sec. 1301. Policy on Modernization of Electricity Grid

… support the modernization of the Nation’s electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve each of the following, which together characterize a smart grid:

(1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.

(2) Dynamic optimization of grid operations and resources, with full cyber-security.

(3) Deployment and integration of distributed resources and generation, including renewable resources.

(4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.

(5) Deployment of “smart” technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.

(6) Integration of “smart” appliances and consumer devices.

(7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.

(8) Provision to consumers of timely information and control options.

(9) Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.

(10) Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services.

Figure 1.4 EISA 2007 Sec. 1301. Policy on Modernization of Electricity [7]

1.3.1 What is smart grid

The term “Smart Grid” was coined by **Andres E. Carvallo** on April 24, 2007 at an IDC (International Data Corporation) energy conference in Chicago, where he presented the Smart Grid as the *combination of energy, communications, software and hardware.* His definition of a Smart Grid is that it is the integration of an electric grid, a communications network, software, and hardware to monitor, control and manage the creation, distribution, storage and consumption of energy. The 21st century Smart Grid reaches every electric element, it is self-healing, it is interactive, and it is distributed.

“The term ‘Smart Grid’ refers to a modernization of the electricity delivery system so it monitors, protects, and automatically optimizes the operation of its interconnected elements—from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances, and other household devices [7].

“The Smart Grid will be characterized by a two-way flow of electricity and information to create an automated, widely distributed energy delivery network. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and enable the near instantaneous balance of supply and demand at the device level.” [6]

A Smart Grid is the electricity delivery system (from point of generation to point of consumption) integrated with communications and information technology for enhanced grid operations, customer services, and environmental benefits [11].

The Smart Grid, therefore from the above definitions is summarized in the text box of Figure 1.5

The Smart Grid, in quintessence, is a blend of communications and electrical capabilities that consent to utilities to recognize, optimize, and standardize energy usage, costs of demand and supply, and the overall reliability & efficiency of the system. This enhanced technology allows electricity suppliers to interact with the power delivery system and reveal where electricity is being used and from where it can be drawn during times of crisis or peak demand.

Figure 1.5 Gist of the Smart Grid [6][7][11]

In order to achieve a modern grid, a wide range of technologies have to be developed and implemented. These are the essential technologies that must be implemented by the grid operators and the managers to have tools and training that is needed to operate modern grid.

1.3.2 Smart Grid Technologies (SGT)

The US Department of Energy defines the following five fundamental technologies that derive the Smart Grid systems:

- *Integrated communications* – connecting components to open architecture for real-time information and control, allowing every part of the grid to both ‘talk’ and ‘listen’

- *Sensing and measurement technologies* – to support faster and more accurate response such as remote monitoring, time-of-use pricing and demand-side management

- *Advanced components* – to apply the latest research in superconductivity, storage, power electronics and diagnostics

- *Advanced control methods* – to monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event

- *Improved interfaces and decision support* – to amplify human decision-making, transforming grid operators and managers quite literally into visionaries when it comes to seeing into their systems [7].

The above written five technologies sum up to make the smart grid more efficient and reliable than the present grid. Table 1.2 summarizes the difference between the present grid and the smart grid [10].

Characteristic	Today’s Grid	Smart Grid
Enables active participation by consumers	Consumers are uninformed and non-participative with power system	Informed, involved and active consumers – demand response and distributed energy resources
Accommodates all generation and storage options	Dominated by central generation – many obstacles for distributed energy resources interconnection	Many distributed energy resources with plug and play convenience focus on renewable
Enables new products, services, and markets	Limited wholesale markets, not well integrated – limited opportunities for consumers	Mature wholesale markets, growth of new electricity markets for consumers
Provides power quality for the digital economy	Focus on outages – slow response to power quality issues	Power quality is a priority with a variety of quality/price options – rapid resolution of issues
Optimizes asset utilization and operate efficiently	Little integration of operational data with asset management – business process	Greatly expanded data acquisition of grid parameters – focus on prevention minimizing impact to consumers
Anticipates & responds to system disturbances (self-heals)	Responds to prevent further damage – focus is on protecting assets following faults	Automatically detects and responds to problems – focus on prevention, minimizing impact to consumer
Operates resiliently against attack and natural disaster	Vulnerable to malicious acts of terror and natural disasters	Resilient to attack and natural disasters with rapid restoration capabilities

Table 1.2 Today’s grid and Smart grid [10]

Smart grid technologies allow us to manage energy usage and save money by giving the liberty to choose when and how to use our electricity. It is this feature of the technology that allows us to optimize the integrated demand-supply chain use of electricity. A year-long study by the U.S. Department of Energy showed that real-time pricing information provided by the smart meter help consumers reduce their electricity costs 10% on average and 15% on peak consumption [7].

1.3.3 Anticipated Savings using SGT

The grid as it exists today was originally designed more than fifty years ago, long before the creation of computer and telecommunication systems that we rely on today. The pressure that our increased power-needs exercise on the grid is shown through interruption of service and occasional blackouts, which pose significant economic and safety threats to our society. Smart grids have the potential to offer a number of advances, including some that automatically monitor and evaluate grid conditions, and report these conditions back to the utility's control room when they occur. Devices on the network can communicate with each other to automate re-routing and switching to avoid power lines with faults, and detect and even repair faults in wires before they lead to outages.

The smart grid also introduces a new level of communication between the consumer and the power suppliers. The current interface between the suppliers and the customer is the meter, which has remained basically the same, technologically-speaking, for the past century, and cannot communicate information to or from the consumer. Smart grids, however, allow power companies and consumers to gather precise information about the quantity and timing of household consumption, and enable consumers to receive information, such as real-time pricing and emergency grid requests to lower energy consumption [11].

Smart grid improvements will also integrate with intermittent energy sources that pose a challenge to the current system, like wind and solar power. New technologies will encourage consumers to invest in "distributed generation," or locally-generated power sources, such as solar panels on a home, to supplement their power needs [12]. Making such investments worthwhile to consumers also requires regulatory change to allow different pricing contracts. For example, a home could be powered by its own solar energy during the day, and the consumer could sell any extra energy produced by his or her panels back to the larger grid (this contract option is called "net metering"). The credit for the energy sold during the day may cover what the home uses that evening. Smart grids would also accommodate plug-in hybrid cars, allowing consumers to move away from petroleum-based transportation.

Despite all of the benefits offered by smart grids, such a dramatic change in technology and approach will not be immediately adopted by industry or by regulators. Pilot projects, such as one recently completed in the Pacific Northwest, are important opportunities for researchers and regulators to learn about the potential effects of smart grid technologies [10]

The Smart Grid Technologies that are proven efficient in reducing the growing energy needs of residential customers cannot be applicable for those of Industrial loads. The work conducted in the thesis – that is a part of more comprehensive study in the University of New Orleans Power and Energy Research Laboratory (PERL), proposes a way on how smart grid can benefit the Industrial customers. Figure 1.6 is a replica of Figure 1.1 with inclusion of Smart Grid Technologies as the means of two-way communication between the electricity service providers and the Industrial plants.

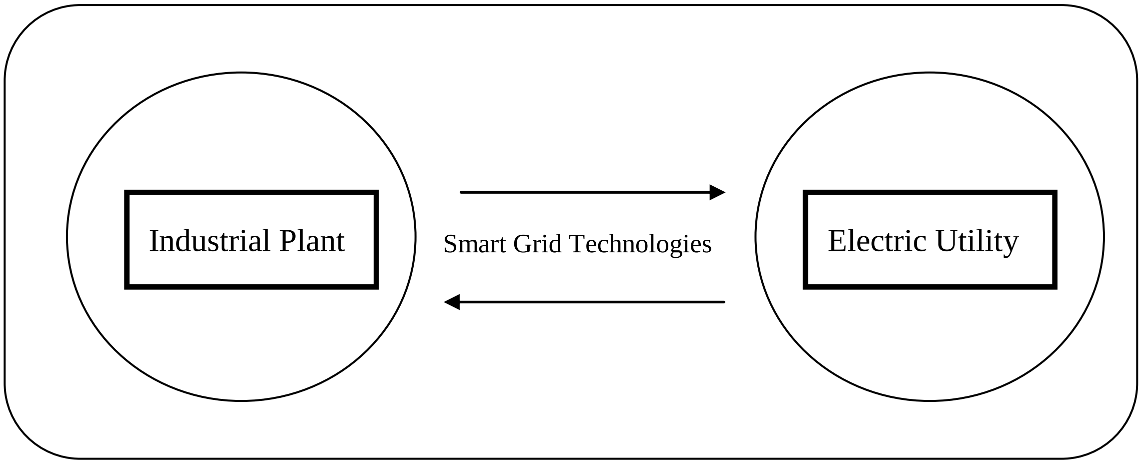


Figure 1.6 Integrated Industrial Systems with Smart Grid Technologies

1.4 Impact of Smart Grid Technologies on Economy

As U.S. industry in the digital age has become more dependent on high-quality energy delivery, our economic security for growth becomes more dependent on reliable energy [9]. For this reason, we must promote continuity of energy and reliability. The full deployment of Smart-Grid technologies will mitigate dramatically the billions of dollars lost by American businesses each year as a result of the power fluctuations, congestions, and failures of the current electrical grid. Increasing energy efficiency and reliability will be crucial to improving the competitiveness of American businesses in a global economy.

The capacity of optimization offered by the Smart Grid will improve energy delivery reliability, lower business costs, and reduce waste [9]. While residential consumers suffer what typically amount to minor inconveniences resulting from power blackouts, the impact of power inconsistency on industry can be devastating. One 2005 power outage in southern California disrupted an estimated $75 billion dollars in economic activity [11]. Massive power outages are occurring at an unprecedented frequency and industry is an unfortunate casualty. Application of the Smart Grid Technologies for optimizing system reliability and resume electrical normalcy in short order, or avoid a disruption entirely, will provide the energy security that industry requires to sustain an energy dependent economy. Like with residential consumers of electricity, businesses will reap similar benefits from implementation of SGT demand response capabilities. But by consumer and corporate empowerment, as well as its environmental impact, the Smart Grid is creating new markets as private industry develops energy efficient and intelligent appliances, smart meters, new communications capabilities, and passenger vehicles. The Department of Energy predicts that Smart Grid deployment will open a $100 billion market in smart technologies [8]. These new market technologies will lower consumer and corporate electricity costs, and have a dramatic impact on the environment through efficiency and resource utilization gains. The implementation of the Smart Grid creates approximately $2 trillion per year additional GDP [11]. Thus, industry is not only made more competitive and secure by the adoption of the Smart Grid, but it is afforded new market opportunities.

1.5 Contribution of Thesis

The main objective of the study is to evaluate the current electric utility operation and the fuel savings by use of smart grid technology in – coordinating electricity supply and demand, analyze the future trends of electricity supply and demand as the price of fuel increases and environmental issues gain more importance, and make suggestions to industrial customers and electric utilities for implementing optimum operation and fuel savings guidelines regarding the present and future investment alternatives. The study mainly focuses on the benefit of designing a user – (utility and customer) friendly system that increases the efficiency and reliability of the integrated transmission system, equally holding an eye on the cost of operation and restoration time after the occurrence of a blackout. This precisely means, ***Dollar Savings by using Smart Grid Technologies*** to optimally determine the cost of producing the next mega-watt hour of energy.

The information about smart grid technologies, industrial load management, and impact of smart grid technologies on economy is included in **Chapter 1**. The chapter further addresses the Department Of Energy defined smart grid technologies, notes on smart savings, industrial loads classification, the load models, and the load management techniques.

The **Chapter 2** provides a brief description of the industries operating in Louisiana, their load profiles and electric energy consumption patterns. The energy consumption and cost in operating a pulp and paper plant shall also be investigated based on the literature.

The industrial load model is studied in **Chapter 3**. Mathematics for representing industrial load profiles in general and a hypothetical pulp and paper manufacturing plant in particular are presented in this chapter. Then the chapter focuses on suitable mathematical load profile for describing a pair of industrial customer and an electric utility connected by smart grid technology. Once the load profile of the pair of industrial customer served by an electric utility is presented, we shall apply optimization techniques for finding the most profitable use of electricity when studied from industrial plant, electric utility, and/or the pair of electric utility and industrial plants "integrated systems approach" point of view. In implementing the optimization technique, we shall make use of the information that is available from smart grid technology.

In **Chapter 4**, we provide the description of test system represented by IEEE 39-Bus System is given and the collected data for its simulation.

Chapter 5 is devoted to simulating the model described in Chapter 3 using the Test System represented by the IEEE 39-Bus System. For simulating the proposed test systems, we shall use Mathworks – Matlab, Simulink; PSS/E or PowerWorld as the need arises. We shall simulate "what if scenarios" using different load profiles and optimization objective function in this chapter. Combination of the developed 24-hour load profile of Chapter 3 and optimal power flow programs are used to determine the minimum dollar per mega-watt hour of energy produced by the IEEE 39-Bus Test System.

Chapter 6 is devoted to summarizing the results obtained in Chapter 5 and to make concluding remarks for extension of the ideas presented in the thesis for study of large scale systems such as Entergy Transmission System. The feasibility study partially presented in this thesis is supported by funds available from Entergy Services Inc. We greatly appreciate their support of a graduate student and the Principal Investigator for conducting the research.

2. Manufacturing Industries

2.1 Discussion

This Chapter articulates about the utilities and the major manufacturing industries' operation and how much energy (fuel and electricity) is used by each sited industry. We provide information on generation capacity of Louisiana, which includes both utility and nonutility owned generation. And, we shall outline electricity pricing and utilization of major manufacturing plants – pulp and paper, petroleum refining, chemical, and steel manufacturing industries, then describe the reason for considering pulp and paper plant as the industrial load for the system.

The study about the Industries operating in LA is a significant part of the work since one of the objectives of the thesis is to develop the industrial plant load profile in order to find an optimum solution that maximizes the profit in fuel savings by the integrated industrial electric system.

The Industrial user and the Utility for the moment in the study comprise of the ones that are operating in state of Louisiana, and may later be extended to include the Utilities and the plants operating in USA. The ten largest plants by generation capacity in Louisiana are tabulated in Table 2.1.

	Plant	Net Summer Capacity	Operated by
1.	Willow Glen (Gas)	1,832	Entergy Gulf States Louisiana LLC
2.	Nine Mile point (Gas)	1,752	Entergy Louisiana Inc.
3.	Big Cajun 2	1,243	Louisiana Generating LLC
4.	R. S. Nelson	1,416	Entergy Golf States Louisiana LLC
5.	Little Gypsy	1,198	Entergy Louisiana Inc.
6.	Waterford 3 (Nuclear)	1,157	Entergy Louisiana Inc.
7.	Acadia Energy Centre	1,063	Acadia Power Partners
8.	River Bend (Nuclear)	970	Entergy Golf States Louisiana LLC
9.	Rode macher (Coal)	952	Cleco Power LLC
10.	Michoud	825	Energy New Orleans Inc.

Table 2.1 Ten largest plants in Louisiana by generation capacity

Almost every function of industry uses energy. Efficient use of this energy is affected by, among other things, available technology, capital investment, and the cost of energy. Cost of energy consumption changes by weather conditions and most importantly by international politics and population growth. Economic and population growth of developing countries has severely impacted energy pricing and its distribution to USA. The “critical gap” of energy that may be experienced in USA by 2020 is depicted in figure 2.1 through reference [13].

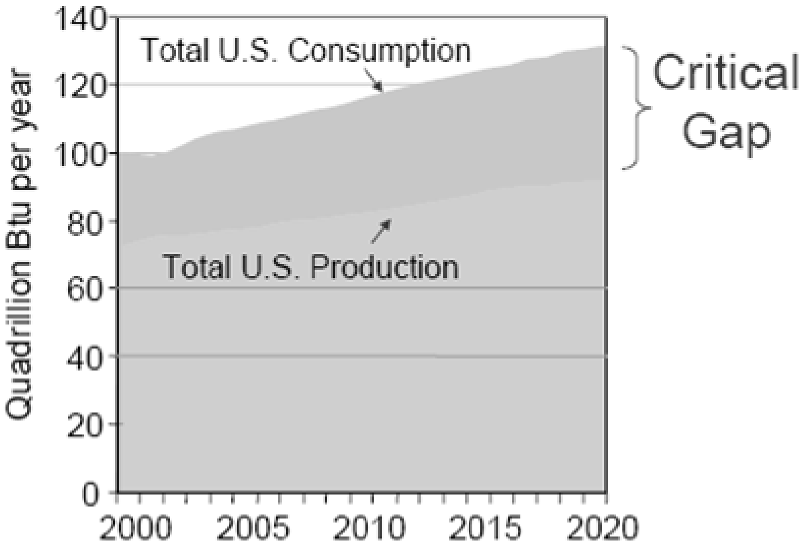


Figure 2.1 Total US energy production vs consumption, 2000-2020[36]

Since 1973, the cost of premium fuels such as petroleum distillates and natural gas has increased over a factor of three in real terms. In response, the industrial sector has taken numerous steps to reduce its energy use per unit of output. However, many opportunities still exist to use energy even more efficiently.

The chapter focuses on four industries that use the huge amount of energy comparative to others, and which are also the main industries in Louisiana. They are – Pulp and Paper manufacturing, Petroleum Refineries, Chemical and Steel manufacturing Industries. If it is assumed that conservation and the more efficient use of energy had any role to play in US manufacturing, it would be most apparent in these industries. In the recent past, these industries used nearly 10 quadrillion BTU (Quads) of final energy (about 43% of all energy used by industrial sector). Thus, these industries are likely to be the leaders in increasing energy efficiency.

2.2 Major Manufacturing Industries

The general classification of manufacturing industries is into nine categories:

- Oil and Gas Exploration and Production
- Mining
- Petroleum Refining
- Chemical, Petrochemical
- Pharmaceutical
- Paper and Pulp
- Agricultural Production
- Food Processing Electronics &
- Home Appliances

In 1981, U.S. industry used over 23 Quads of energy-bearing materials, mostly as fuel, but also, in some cases, as feedstock. Manufacturing accounted for about 75 percent of that total; mining accounted for another 12 percent; and agriculture and construction, another 6 percent. The four manufacturing industries studied in depth in the research accounted for about 57 percent of the total energy used in manufacturing, including 74 percent of the oil and 60 percent of the natural gas.

Between 1972 and 1981, American Industrial energy use declined by over 2Quads, and energy efficiency improved by almost 18% of production. Even more notable than the drop in absolute energy consumption was the decline in the rate of energy use compared to the rate from previous decade and if growth rates of that decade had continued, industrial energy use would have reached nearly 40 Quads by 1981 [15].

In the pulp and paper industry, total energy use has risen slightly since 1972. However, the industry is more energy self-sufficient, and energy use from purchased fuels has declined. The integrated mills that convert trees to pulp and then to paper are almost 25 percent more efficient now compared to early 70's. Mills that convert purchased pulp to paper are almost 20 percent more efficient. Much of this energy efficiency has shown up in decreased use of residual fuel oil (down 40% since 1972). Overall, the paper industry has exceeded its voluntary goal of 20-percent improvement by almost 5percentage points.

The petroleum refining industry has decreased its overall energy use per unit of output by 20.8 percent, primarily by reductions in natural gas use (down 37 percent since 1972) and distillate and residual fuel oil use (down 62 percent and 31 percent respectively). Based on 1972 production levels, the industry exceeded its voluntary goal of a 20-percent energy savings.

In the Chemical industry, energy use per unit of output has decreased by 24.2 percent since 1972 through decreased use of natural gas (down 24 percent) and residual fuel oil (down 42 percent). Compared to 1972 production levels, the industry exceeded its 1980 industry improvement by more than 10 percentage points.

The steel industry has decreased its use of energy per unit of output by 17 percent, mostly through decreased use of bituminous coal (down 35 percent) and metallurgical coke (down 36 percent)

According to the US Department of Energy, Energy information Administration (EIA), Manufacturing Energy Consumption Survey, Consumption of Energy 7988 - Report No. DOE/EIA-0512(88), May 1991; and State energy Data Report, Consumption Estimates 1960-1990 - Report No. DOE/EIA-0214(90), May1992, the pie chart in Figure 2.3 depicts the energy consumption by different industries. [13]

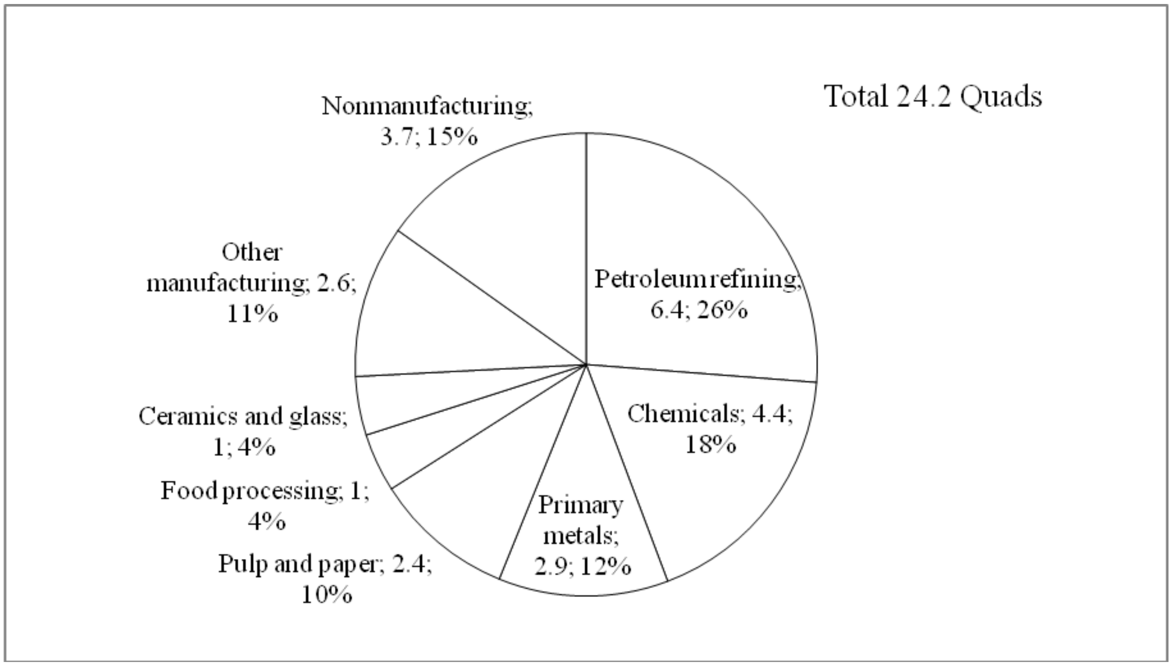


Figure 2.2 Industrial Energy Use [13]

The costs associated in the fuel and electricity consumption in manufacturing process of various industrial loads in Louisiana is described in the subsequent parts of the chapter.

2.2.1 Fuel Consumption and Costs

Every industrial operation needs fuel. Below is the list of different forms of fuel used in the Industrial Plants and Figures 2.4 and 2.5 are the pie charts for fuel consumption and price respectively by industries.

1. Coal
2. Petroleum
3. Natural Gas
4. Nuclear
5. Hydroelectric
6. Geothermal/Solar/Wind
7. Biomass/other

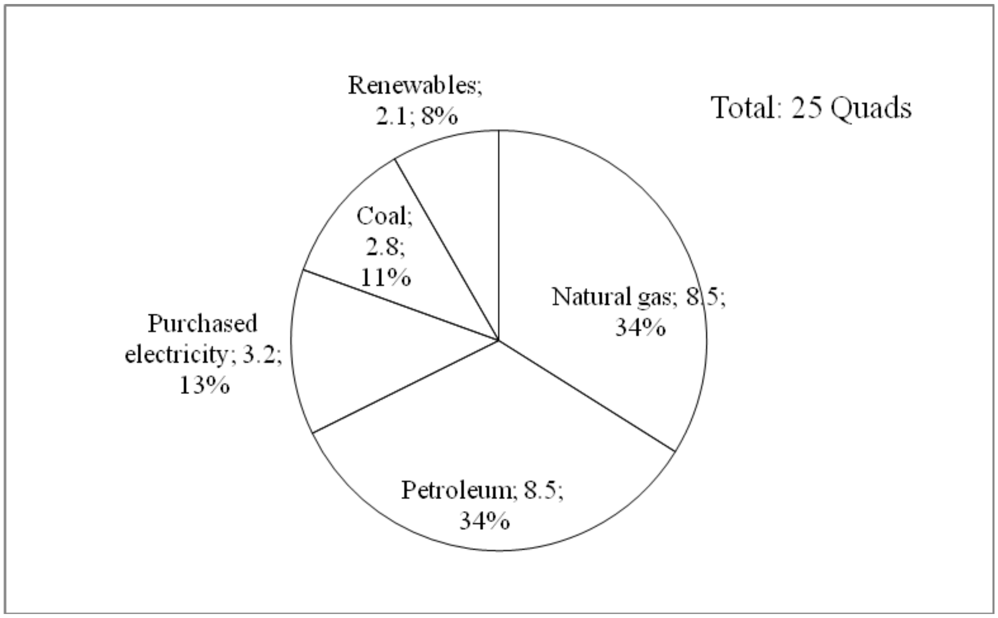


Figure 2.3 Industrial Energy Consumption by fuel [13]

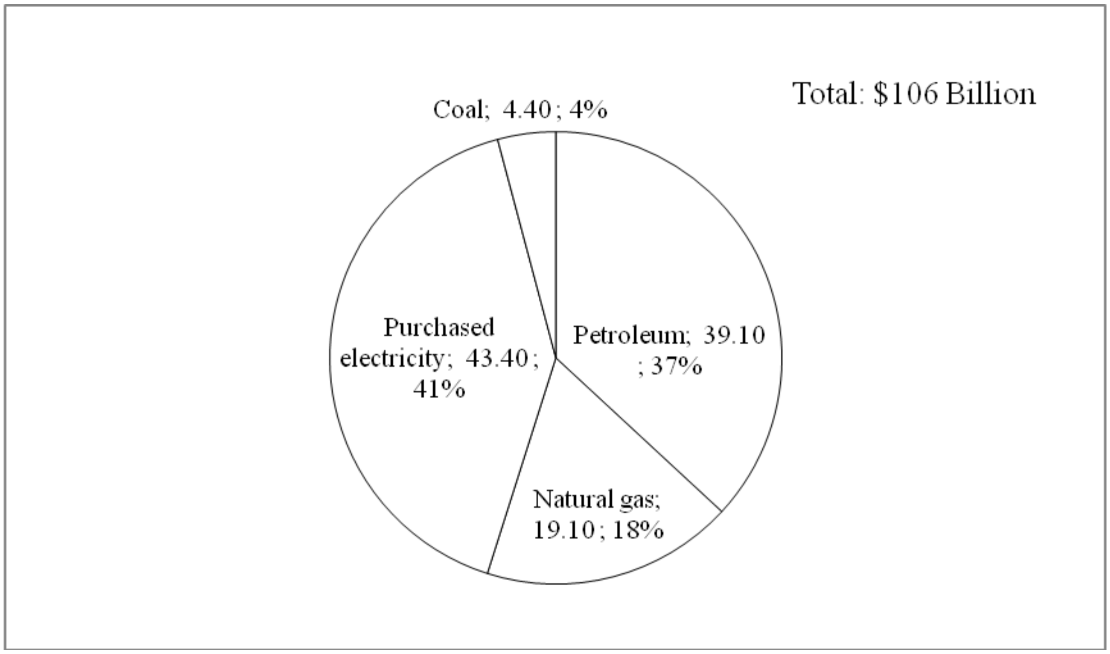


Figure 2.4 Industrial Energy Expenditures by fuel [13]

As seen from Figure 2.3, the two largest sources of industrial energy are natural gas and petroleum products. They account for nearly 70 percent of industrial energy use. Electricity is the third largest energy source in terms of end-use energy content, but is considered as the largest when generation, transmission, and distribution losses are included. Electricity also accounts for the largest share of industrial energy expenditures (Figure 2.4) [13].

2.2.2 Cost – Effective Method

Cost effective methods to effectively utilize the fuel and reduce the cost of its production include – conservation of fossil fuels, conservation of electricity, cogeneration, and fuel switching and electrification.

Co-generation, among all is widely used method and is defined as – production of electrical energy and another form of useful energy, such as heat or steam, through the sequential use of energy. In recent years, Co-generation may also refer to – simultaneous production of mechanical power that can be used for electrical purposes with the waste energy, used as useful heat by the traditional fuel or solar energy sources.

As with cogeneration, the “waste heat” byproduct that results from power generation is harnessed, thus increasing the overall efficiency of the system. Figure 2.6 describes how much electricity is been co-generated in manufacturing Industries.

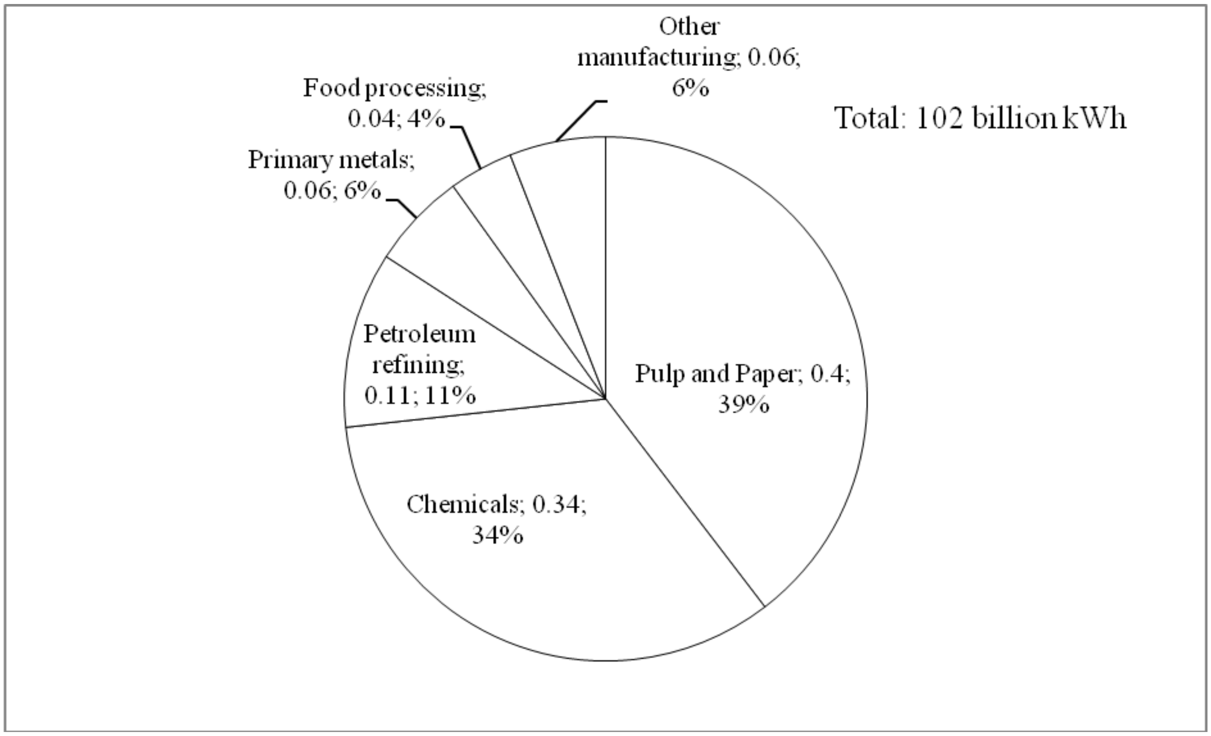


Figure 2.5 Electricity Co-generated in manufacturing Industries [13]

2.3 Industrial Plants as Energy Producers

Besides being energy consumers, plants in several industries (e.g., pulp and paper, chemical, and petroleum refining) are large energy producers. They, or third-party partners, produce electricity with cogeneration facilities, and sell to the grid whatever power they cannot use at the plants. However, the sale of power does not follow an optimal policy. The electricity sales can be a large source of revenues and as industrial plant energy producers could benefit from sales of excess energy in an optimum fashion. These companies have a great deal at stake in the many rules governing electricity generation, transmission, and distribution. For example, two changes that many large industrial companies would like to see are: 1) being able to sell their power to retail customers (retail wheeling), and 2) being able to transform power from one of their plants to another over the grid (self-wheeling). Currently, neither of these practices is allowed. Access to the electricity, market affects the value of cogenerated electricity and thus the economics of constructing cogeneration facilities. Increased access to electricity markets increases the overall cogeneration potential of industry. Cogeneration, as discussed earlier, the simultaneous production of both electricity and steam, usually consumes less fuel than would be needed to produce both separately. Many companies that produce and use steam find it profitable to cogenerate and to sell any unneeded power. PURPA (Public Utility Regulatory Policy Act), enacted in 1978, encourages cogeneration by mandating that utilities purchase the excess electricity at rates set by the avoided cost of procuring the additional power. Prior to PURPA, companies that sold cogenerated electricity to another user were subject to burdensome public utility regulations. EPACT (Energy Policy ACT) further encourages cogeneration by increasing electricity transmission access. This will enable co-generators to sell their power to utilities offering prices higher than those of the local utility.

From this point on our study narrows down to a typical manufacturing plant with co-generation capability that estimates the future demand and sells the power to utility. Since the co-generated energy is high, the pulp and paper manufacturing plant is considered for the study.

2.4 Pulp and Paper Manufacturing Industry

The pulp and paper industry is the least technologically advanced in USA and depends heavily on electricity as an energy source, although a major share of electricity needs are met by co-generation. The cost of purchased electricity is strongly connected to the mill production cost and it may be as 50% of the total cost. Purchased energy and energy-related capital investments represent major production costs in the paper and pulp industry.

Pulp, paper, and paperboard mills account for 95% of energy use in the U.S. paper and allied products industry and about 12% of total manufacturing energy use in the U.S. Paper is one of the few basic materials for which per-capita demand has not saturated in the United States. The increase in per capita consumption averaged 1.8% per year from 1960 to 1980, 1.6% per year from 1980 to 1993, and has been projected at 0.6% per year during 1990 to 2040. [13][14]

The value of shipments from the U.S. paper and allied products industry was $129 billion in 1991, ranking it eighth among all U.S. manufacturing industries. New capital expenditures in the last decade have averaged 10.4% of revenues, making paper and allied products the most capital intensive of the manufacturing industries. The capital intensity of the industry and associated scale economies have contributed to the closing of many smaller pulp and paper mills in recent years.

The pulp and paper industry could save millions of dollars each year by using efficient motor systems. Most induction motors used in Pulp and Paper industry have been installed prior to 1976 when new energy efficient induction motors were manufactured according to federal government guidelines imposed after Oil Embargo of 1973 [14]. Implementation of older technologies and energy efficiency guidelines along with new and innovative smart grid technologies that provides cost benefits to the industrial customers and the utilities are formulated to achieve the load management goals. Table 2.2 provides a summary of fuel type and their annual use for 1972, 1992, and 1993.

	1993 %	1992 %	1972 %
Purchased Fuel:			
Purchased Electricity	6.5	6.4	6.4
Coal	12.9	12.7	10.7
Residual Fuel Oil	6.7	6.1	21.2
Distilled Fuel Oil	0.2	0.2	1.0
Natural Gas	16.6	17.2	21.1
Other	1.8	1.8	1.3
Total	44.7	44.4	59.7
Self-Generated Fuel:			
Wood Residues	8.4	9.1	2.0
Bark	6.1	5.7	4.5
Spent Pulping Liquors	39.5	39.6	33.3
Self-generated Hydro	0.5	0.6	0.4
Other	0.8	0.6	0.1
Total	55.3	55.6	40.3

Table 2.2 Fuel and Energy Consumption % in the U.S. Pulp and Paper Industry [15]

Comparing the rows of Table 2.2 corresponding to the total energy consumption reveals that the Purchased Fuel has decreased from 59.7% to 44.7% while Self-Generated Fuel has increased from 40.3% to 55.3% from 1972 to 1993 respectively.

2.4.1 Fuel consumption in pulp and paper manufacturing

According to the Manufacturing Energy Consumption Survey (MECS), the wood products sector generated 252 trillion Btu, or 50% of the industry's energy needs, from wood residues. Remaining energy needs were met by electricity, natural gas, and fuel oil. Of the 1,294 trillion Btu self-generated by the pulp and paper industry, approximately 70% was provided by black liquor from pulping operations, with 25% provided by wood residues (Figure 2.6). The pulp and paper industry is a large electricity consumer; since many newer processes are electricity-intensive, the sector will likely increase its use of electricity as production increases. The industry also uses large amounts of fuel oil relative to other industries [13].

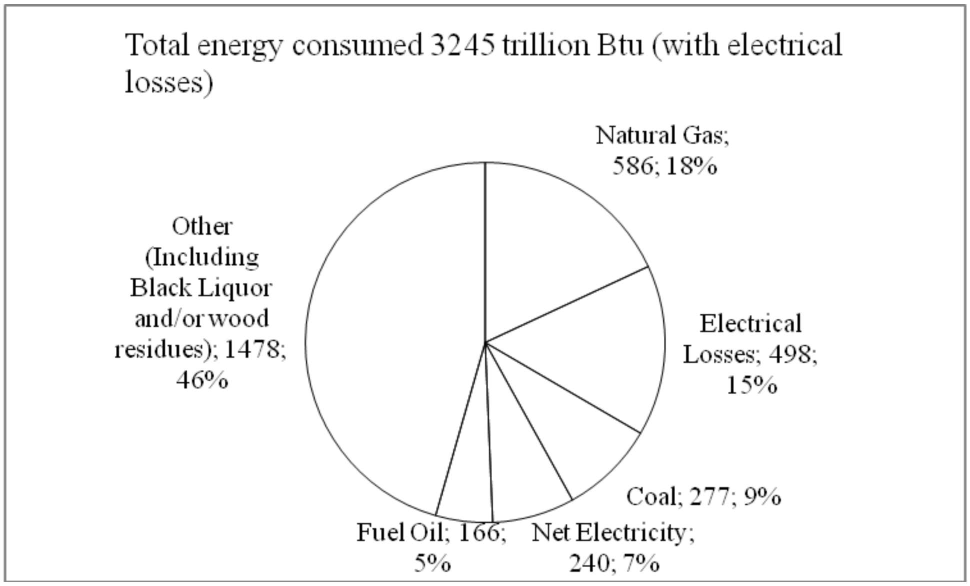
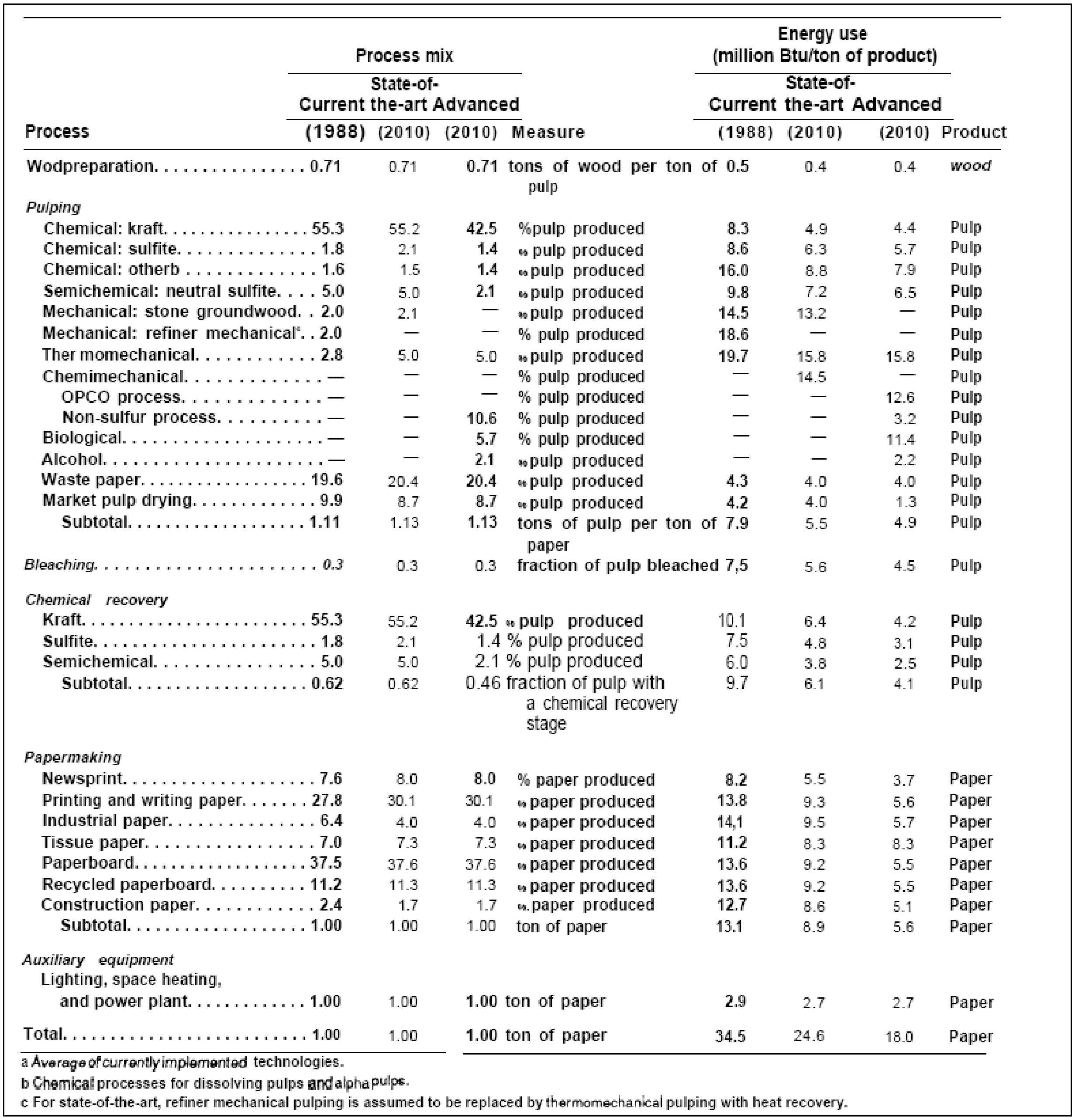


Figure 2.6 Energy consumption by pulp and paper plant [13]

The pulp and paper industry uses 84% of the fuel energy consumed by the forest products industry as a whole. Paper mills, many of which have integrated pulping operations, consume almost half of the 2.7 quads used in the pulp and paper industry (Table 2.3) [15].



Process	Process mix			Measure	Energy use (million Btu/ton of product)			Product
	Current (1988)	State-of-the-art (2010)	Advanced (2010)		Current (1988)	State-of-the-art (2010)	Advanced (2010)	
Wodpreparation	0.71	0.71	0.71	tons of wood per ton of pulp	0.5	0.4	0.4	*wood*
Pulping								
Chemical: kraft	55.3	55.2	42.5	%pulp produced	8.3	4.9	4.4	Pulp
Chemical: sulfite	1.8	2.1	1.4	% pulp produced	8.6	6.3	5.7	Pulp
Chemical: other[b]	1.6	1.5	1.4	% pulp produced	16.0	8.8	7.9	Pulp
Semichemical: neutral sulfite	5.0	5.0	2.1	% pulp produced	9.8	7.2	6.5	Pulp
Mechanical: stone groundwood	2.0	2.1	—	% pulp produced	14.5	13.2	—	Pulp
Mechanical: refiner mechanical[c]	2.0	—	—	% pulp produced	18.6	—	—	Pulp
Ther momechanical	2.8	5.0	5.0	% pulp produced	19.7	15.8	15.8	Pulp
Chemimechanical	—	—	—	% pulp produced	—	14.5	—	Pulp
OPCO process	—	—	—	% pulp produced	—	—	12.6	Pulp
Non-sulfur process	—	—	10.6	% pulp produced	—	—	3.2	Pulp
Biological	—	—	5.7	% pulp produced	—	—	11.4	Pulp
Alcohol	—	—	2.1	% pulp produced	—	—	2.2	Pulp
Waste paper	19.6	20.4	20.4	% pulp produced	4.3	4.0	4.0	Pulp
Market pulp drying	9.9	8.7	8.7	% pulp produced	4.2	4.0	1.3	Pulp
Subtotal	1.11	1.13	1.13	tons of pulp per ton of paper	7.9	5.5	4.9	Pulp
Bleaching	*0.3*	0.3	0.3	fraction of pulp bleached	7,5	5.6	4.5	Pulp
Chemical recovery								
Kraft	55.3	55.2	42.5	% pulp produced	10.1	6.4	4.2	Pulp
Sulfite	1.8	2.1	1.4	% pulp produced	7.5	4.8	3.1	Pulp
Semichemical	5.0	5.0	2.1	% pulp produced	6.0	3.8	2.5	Pulp
Subtotal	0.62	0.62	0.46	fraction of pulp with a chemical recovery stage	9.7	6.1	4.1	Pulp
Papermaking								
Newsprint	7.6	8.0	8.0	% paper produced	8.2	5.5	3.7	Paper
Printing and writing paper	27.8	30.1	30.1	% paper produced	13.8	9.3	5.6	Paper
Industrial paper	6.4	4.0	4.0	% paper produced	14,1	9.5	5.7	Paper
Tissue paper	7.0	7.3	7.3	% paper produced	11.2	8.3	8.3	Paper
Paperboard	37.5	37.6	37.6	% paper produced	13.6	9.2	5.5	Paper
Recycled paperboard	11.2	11.3	11.3	% paper produced	13.6	9.2	5.5	Paper
Construction paper	2.4	1.7	1.7	% paper produced	12.7	8.6	5.1	Paper
Subtotal	1.00	1.00	1.00	ton of paper	13.1	8.9	5.6	Paper
Auxiliary equipment								
Lighting, space heating, and power plant	1.00	1.00	1.00	ton of paper	2.9	2.7	2.7	Paper
Total	1.00	1.00	1.00	ton of paper	34.5	24.6	18.0	Paper

[a] Average of currently implemented technologies.
[b] Chemical processes for dissolving pulps and alpha pulps.
[c] For state-of-the-art, refiner mechanical pulping is assumed to be replaced by thermomechanical pulping with heat recovery.

Table 2.3 Energy use by pulp and paper technologies [15]

On an average, about 35 million Btu are used to produce a ton of paper [15]. The most energy-intensive steps are the papermaking, pulping, and chemical recovery steps. Widespread adoption of state-of-the-art technologies can reduce energy consumption by an estimated 29 percent (Table 2.3) from average practices. Advanced technologies could possibly reduce overall costs associated in the manufacturing process of pulp and paper plant.

2.4.2 Energy expenditures in pulp and paper plant

The forest products industry spent $7.6 billion on purchased energy in 2006, almost 10% of total U.S. manufacturing energy expenditures. Of this amount, about $6 billion was spent by the pulp and paper industry. Electricity purchases represent the largest share of energy costs, almost half of the pulp and paper industry's energy expenditures (Figure 2.7)

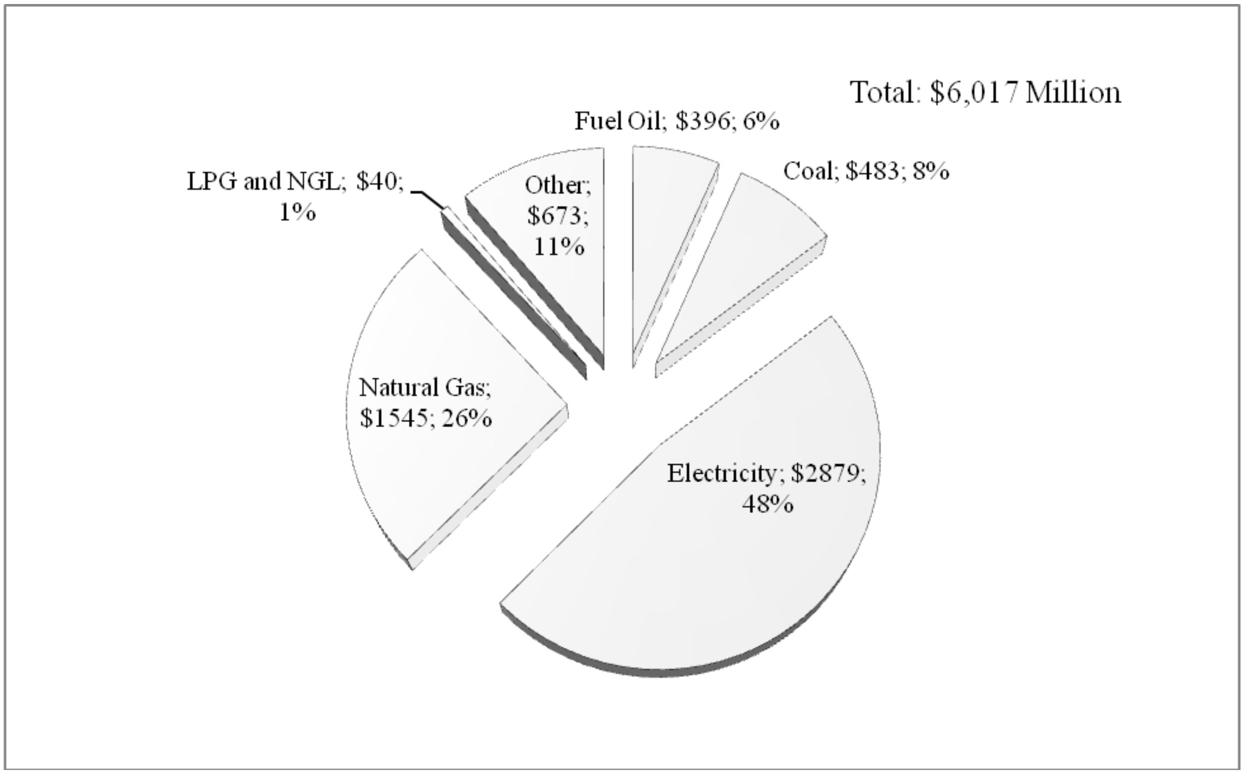


Figure 2.7 Energy Expenditures (NAICS 322 Pulp & Paper) [15]

Over 45% of the electricity used by the pulp and paper industry is generated onsite, primarily by means of cogeneration. The pulp and paper industry is the largest co generator in the manufacturing sector, producing more than 49.4 billion kilowatt-hours using cogeneration technologies. The primary technology used is steam turbines supplied by bed boilers, and many are fueled at least partially by biomass. Typically, these systems generate high-pressure, high-temperature steam for use first in electric power turbines and then in process applications. The wood products sector also cogenerates electricity but only about 6% of the sector's total net electricity demand, or 1.4 billion kilowatt-hours.

The load model and the mathematics for representing the industrial load profiles for the pulp and paper manufacturing industry are discussed in Chapter 3. In the later parts of the chapter, we shall look at the mathematical load profile for describing a pair of industrial customer and an electric utility connected by smart grid technology. And the optimization techniques for finding the most profitable use for exchanging the available electricity are reported. The Smart Grid benefits for procuring electricity from industry, utility point of view are also presented.

3. Load Model

3.1 Load Profiles and Forecast

Mathematical model for representing industrial load profiles in general and a hypothetical pulp and paper manufacturing plant in particular is presented in this chapter.

To develop a model or to study the load profile, knowledge about load forecast is essential. The load forecast curves of industries normally exhibit nonlinear and mostly dynamic behavior and they have to be studied in respective time frames lasting from fraction of a second to several hours. As the time span of the study increases, load behaviors reach their steady-state and are occasionally represented by constant impedance models. In this study we shall mainly focus on the hourly load profiles and different 24-hour load variation behaviors and shall not be concerned about electromechanical dynamics.

Load forecasting is vitally important for the electric industry in the deregulated economy. It has many applications including energy purchasing and generation, load switching, contract evaluation, and infrastructure development [22]. A large variety of mathematical methods have been developed for load forecasting. Accurate models for electric power load forecasting are essential to the operation and planning of a utility company. Load forecasts are extremely important for energy suppliers, Independent System Operators (ISO), financial institutions, and other participants in electric energy generation, transmission, distribution, and markets [16]. Load forecasts can be divided into three categories: short-term forecasts which are usually from one hour to one week, medium forecasts which are usually from a week to a year, and long-term forecasts which are longer than a year. The forecasts for different time horizons are important for different operations within a utility company [17]. The natures of these forecasts are different as well. For example, for a particular region, it is possible to predict the next day load with an accuracy of approximately 1-3%. However, it is impossible to predict the next year peak load with the similar accuracy since accurate long-term weather forecasts are not available. For the next year peak forecast, it is possible to provide the probability distribution of the load based on historical weather observations. It is also possible, according to the industry practice, to predict the so-called weather normalized load, which would take place for average annual peak weather conditions or worse than average peak weather conditions for a given area. Weather normalized load is the load calculated for the so-called normal weather conditions which are the average of the weather characteristics for the peak historical loads over a certain period of time. The duration of this period varies from one utility to another. Most companies take the last 25-30 years of data [14]. Load forecasting has always been important for planning and operational decision conducted by utility companies. However, with the deregulation of the energy industries, load forecasting is even more important. With supply and demand fluctuating and the changes of weather conditions and energy prices increasing by a factor of ten or more during peak situations, load forecasting is vitally important for utilities. Short-term load forecasting can help to estimate load flows and to make decisions that can prevent overloading. Timely implementations of such decisions lead to the improvement of network reliability and to the reduced occurrences of equipment failures and blackouts. Load forecasting is also important for contract evaluations and evaluations of various sophisticated financial products on energy pricing offered by the market. In the deregulated economy, decisions on capital expenditures based on long-term forecasting are also more important than in a non-deregulated economy when rate increases could be justified by capital expenditure projects. Most forecasting methods use statistical techniques or artificial intelligence algorithms such as regression, neural networks, fuzzy logic, and expert systems. Two of the methods, so- called end-use and econometric approach are broadly used for medium- and long-term forecasting. A variety of methods, which include the similar day approach, various regression models, time series, neural networks, statistical learning algorithms, fuzzy logic, and expert systems, have been developed for short-term forecasting. As we see a large variety of mathematical methods and ideas have been used for load forecasting, the development and improvements of appropriate mathematical tools will lead to the development of more accurate load forecasting techniques. The accuracy of load forecasting depends not only on the load forecasting techniques, but also on the accuracy of forecasted weather scenarios. Weather forecasting is an important topic which is outside of the scope of our study.

Our objective in this chapter is to forecast the 24-hour load curve and to use it in the study to find the optimum solution to maximize the fuel savings and to estimate the profit to Integrated Industrial Electric system, with a pulp and paper manufacturing plant as the industrial load.

3.2 <u>Pulp & paper model</u>

The sophisticated techniques that are available to control use of electricity may be categorized as – those that reduce demand by increasing appliance efficiency and reducing waste, those that direct and control load to make character of demand curves match the character of supply, and end-use management. Of these the main role of managing the demand of a utility system is to reduce the peak load. Tariff during peak demand periods have induced industries to adjust scheduling for full-scale production and maintenance activities, increase level of productive off-peak periods and generate their own power from industrial by-products. The power shortfall is problematic, but the availability of excess power during off-peak periods can be sold out to neighboring utilities at lower rates, increasing the dollars for both industry and utility. The extreme shortfall in power availability in a grid can be eliminated by load shedding; which may not suit well for industrial consumers.

The manufactory process of paper in pulp and paper plant makes use of little leftover steam from the boiler (fuel and water are burnt and steam is produced which is fed to turbine that rotates and produces electricity) and the steam from the turbine. The high pressured steam is used for pulp chemicals, medium for the rough paper and the cartons and, the low pressure for the fine paper. Figure 3.1 depicts the process of producing both electricity and paper in an industrial pulp and paper plant equipped by co-generation facility.

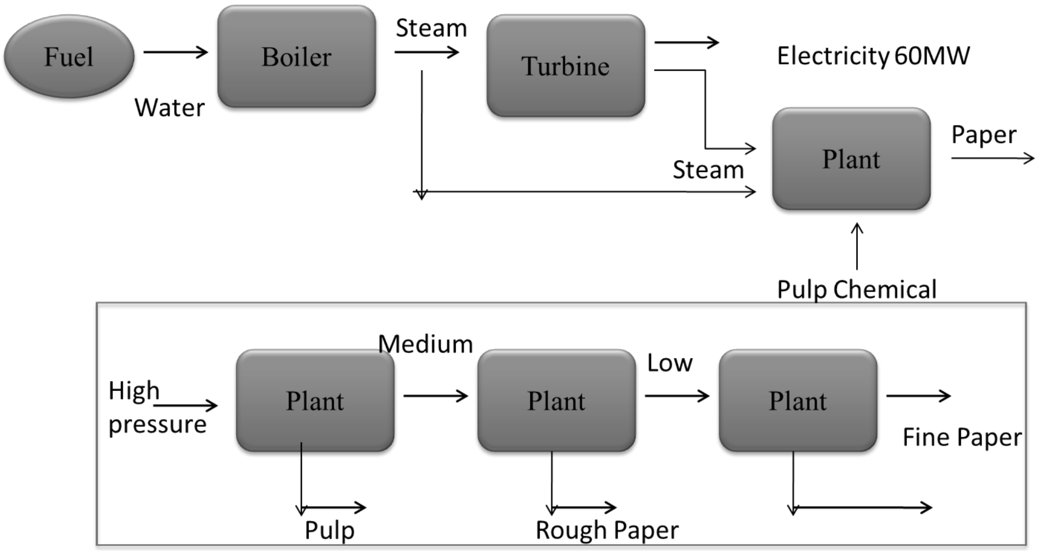


Figure 3.1 Block diagram of paper manufacturing process

3.3 Load Profile of Pulp and Paper model

To create a load profile for the chosen industrial manufacturing plant (pulp and paper) a method used in the paper "Daily load profiles of residential, commercial and industrial low voltage customers," [22] is adopted.

Initially, a data base was prepared with the information regarding the industrial consumers. Data was grouped according to the activity and within this activity the consumers were displayed by the descendent order of the monthly average energy as in Table 3.1. Afterwards the activities were sorted out based on the number of consumers as well as their total energy consumption as in Table 3.2.

		ENERGY		CUSTOMERS	
Industrial Activities	CODE	RANK	MWh	QTY	RANK
Bakery	2670	1	27854	3471	2
Clothes Factory	2510	2	6460	5562	1
Building Construction	3210	3	2852	2099	4
Lumber Mill	1160	4	1691	3434	3
Wooden Furniture	1610	5	1465	164	6
Cement Parts	1060	6	1174	2014	5
Wiring and Loom	2420	7	924	306	18
Var. Wooden Artef.	1550	8	904	979	8
Plastic Gadgets	2350	9	882	228	24
School Mat Printing	2920	10	879	813	9
Electronics	1370	11	874	349	16
Plastic Ind. Purpose	2320	12	821	220	25

Table 3.1 Low size Industrial loads [22]

Activities	By MWh/month	By Customers number
1 to 10	63	58
1 to 20	71	67
1 to 30	79	76
1 to 40	83	80
1 to 50	87	85
1 to 160	90	88

Table 3.2 Activity participation (%) [22]

Twenty six main industrial activities (consumers connected in low voltage) were selected for the measurement campaign that includes more than 71% of the energy consumption and more than 67% of the number of customers. Ideally pulp and paper is of high size. But because we don't have access to an actual pulp and paper industrial plant information, we have utilized the "mean" and "variance" of the data from the reference [22] as in Figure 3.2, and created the load profile for specific loads in the IEEE 39-Bus Test System of Chapter 4. The daily load curve of pulp and paper plant is depicted in Figure 3.3

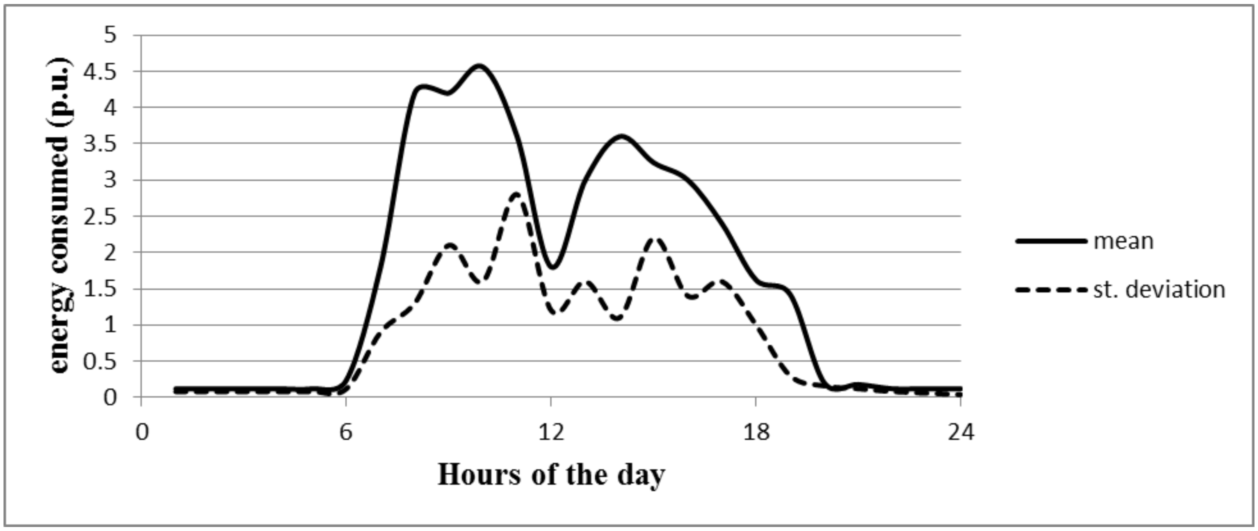


Figure 3.2 Representative *mean* and *standard deviation* curves of one industrial activity

The one possible way that could be adopted is - to contact utility (Entergy) and take help in reaching the utilization of energy by industries and list out the industries operating (for example – petrochemical, food processing, pulp and paper etc.) to rank them by the number of consumers and the MWh they use, one activity called petrochemical has 53 (approx.) companies in Louisiana and similarly an activity called pulp and paper has 10 customers. The former one uses very high amount of energy compared to the later, in fact one Exxon mobile in Baton Rouge alone consumes the energy that is equal to ten pulp and paper plants. The exact information regarding the above discussion is not available. One can find the amount of electricity that is sold by Entergy or the amount that goes to Industry easily but, cannot estimate how much a pulp and paper plant uses or a petrochemical company uses. If, let us assume, we find the information that says – energy utilization of petrochemical in LA is five times as large as pulp and paper, then the model for a particular industry can be figured out roughly. Since, the percentage and the total are known; ranking needs to be done with larger on the top based on energy consumed. If we have the % and if we know MW usage for day/month/year, one can create the appropriate load profile model for each type of industries outlines in Chapter 2. We may not be able to come up with a graph like the one in the Reference [22] because that is based on actual measurements. Table 3.3 tabulates the ranking of major industries described in Chapter 2 based on the total energy consumption.

RANK	Industrial Activities	Energy Consumed	
		Quads	Billion MWh
1	Petroleum refining	6.4	1.88
2	Chemicals	4.4	1.29
3	Nonmanufacturing	3.7	1.08
4	Primary metals	2.9	0.85
5	Pulp and paper	2.4	0.70
6	Food processing	1	0.29
7	Ceramics and glass	1	0.29
8	Other manufacturing	2.6	0.76

Table 3.3 Ranking of major industries based on energy consumed [13]

Although petro chemical is ranked on top and may be 5th from top is pulp and paper, we decided to focus on pulp and paper for the reason that it is technologically lower than compared to petrochemical. So, if there is an energy saving, then it would be more in pulp and paper.

The tables and the graphs could be plotted based on the above idea in the future works. Instead, for the completion of thesis, we focus on published data. The data considered may not lead to 100% accurate results but can be taken as first step in our proposed methodology which determines how the Smart grid can be used. The "mean" and "variance" are known, the average power consumed by the plant is assumed to be 120MW, and normal distribution is used to determine a 24-hour load profile of a typical pulp and paper plant in Louisiana.

When the values obtained are compared to those of the utility and the plant, one may find a little discrepancy, the more the number of actual measurements; the more accurate is the model. If we have only one measurement, there could be huge discrepancy. If there are ten measurements, the discrepancy may not really be that much and the model may be acceptable with reasonable accuracy. This is because; the more the number of actual measurements, the closer the model follows a normal distribution.

None of the industries in the state of Louisiana have a model, and pulp and paper is no exception. For example, when we reach the plant and ask for the load profile, they will hesitate to give because, normally this piece of information is not allowed to be carried outside. But, based on the data that was collected between 1980 and 1995, 15 years of data that is 15 years back without disseminating any confidential information, it can be utilized for modeling. At this stage of the study, we are seeking an estimate of the "mean" and "variance" and typical load variation of an industrial load.

Based on the published and selected mean and variance, the energy required for a typical 120MW plant to operate at each hour of the day is tabulated in Table 3.4.

Hours of the day (i)	Load (MW)	Hours of the day (i)	Load (MW)
1	12	13	300
2	12	14	360
3	12	15	324
4	12	16	300
5	12	17	240
6	24	18	62
7	180	19	42
8	420	20	20
9	420	21	18
10	456	22	12
11	360	23	12
12	180	24	12

Table 3.4 Hourly energy consumption by the industrial plant

The Figure 3.3 shows the curve describing the energy consumption of a typical pulp and paper manufacturing industry. The consumed energy serves the daily load of the plant.

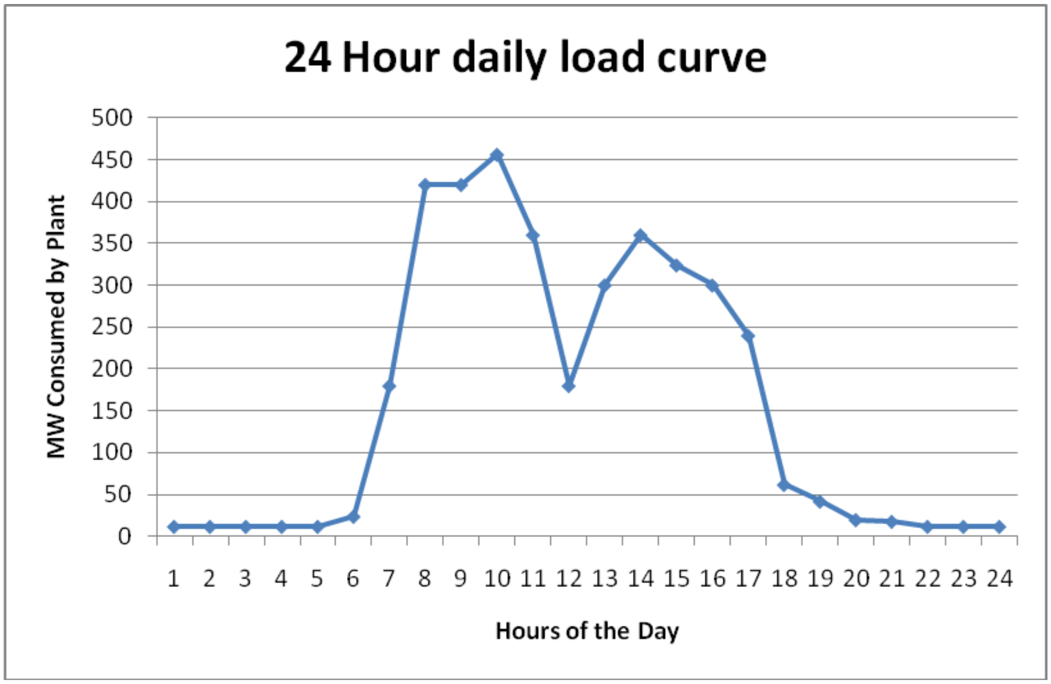


Figure 3.3 Daily load curve of pulp and paper industry

As seen from the curve, the load is low during the early hours; it mounts up during the day and decreases gradually. This knowledge when integrated with the electric utility generation production by use of smart grid technologies shall provide substantial fuel savings. We shall describe the fuel savings in more detail in later sections. The system lambda, which is the cost of producing next MW over next hour by the utility, is determined by running economic dispatch problem on IEEE 39 Bus Test System connected with industrial load at one of its load buses. When the power output and power need of a typical plant are known to an electric utility via use of Smart Grid Technology, then the Smart Grid Transaction can be modeled based on this information.

3.4 Power System Control Problem

A power station is constructed, commissioned and operated to supply required power to consumers with generators running at rated capacity for maximum efficiency. The fundamental problem in generation, transmission, and distribution of electrical energy is the fact that the bulk storage of electrical energy for a long duration is not possible. In other words, Electrical energy must be generated and transmitted to the point of consumption at the instant of demand. The electricity generation is not constant, but varies in order to supply the load. Because of the uncertain demands of consumers, the load on the power station varies from time to time, and therefore generation also varies. Therefore, there is a need to study the complexities met in deciding the size and capacity of generating units that must be installed in a power plant to successfully meet varying energy demands on a day to day basis.

The whole power system control problem is a hierarchical one as seen in Figure 3.4. It explains that, in order to start the generation process, the first step is to forecast the load. Once load forecasting is done, then the power plants which supply the load are to be determined.. From the available units of the power plants, we have to know which units are on (1), and which units will be off (0) because all units need not be loaded to serve the demand. Once we know the available units, referred to committed units, we should know how much each unit should be loaded depending on the need and the sub-objective function – economy, reliability, security, voltage control etc. We only focus on Economic Dispatch Process of finding the optimum megawatt output of “committed” units for minimizing the total fuel cost to supply the load, considering power losses in the transmission system.

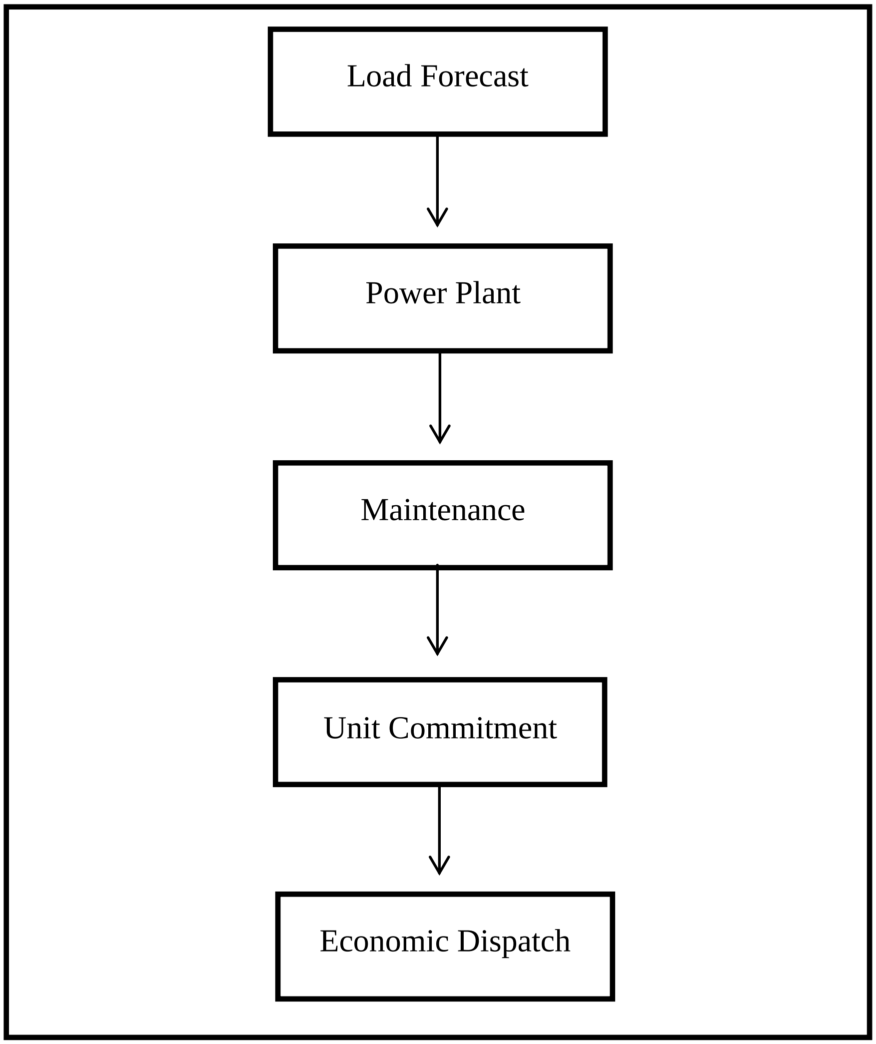


Figure 3.4 Flow Chart for optimal power system

Fortunately, one does not need a real-world interconnected network to approach for the study of power systems. As the Interconnected Power systems are the largest and most complex systems ever built by man, simple benchmark systems are often enough to understand every aspect of power system. Figure 3.5 depicts the eight zonal scheme of the New England system.

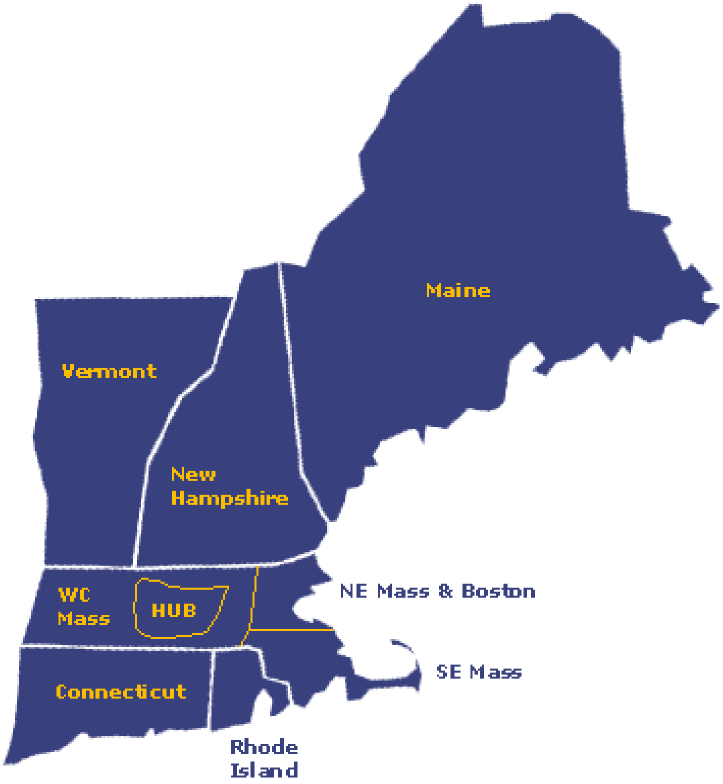


Figure 3.5 New England System

The power system in the figure 3.6 is the representation of New England interconnected system. It is the IEEE 39 bus system and is well known as 10-machine New-England Power System. The system has 39 buses, 48 transmission lines, and 10 generating units. The 39 buses are divided into 9 PV buses, one slack bus and 29 PQ buses that are interconnected by 48 branches. Among the 39 buses, 19 buses have their own customer loads. The one-line diagram of the system is shown in the Figure 3.6.

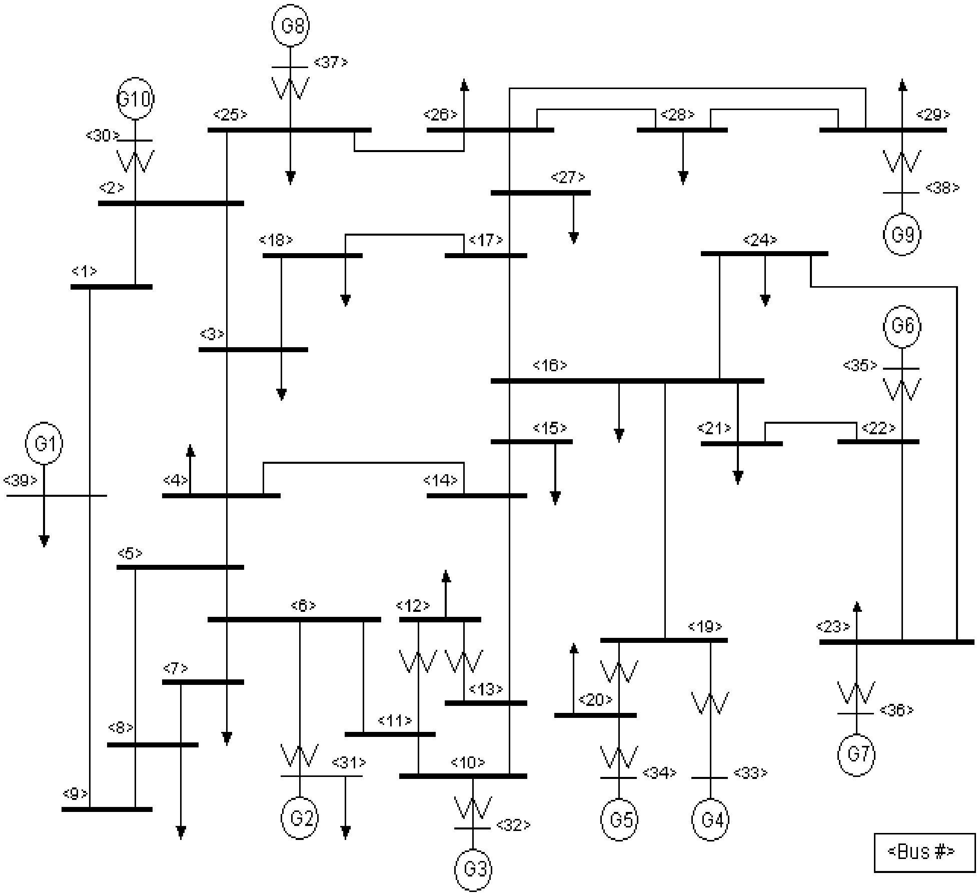


Figure 3.6 IEEE 39 bus system

Normally, most of the buses (85%) are PQ-buses, 15% are PV and there is one slack bus. The slack bus is also called as reference bus or swing bus as rest of the bus angles swing with respect to this bus or rest of the angles, from $\delta_2, \delta_3, ..., \delta_n$ are referred to the slack bus which is normally given by δ_1 and is mostly equal to zero. The slack bus is also used to satisfy a portion of losses. Losses in a system are not known till the end of the load flow solution. So, there should be a bus, preferably with the biggest unit in the system and preferably located at the center so that the distance travelled to feed that power plant is very less which reduces the losses in transmission. The 15% called PV buses generally have generators attached but, this is not necessary. The condition of PV bus is only to keep voltage constant. So, it can have a bank of capacitors or inductors attached to keep voltage constant. Loosely this bus has several names – PV bus, Generator bus, Voltage control bus. And, PV buses are limited to only 15% because, power station power generation is highly capital intensive business as generation of 1MW of power needs $1million.

3.5 Optimal Power Flow

Optimal power flow involves the optimization of an objective function that can take various forms, for example, minimization of total production cost, or minimization of total loss in transmission networks subject to a set of physical and operating constraints. Constraints may include generation and load balance, bus voltage limits, power flow equations, and active and reactive power limits. The objective of the problem is to solve an optimal power flow problem with the objective of minimization of total production cost using an optimization method such as primal-dual interior point method. The outcome of the optimization is the system lambda – the cost of producing the next MWhr.

An OPF problem can be formulated as –

$$\text{Minimize } F(x,u) \tag{3.1}$$

$$\text{subject to } g(x,u) = 0,$$

$$h(x,u) \leq 0$$

where in Equation 3.1:

$F(x,u)$ = objective function

u = set of control variables (e.g., generator active power, generator voltage, transformer tap position)

x = set of dependent variables (e.g., load bus voltage, phase angle)

$g(x,u)$ = power flow constraints

$h(x,u)$ = set of non-linear inequality constraints

The objective function of interest in the thesis is designated as the minimization of the total fuel cost of scheduled generating units. Such a minimization problem is most used as it reflects current economic dispatch practice and importantly, cost related aspect is always ranked high among operational requirement in power systems. Various techniques have been proposed to solve the OPF problem for example, non-linear programming [25], quadratic programming [26], linear programming [27]-[29], and interior point methods [30]-[32]. Among these, the interior point method has been of recent interest and is employed by MatPower of MatLab to solve the OPF problem in this research. The interior point (IP) technique was proposed by N.K.Karmarkar [25]. It can solve a large-scale linear programming problem by moving through the interior, rather than the boundary as in the simplex method, of the feasible region to find an optimal solution. The IP method was originally proposed to solve linear programming problems; and, later it was implemented to efficiently handle quadratic programming problems [33]-[35].

The interior point technique starts by determining an initial solution using Mehrotra's algorithm [36], which is used to locate a feasible or near-feasible solution. There are then two procedures to be performed in an iterative manner until the optimal solution has been found. The former is the determination of a search direction for each variable in the search space by a Newton's method. The latter is the determination of a step length normally assigned a value as close to unity as possible to accelerate solution convergence while strictly maintaining primal and dual feasibility. A calculated solution, in each of the iterations will be checked for optimality by the Karush-Kuhn-Tucker (KKT) conditions, which consist of primal feasibility, dual feasibility and complementary slackness [32].

OPF formulation consists of three main components: objective function, equality constraints, and inequality constraints. In this thesis, we utilize a quadratic objective function to reflect the cost of producing specific MW output by unit $i = 1,2,3,....,m$, where m is the number of committed units.

$$MinC_T = \sum_{i=1}^{m} C_i(P_{Gi}) = \sum_{i=1}^{m} a_i + b_i * (P_{Gi}) + c_i * (P_{Gi})^2 \tag{3.2}$$

In Equation 3.2, the co-efficient a_i, b_i and c_i for $i = 1,2,3,....,m$ are found experimentally. Minimization is performed on the total cost C_T with P_{Gi} and C_i determined for optimal solution while satisfying constraints of Equation 3.3 – 3.6.

The equality constraints are active/reactive power flow equations and generation/load balance.

$$P_i(V,\delta) - P_{Gi} + P_{Di} = 0 \tag{3.3}$$

$$Q_i(V,\delta) - Q_{Gi} + Q_{Di} = 0 \tag{3.4}$$

$$\sum_{i=0}^{m} (P_{Gi}) - \sum_{i=0}^{l} (P_{Di}) - P_L = 0 \tag{3.5}$$

$$\text{Real Power } P_i(V,\delta) = |V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i);\ i = 1,2,\ldots.,n \tag{3.6}$$

$$\text{Reactive Power } Q_i(V,\delta) = -|V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i);\ i = 1,2,\ldots.,n \tag{3.7}$$

In Equations (3.6) and (3.7) n is the number of system buses.

$$P_L = \sum_{i=1}^{n} P_i \tag{3.8}$$

Transmission loss (P_L) given by Equation 3.8 can be directly calculated from the power flow Equation 3.6. At bus $i = 1,2,\ldots.,n$; $P_i = P_{Gi} - P_{Di}$, and hence P_L is calculated from Equation 3.8.

The inequality constraints consist of generator active/reactive power limits, voltage magnitude limits, and transformer tap position limits.

$$P_{Gi\min} \le P_{Gi} \le P_{Gi\max} \tag{3.9}$$

$$Q_{Gi\min} \le Q_{Gi} \le Q_{Gi\max} \tag{3.10}$$

$$V_{i\min} \le V_i \le V_{i\max} \tag{3.11}$$

$$T_{k\min} \le T_k \le T_{k\max} \tag{3.12}$$

where generator active and reactive power, voltage magnitude and transmission flow upper and lower limits are provided in Equation 3.9, 3.10, 3.11 and 3.12 respectively.

To find minimum fuel cost by solving Equation 3.2, we need to find the transmission line losses using Equation 3.6 and Equation 3.8. The total loss P_L is then used as a constraint of minimization of fuel cost according to equation 3.5. And, the traditional power flow program converts to optimal power flow. When transmission line losses are ignored, then there is no need to perform load flow and to determine P_L. Therefore, the problem converts to:

$$MinC_T = \sum_{i=1}^{m} C_i(P_{Gi}) = \sum_{i=1}^{m} a_i + b_i * (P_{Gi}) + c_i * (P_{Gi})^2 \qquad 3.13$$

Subject to $\sum_{i=1}^{m} P_{Gi} = \sum_{i=1}^{n} P_{Di}$ 3.14

For this case, there is no need to use the interior point method and one may use quadratic nonlinear programming to find the minimum fuel. When line losses ignored, the minimum fuel cost may be determined from Equation 3.15

$$\lambda = \frac{dC_i(P_{Gi})}{dP_{Gi}} = b_i + 2c_i P_{Gi} \qquad 3.15$$

$$\sum_{i=1}^{m} P_{Gi} = \sum_{i=1}^{n} P_{Di} = P_D \qquad 3.16$$

From Equation 3.15 and 3.16, we arrive at the minimum fuel cost of Equation 3.18.

$$P_{Gi}^* = \frac{\lambda - b_i}{2c_i} \qquad 3.17$$

Subject to $\sum_{i=1}^{m} \frac{\lambda - b_i}{2c_i} = P_D$ 3.18

Equation 3.17 and 3.18 are solved iteratively by choosing different values for λ until Equation 3.18 with known P_D and b_i and c_i is satisfied. The final value of λ that satisfies Equation 3.18 is the minimum dollar for producing the next MWhr – or the System Lambda. Once we find P_{Gi}^*, the minimum fuel cost is determined by Equation 3.19.

$$C_T^* = \sum_{i=1}^{m} a_i + b_i(P_{Gi}^*) + c_i(P_{Gi}^*)^2 \qquad 3.19$$

We shall use the mathematical formulation and the OPF of MatPower to find the system λ when an industrial load (selected as bus "s" in Chapter 5) is considered as fixed load or variable load over a 24-hour period. Furthermore, we shall determine the minimum cost of producing the next MW of generation for the next hour (Bus λ_i i = 1,2,3,…,n) at each load bus in the system. Among the λ_i , i = s corresponds to the bus that is equipped with co-generation capability that partially satisfies its own load at certain hours of the day, but exceeds its own requirement for other hours in a 24-hour period. The hourly Bus-λ_i are included for buses 7, 21, and 23 in Chapter 5.

3.6 Load Flow Study and Proposed Methodology

The Load Flow study is the basic study for any power system engineer or an electric energy system engineer. It gives the pulse of the system and is a prerequisite for fault study, stability study, and economic operation. Load Flow Study in Power System parlance is the steady state solution of the power system network, resulting in voltage magnitude $|V|$, voltage angle δ, real power P, reactive power Q, line flows P_{ij}, Q_{ij} and losses. Ideally, if all the line flows are added it should be equal to zero, instead it ends up with a value because, we have losses in the system and there is no practical system in which there are no leakages or losses.

Repetitive load flow runs provide continuous monitoring of current state of the system. The monitoring and control action are taken by Power system control centers also known as energy control centers or Load Dispatch center.

In this study, we have created a 24 hour load profile of an industrial plant with power factor of 0.85 to replicate performance of a typical Pulp and Paper Industrial Plant. Several load buses among the 19 load buses of the IEEE 39-Bus Test System were selected as candidate locations for the co-generation load bus – a load bus that at certain time of the day may serve as generator bus.

Based on the hourly load requirement of the selected bus, bus $i = s$, we use Equation 3.6 and iterative load flow equation to solve for P_i, $i = 1,2,....,n$ including $i = s$.

Knowledge of P_i for $i = 1,2,....,n$ allows use of Equation 3.8 to determine the total system loss P_L. Equation 3.5 and the known P_L and P_D , shall provide the total generation P_G by the utility generation. However, the total P_G is obtained by different combination of P_{Gi} and at different fuel cost of $C_i(P_{Gi})$. Equation 3.2 is then used to find the combination of P_{Gi}, $i = 1,2,....,m$ for minimum (optimum) fuel cost. In this study we are not concerned with equality constraints of Equation 3.4 or inequality constraint of Equation 3.10 – 3.12. Interactive optimization of Equation 3.2 with the power loss P_L identified by actual load flow calculation shall result in the minimum dollar for production of the next MW in the next hour – a valuable information that can shared by both the electric utility and its industrial customer $i = s$ by use of smart grid technology. The shared information on the cost of producing the next MWhr with and without the generation produced by the cogeneration at bus $i = s$ shall provide necessary information for power transaction – buying or selling by either the utility or the industrial plant – through smart grid transaction.

3.7 Role of Smart Grid in Optimizing the Operation

The main idea as said earlier in the introduction is to apply smart grid as a bridge between the industrial plant and electric utility. The industrial plant, pulp and paper mill is one of the load buses in the IEEE 39 Bus Test System that serves as the electric utility. At every hour of the day there are two types of costs, the buying and selling costs, associated with each – supply and demand. The costs change depending on the time varying demand charge. The demand differs all the day based upon how much it is used. And this can be studied by the load patterns and the energy curves.

A residential customer can benefit easily by using smart devices which give complete information on when to use a particular device whether it might be a dish washer or washing machine and how to save electricity thereby paying fewer dollars on the consumption. On the other hand industrial customers cannot adopt such method of saving electricity and reducing dollars on their energy bills by installing smart meters. They just cannot turning off the manufacturing machines and generators when the energy costs are high and start the production again when cost is low loss. Instead they have an option to sell electricity to the electricity service provider when they actually do not need it, or when they have to pay more and for the less demand and at greater fuel costs. The utility also will wish to buy the electricity from the industries reducing the fuel costs for producing electricity. The industry can now consume electricity only when it needs and puts down the manufacturing process and sells electricity in the off peak period. There by reducing the dollars to both plant and utility

The process of reducing the dollars and increasing the energy efficiency can be done by applying the smart grid between the demand and supply making use of its technologies.

The smart grid transaction between a typical industrial plant and electric utility is depicted by Figure 3.7.

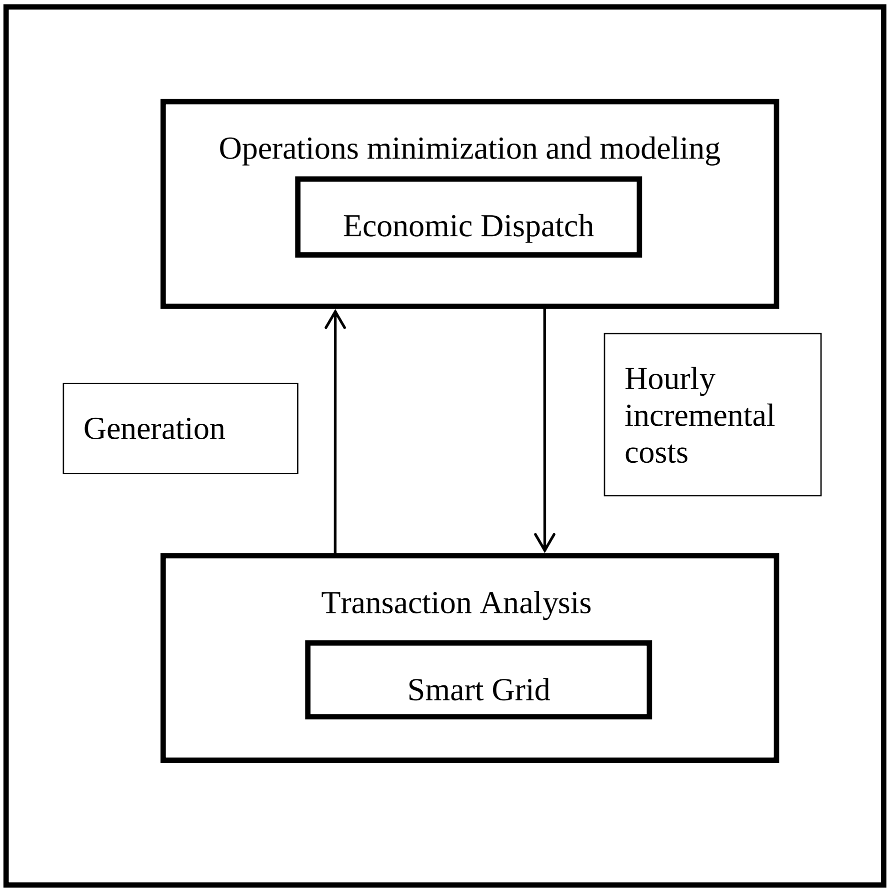


Figure 3.7 Interaction of economic dispatch and transaction analysis

The upper block in Figure 3.7 explains that the Economic Dispatch (losses included) problem is solved at the utility (IEEE 39 Bus Test System in the study) and the values of lambda, that is cost of producing next MW over next hour by the utility are determined at every hour and are made available to the Smart Grid transaction display. Along with the variable load profile of the Industrial plant and hourly incremental cost that the utility determines at every hour, the power generation to meet the load with the optimal fuel is estimated and is made available at the display unit. If these values are known, then the Smart Grid Transaction can be modeled based on the amount that the utility wants to sell this next MWhr (depending on the hour of the day as load is not constant throughput the day) and to see if the plant wants to sell or buy.

The details about the Test System are presented in Chapter 4 and the simulation results for the IEEE 39 Bus Test System connected with industrial load at one of its selected load buses are given in Chapter 5.

4. Simulation Test System

4.1 IEEE 10 Generator 39 Bus System

4.1.1 General Outline

The IEEE 39 Bus Test System is well known as 10-machine New-England Power System. The test system chosen for the study is the IEEE 39 bus system. The system has 39 buses, 48 transmission lines, and 10 generating units. The 39 buses are divided into 11 PV buses and 28 PQ buses that are interconnected by 48 branches. Among the 39 buses, 19 buses have their own customer loads. The one-line diagram of the test system is shown by the Figure 4.1.

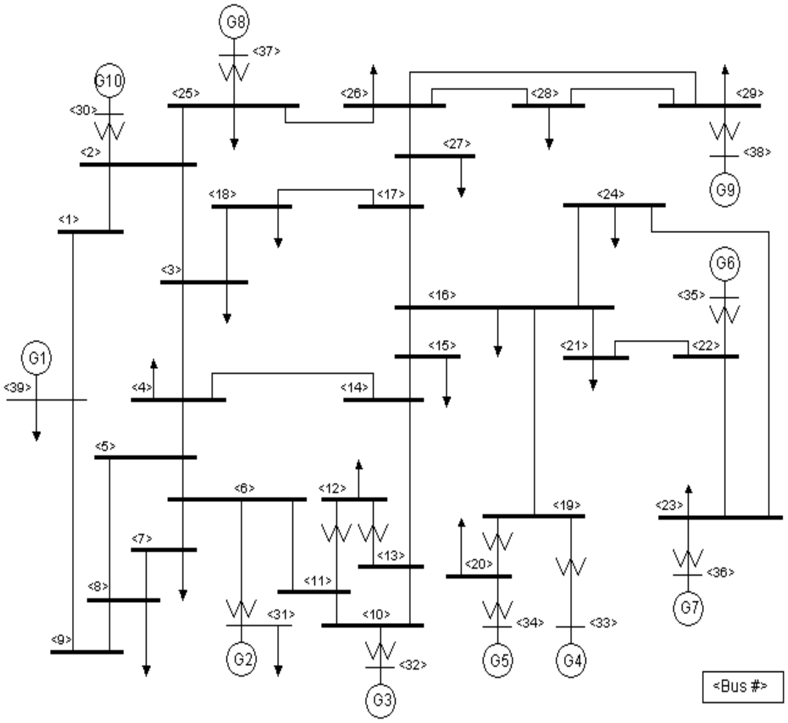


Figure 4.1 10-machine New-England Power System [38]

4.1.2 Basic Data and Characteristics

To simulation the Test System and to evaluate the system losses and the optimum generation dispatch, we need to provide generator, line, transformer, and load data. The appropriate data for the Test system appear in subsequent subsections.

4.1.2.1 Generator Data

Parameters for the two-axis model of the synchronous machine are shown in Table 4.1 and 4.2. All values are given on the same system base MVA.

Bus	Type	Voltage(pu)	P_{load}(MW)	Q_{load}(MVar)	P_g(MW)	Q_g(MVar)	Unit No.
30	PV	1.0475	0.0	0.0	250	-	Gen10
31	Slack	0.9820	9.2	4.6	1045.5	-	Gen2
32	PV	0.9831	0.0	0.0	650	-	Gen3
33	PV	0.9972	0.0	0.0	632	-	Gen4
34	PV	1.0123	0.0	0.0	508	-	Gen5
35	PV	1.0493	0.0	0.0	650	-	Gen6
36	PV	1.0635	0.0	0.0	560	-	Gen7
37	PV	1.0278	0.0	0.0	540	-	Gen8
38	PV	1.0265	0.0	0.0	830	-	Gen9
39	PV	1.0300	1104	250	1000	-	Gen1

Table 4.1 Generator data

Bus	Unit No.	P_g(MW)	P_{gmax}(MW)	P_{gmin}(MW)	a($/h)	b($/MWh)	c($/MW^{2}h)
30	Gen10	250	350	42	20	5.2	0.0100
31	Gen2	1045.5	1145.5	137.56	10	6.3	0.0030
32	Gen3	650	750	90	30	5.5	0.0055
33	Gen4	632	732	87.84	20	8.0	0.0065
34	Gen5	508	608	72.96	10	9.5	0.0050
35	Gen6	650	750	90	40	7.0	0.0058
36	Gen7	560	660	79.20	40	1.2	0.0030
37	Gen8	540	640	76.80	20	1.3	0.0012
38	Gen9	830	930	111.60	10	1.2	0.0010
39	Gen1	1000	1100	132	10	2.0	0.0014

Table 4.2 Generator cost co-efficient [38]

4.1.2.2 Line/Transformer Data

The network data for the Test System is shown in the Table 4.3. All values are given on the same system base MVA.

From Bus	To Bus	R	X	B	Magnitude	Angle
1	2	0.0035	0.0411	0.6987	0	0
1	39	0.001	0.025	0.75	0	0
2	3	0.0013	0.0151	0.2572	0	0
2	25	0.007	0.0086	0.146	0	0
3	4	0.0013	0.0213	0.2214	0	0
3	18	0.0011	0.0133	0.2138	0	0
4	5	0.0008	0.0128	0.1342	0	0
4	14	0.0008	0.0129	0.1382	0	0
5	6	0.0002	0.0026	0.0434	0	0
5	8	0.0008	0.0112	0.1476	0	0
6	7	0.0006	0.0092	0.113	0	0
6	11	0.0007	0.0082	0.1389	0	0
7	8	0.0004	0.0046	0.078	0	0
8	9	0.0023	0.0363	0.3804	0	0
9	39	0.001	0.025	1.2	0	0
10	11	0.0004	0.0043	0.0729	0	0
10	13	0.0004	0.0043	0.0729	0	0
13	14	0.0009	0.0101	0.1723	0	0
14	15	0.0018	0.0217	0.366	0	0
15	16	0.0009	0.0094	0.171	0	0
16	17	0.0007	0.0089	0.1342	0	0
16	19	0.0016	0.0195	0.304	0	0
16	21	0.0008	0.0135	0.2548	0	0
16	24	0.0003	0.0059	0.068	0	0
17	18	0.0007	0.0082	0.1319	0	0
17	27	0.0013	0.0173	0.3216	0	0
21	22	0.0008	0.014	0.2565	0	0
22	23	0.0006	0.0096	0.1846	0	0
23	24	0.0022	0.035	0.361	0	0
25	26	0.0032	0.0323	0.513	0	0
26	27	0.0014	0.0147	0.2396	0	0
26	28	0.0043	0.0474	0.7802	0	0

Table 4.3 Line data

4.1.2.3 Power and Voltage Set-points

Table 4.4 tabulates the bus data. All values are given on the same system base MVA. Note that generator 2 is the swing node.

Bus	Type	Voltage [PU]	Load		Generator		
			MW	MVar	MW	MVar	Unit NO.
1	PQ	-	0.0	0.0	0.0	0.0	
2	PQ	-	0.0	0.0	0.0	0.0	
3	PQ	-	322.0	2.4	0.0	0.0	
4	PQ	-	500.0	184.0	0.0	0.0	
5	PQ	-	0.0	0.0	0.0	0.0	
6	PQ	-	0.0	0.0	0.0	0.0	
7	PQ	-	233.8	84.0	0.0	0.0	
8	PQ	-	522.0	176.0	0.0	0.0	
9	PQ	-	0.0	0.0	0.0	0.0	
10	PQ	-	0.0	0.0	0.0	0.0	
11	PQ	-	0.0	0.0	0.0	0.0	
12	PQ	-	7.5	88.0	0.0	0.0	
13	PQ	-	0.0	0.0	0.0	0.0	
14	PQ	-	0.0	0.0	0.0	0.0	
15	PQ	-	320.0	153.0	0.0	0.0	
16	PQ	-	329.0	32.3	0.0	0.0	
17	PQ	-	0.0	0.0	0.0	0.0	
18	PQ	-	158.0	30.0	0.0	0.0	
19	PQ	-	0.0	0.0	0.0	0.0	
20	PQ	-	628.0	103.0	0.0	0.0	
21	PQ	-	274.0	115.0	0.0	0.0	
22	PQ	-	0.0	0.0	0.0	0.0	
23	PQ	-	247.5	84.6	0.0	0.0	
24	PQ	-	308.6	-92.0	0.0	0.0	
25	PQ	-	224.0	42.2	0.0	0.0	

Table 4.4 Bus Data (cont.)

Bus	Type	Voltage [PU]	Load		Generator		
			MW	MVar	MW	MVar	Unit NO.
26	PQ	-	139.0	17.0	0.0	0.0	
27	PQ	-	281.0	75.5	0.0	0.0	
28	PQ	-	206.0	27.6	0.0	0.0	
29	PQ	-	283.5	26.9	0.0	0.0	
30	PV	1.0475	0.0	0.0	250.0	-	Gen 10
31	Slack	0.982	9.2	4.6	1045.5	-	Gen2
32	PV	0.9831	0.0	0.0	650.0	-	Gen3
33	PV	0.9972	0.0	0.0	632.0	-	Gen4
34	PV	1.0123	0.0	0.0	508.0	-	Gen5
35	PV	1.0493	0.0	0.0	650.0	-	Gen6
36	PV	1.0635	0.0	0.0	560.0	-	Gen7
37	PV	1.0278	0.0	0.0	540.0	-	Gen8
38	PV	1.0265	0.0	0.0	830.0	-	Gen9
39	PV	1.03	1104.0	250.0	1000.0	-	Gen1

Table 4.5 Bus data

The results obtained by simulating the load model are summarized in Chapter 5. And the concluding remarks for extension of the ideas presented in the thesis for study of large scale systems such as Entergy Transmission System are written in Chapter 6.

5. Simulation & Analysis

5.1 Methodology

Chapter 5 is devoted to simulating the model described in Chapter 3 and the Test System represented by the IEEE 39-Bus System. For simulating the proposed test systems, we shall use Matpower in Matlab environment. We shall simulate “what if scenarios” using different load profile and optimization objective.

The study of Industrial loads operating in Louisiana resulted petro chemical to be ranked on top and pulp and paper 5th from top. We decided to focus on pulp and paper because; they are built to use less energy efficiency technology than the petrochemical industry and if there is an energy saving, then it will be more in pulp and paper than petrochemical. Initially, the 24 hour daily load profile of a pulp and paper plant (with cogeneration facility) is determined using the mean and variance of the curve plotted in [22]. Their approach to calculate the load profile along with an alternative way is described in Chapter 3. The Integrated system study is done by considering the IEEE 39 bus system with 10 generators and 19 loads. The details about the system are discussed in Chapter 4. Industrial plant with variable load is connected to one of the load buses (preferably one that has the power factor closer to that of pulp and paper, approximately 0.85) of the IEEE 39 bus system which is bus $s = 19$. Although to begin with, the system has 10 generating units, but since the plant is capable of producing power through cogeneration, the system now has 11 units in addition to one with cogeneration which is not really a full generating unit but serves the purpose at lower peaks when the cost is higher. It is assumed that the load is constant at every other bus except the bus with the industrial plant where it changes hourly. The system lambda, which is the cost of producing next MW over next hour by the utility, is determined by running economic dispatch problem on IEEE 39 bus system. If this amount is known, then the Smart Grid Transaction can be modeled based on what amount the utility wants to sell this next MWhr and see if the plant wants to sell the power through co-generation or buy from utility. The generator cost co-efficients a (\$/h), b (\$/MWh), c (\$/MW^{2}h); minimum and maximum values of the real power of generators are determined using [37] and PowerWorld software, losses are calculated from load flow, and Optimal power flow is run using Matpower from Matlab environment to compute the Total fuel cost (\$/h), System Lambda (\$/MWh), Real power of the 10 generating units (MW), Total Generation (MW), Total Load (MW), Losses (MW). Table 5.2, 5.3, 5.4, 5.5, 5.6, 5.7 are the three sets of tabulated results when the load is connected at three different buses.

5.2 Results & Analysis

The optimal power flow is run on IEEE 39-Bus Test System consisting of 19 loads and 10 generating units using Matpower. The bus data (Table 4.4, 4.5), generator data (table 4.1), branch data (Table 4.3), and generator cost data (a, b, c values tabulated in columns 6, 7, 8 of Table 5.1) are given as the input to the solver. The Test system is connected with Industrial load at one of the selected load bus i=s (for the study buses 21, 7, and 23 are selected). It is assumed that the load is constant at every other bus except the bus with the industrial plant where it changes hourly (Figure 5.1)

Bus	Unit No.	P_G(MW)	P_{Gmax}(MW)	P_{Gmin}(MW)	a($/h)	b($/MWh)	c($/MW^{2}h)
30	Gen10	250	350	42	20	5.2	0.0100
31	Gen2	1045.5	1145.5	137.56	10	6.3	0.0030
32	Gen3	650	750	90	30	5.5	0.0055
33	Gen4	632	732	87.84	20	8.0	0.0065
34	Gen5	508	608	72.96	10	9.5	0.0050
35	Gen6	650	750	90	40	7.0	0.0058
36	Gen7	560	660	79.20	40	1.2	0.0030
37	Gen8	540	640	76.80	20	1.3	0.0012
38	Gen9	830	930	111.60	10	1.2	0.0010
39	Gen1	1000	1100	132	10	2.0	0.0014

Table 5.1 Generator cost data

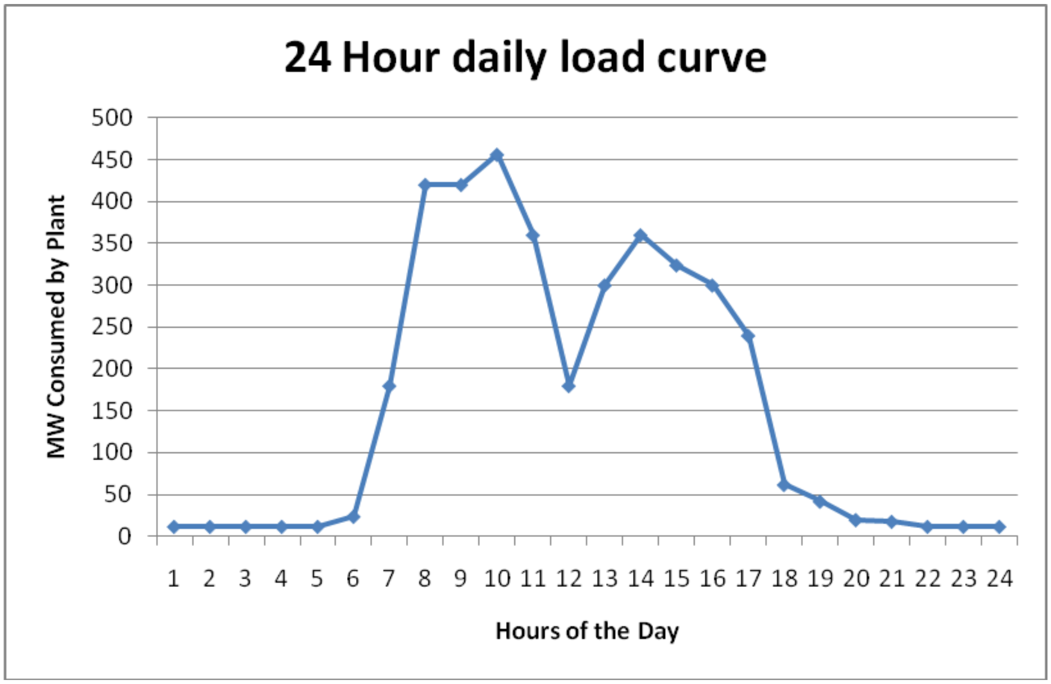


Figure 5.1 24-hour load variation of a typical industrial plant

The hourly results of the OPF problem are presented with two sets of tables showcasing the variation in total fuel cost, system lambda, power from each generating unit to meet the demand at that hour, total generation, total demand and the losses at each hour, when the load is connected to bus # 21 (Table 5.2, 5.3), # 7 (Table 5.4, 5.5), and # 23 (Table 5.6, 5.7).

Hour	Load(MW)	Cost($/hr)	Lambda($/MWh)	P_{G1}	P_{G2}	P_{G3}	P_{G4}
base	274	39127.45	14.705	288.72	172.65	703.34	502.29
1	29.92	35641.7	13.86	287.86	150.25	680.22	445.53
2	29.92	35641.7	13.86	287.86	150.25	680.22	445.53
3	29.92	35641.7	13.86	287.86	150.25	680.22	445.53
4	32.34	35675.25	13.868	287.87	150.47	680.45	446.09
5	31.49	35663.47	13.865	287.87	50.4	680.37	445.89
6	59.35	36051.09	13.961	287.98	152.94	683.01	452.36
7	265.25	38998.92	14.674	288.69	171.84	702.51	500.25
8	599.55	44101.02	15.855	289.55	202.94	734.18	578.35
9	639.52	44738.45	16.081	289.69	208.9	740.23	593.57
10	632.25	44621.76	16.022	289.65	207.33	738.64	589.48
11	676.34	45336.08	16.382	289.86	216.92	748.38	614.46
12	347.25	40213.95	14.961	288.94	179.42	710.27	519.37
13	516.82	42801.57	15.56	289.37	195.19	726.33	558.97
14	551.10	43337.04	15.682	289.45	198.39	729.57	566.99
15	569.27	43622.57	15.747	289.49	200.09	731.3	571.24
16	454.20	41834.16	15.338	289.22	189.35	720.39	544.33
17	479.64	42225.5	15.428	289.28	191.72	722.8	550.28
18	320.97	39821.99	14.869	288.86	176.99	707.78	513.24
19	109.01	36748.64	14.132	288.16	157.48	687.72	463.9
20	44.45	35843.45	13.91	287.92	151.58	681.6	448.9
21	41.18	35797.98	13.899	287.91	151.28	681.29	448.14
22	38.76	35764.36	13.89	287.9	151.06	681.06	447.58
23	38.76	35764.36	13.89	287.9	151.06	681.06	447.58
24	38.76	35764.36	13.89	287.9	151.06	681.06	447.58

Table 5.2 hourly results when load is connected to bus 21 (cont.)

Table 5.3 is the continuation of Table 5.2

Hour	P_{G5}	P_{G6}	P_{G7}	P_{G8}	P_{G9}	P_{G10}	P_{Gt}	P_{Dt}	P_L
base	502.73	651.09	660	640	930	1100	6150.82	6097.3	53.519
1	431.04	580.7	660	640	930	1100	5905.6	5853.22	52.383
2	431.04	580.7	660	640	930	1100	5905.6	5853.22	52.383
3	431.04	580.7	660	640	930	1100	5905.6	5853.22	52.383
4	431.75	581.39	660	640	930	1100	5908.03	5855.64	52.388
5	431.5	581.15	660	640	930	1100	5907.18	5854.79	52.386
6	439.68	589.14	660	640	930	1100	5935.1	5882.65	52.451
7	500.16	648.55	660	640	930	1100	6142.01	6088.55	53.457
8	598.42	746.44	660	640	930	1100	6479.87	6422.85	57.024
9	608	750	660	640	930	1100	6520.39	6462.82	57.567
10	607.94	750	660	640	930	1100	6513.04	6455.55	57.489
11	608	750	660	640	930	1100	6557.62	6499.64	57.983
12	524.27	672.4	660	640	930	1100	6224.66	6170.55	54.111
13	574.12	722.07	660	640	930	1100	6396.04	6340.12	55.919
14	584.2	732.17	660	640	930	1100	6430.76	6374.4	56.359
15	589.53	737.53	660	640	930	1100	6449.17	6392.57	56.602
16	555.71	703.67	660	640	930	1100	6332.68	6277.5	55.8
17	563.19	711.14	660	640	930	1100	6358.41	6302.94	55.47
18	516.54	664.75	660	640	930	1100	6198.16	6144.27	53.885
19	454.26	603.4	660	640	930	1100	5984.92	5932.31	52.61
20	435.3	584.86	660	640	930	1100	5920.16	5867.75	52.414
21	434.34	583.92	660	640	930	1100	5916.89	5864.48	52.407
22	433.63	583.23	660	640	930	1100	5914.46	5862.06	52.401
23	433.63	583.23	660	640	930	1100	5914.46	5862.06	52.401
24	433.63	583.23	660	640	930	1100	5914.46	5862.06	52.401

Table 5.3 hourly results when load is connected to bus 21

Cost ($/MW), which is sum of the quadratic costs of each generating units (Equation 3.2), is minimized using OPF considering the optimal powers P_{G1}, P_{G2}, …, P_{G10} of the generating units. The total power from the generating units satisfies the load plus losses ($P_{Gt} = P_{Dt} + P_L$) at every hour. The losses in the system are determined by load flow study.

At hour 1 when the load is 6097.3MW (32.88 from the Industrial plant), performing optimization the total fuel cost is 35680.13$/MW with the lambda equal to 13.87$/MWh. The loss in the system obtained through load flow is 53.519MW. When the optimal power from each generating unit is added results the amount (6150.82 at hour 1) which is equal to the sum of the total load on the system and the losses.

Table 5.4, 5.5 is the hourly result of the Optimal Power Flow program when the load is connected to bus 7 which tabulates the total fuel cost, lambda, and power from each generating unit, total generation, total load and losses in the system at each hour.

Hour	Load(MW)	Cost($/hr)	Lambda($/MWh)	P_{G1}	P_{G2}	P_{G3}	P_{G4}
base	274	39127.45	14.705	288.72	172.65	703.34	502.29
1	29.92	35641.7	13.86	287.86	150.25	680.22	445.53
2	29.92	35641.7	13.86	287.86	150.25	680.22	445.53
3	29.92	35641.7	13.86	287.86	150.25	680.22	445.53
4	32.34	35675.25	13.868	287.87	150.47	680.45	446.09
5	31.49	35663.47	13.865	287.87	50.4	680.37	445.89
6	59.35	36051.09	13.961	287.98	152.94	683.01	452.36
7	265.25	38998.92	14.674	288.69	171.84	702.51	500.25
8	599.55	44101.02	15.855	289.55	202.94	734.18	578.35
9	639.52	44738.45	16.081	289.69	208.9	740.23	593.57
10	632.25	44621.76	16.022	289.65	207.33	738.64	589.48
11	676.34	45336.08	16.382	289.86	216.92	748.38	614.46
12	347.25	40213.95	14.961	288.94	179.42	710.27	519.37
13	516.82	42801.57	15.56	289.37	195.19	726.33	558.97
14	551.10	43337.04	15.682	289.45	198.39	729.57	566.99
15	569.27	43622.57	15.747	289.49	200.09	731.3	571.24
16	454.20	41834.16	15.338	289.22	189.35	720.39	544.33
17	479.64	42225.5	15.428	289.28	191.72	722.8	550.28
18	320.97	39821.99	14.869	288.86	176.99	707.78	513.24
19	109.01	36748.64	14.132	288.16	157.48	687.72	463.9
20	44.45	35843.45	13.91	287.92	151.58	681.6	448.9
21	41.18	35797.98	13.899	287.91	151.28	681.29	448.14
22	38.76	35764.36	13.89	287.9	151.06	681.06	447.58
23	38.76	35764.36	13.89	287.9	151.06	681.06	447.58
24	38.76	35764.36	13.89	287.9	151.06	681.06	447.58

Table 5.4 hourly results when load is connected to bus 7 (cont.)

Table 5.5 is the continuation of Table 5.4

Hour	P_{G5}	P_{G6}	P_{G7}	P_{G8}	P_{G9}	P_{G10}	P_{Gt}	P_{Dt}	P_L
base	502.73	651.09	660	640	930	1100	6150.82	6097.3	53.519
1	431.04	580.7	660	640	930	1100	5905.6	5853.22	52.383
2	431.04	580.7	660	640	930	1100	5905.6	5853.22	52.383
3	431.04	580.7	660	640	930	1100	5905.6	5853.22	52.383
4	431.75	581.39	660	640	930	1100	5908.03	5855.64	52.388
5	431.5	581.15	660	640	930	1100	5907.18	5854.79	52.386
6	439.68	589.14	660	640	930	1100	5935.1	5882.65	52.451
7	500.16	648.55	660	640	930	1100	6142.01	6088.55	53.457
8	598.42	746.44	660	640	930	1100	6479.87	6422.85	57.024
9	608	750	660	640	930	1100	6520.39	6462.82	57.567
10	607.94	750	660	640	930	1100	6513.04	6455.55	57.489
11	608	750	660	640	930	1100	6557.62	6499.64	57.983
12	524.27	672.4	660	640	930	1100	6224.66	6170.55	54.111
13	574.12	722.07	660	640	930	1100	6396.04	6340.12	55.919
14	584.2	732.17	660	640	930	1100	6430.76	6374.4	56.359
15	589.53	737.53	660	640	930	1100	6449.17	6392.57	56.602
16	555.71	703.67	660	640	930	1100	6332.68	6277.5	55.8
17	563.19	711.14	660	640	930	1100	6358.41	6302.94	55.47
18	516.54	664.75	660	640	930	1100	6198.16	6144.27	53.885
19	454.26	603.4	660	640	930	1100	5984.92	5932.31	52.61
20	435.3	584.86	660	640	930	1100	5920.16	5867.75	52.414
21	434.34	583.92	660	640	930	1100	5916.89	5864.48	52.407
22	433.63	583.23	660	640	930	1100	5914.46	5862.06	52.401
23	433.63	583.23	660	640	930	1100	5914.46	5862.06	52.401
24	433.63	583.23	660	640	930	1100	5914.46	5862.06	52.401

Table 5.5 hourly results when load is connected to bus 7

Table 5.6, 5.7 is the hourly result of the Optimal Power Flow program when the load is connected to bus 23 and which tabulates the total fuel cost, lambda, and power from each generating unit, total generation, total load and losses in the system at each hour.

Hour	Load(MW)	Cost($/hr)	Lambda($/MWh)	P_{G1}	P_{G2}	P_{G3}	P_{G4}
base	247.5	39127.45	14.551	288.72	172.65	703.34	502.29
1	27.02	36004.09	13.784	287.89	152.88	682.76	452.04
2	27.02	36004.09	13.784	287.89	152.88	682.76	452.04
3	27.02	36004.09	13.784	287.89	152.88	682.76	452.04
4	29.21	36034.28	13.791	287.9	153.08	682.96	452.54
5	28.45	36023.8	13.789	287.89	153.01	682.89	452.36
6	53.61	36371.82	13.876	288	155.25	685.24	458.09
7	239.60	39012.61	14.523	288.69	171.93	702.6	500.49
8	541.56	43558.92	15.593	289.57	199.35	730.79	569.66
9	577.67	44124.33	15.725	289.65	202.71	734.23	578.09
10	571.10	44021.11	15.7	289.64	202.06	733.57	576.47
11	610.93	44650.03	15.912	289.77	207.55	739.17	590.42
12	313.67	40097.95	14.783	288.94	178.62	709.51	517.42
13	466.84	42403.79	15.326	289.38	192.53	723.81	552.5
14	497.80	42879.99	15.437	289.46	195.35	726.71	559.61
15	514.21	43133.78	15.495	289.5	196.85	728.24	563.38
16	410.27	41542.49	15.125	289.22	187.38	718.53	539.53
17	433.25	41891	15.206	289.29	189.47	720.67	544.8
18	289.93	39747.99	14.7	288.86	176.48	707.3	511.99
19	98.47	36997.77	14.031	288.18	159.26	689.43	468.3
20	40.15	36185.37	13.861	287.94	154.05	683.98	455.02
21	37.20	36144.59	13.819	287.93	153.79	683.71	454.35
22	35.01	36114.33	13.811	287.92	153.59	683.5	453.86
23	35.01	36114.33	13.811	287.92	153.59	683.5	453.86
24	35.01	36114.33	13.811	287.92	153.59	683.5	453.86

Table 5.6 hourly results when load is connected to bus 23 (cont.)

Table 5.7 is the continuation of Table 5.6

Hour	P_{G5}	P_{G6}	P_{G7}	P_{G8}	P_{G9}	P_{G10}	P_{Gt}	P_{Dt}	P_L
Base	502.73	651.09	660	640	930	1100	6150.82	6097.3	53.519
1	439.28	586.83	660	640	930	1100	5931.68	5876.82	54.857
2	439.28	586.83	660	640	930	1100	5931.68	5876.82	54.857
3	439.28	586.83	660	640	930	1100	5931.68	5876.82	54.857
4	439.91	587.47	660	640	930	1100	5933.85	5879.01	54.837
5	439.69	587.25	660	640	930	1100	5933.09	5878.25	54.844
6	446.92	594.53	660	640	930	1100	5958.03	5903.41	54.625
7	500.46	648.77	660	640	930	1100	6142.94	6089.4	53.544
8	587.56	738.21	660	640	930	1100	6445.13	6391.36	53.773
9	598.13	748.63	660	640	930	1100	6481.43	6427.47	53.963
10	596.1	746.99	660	640	930	1100	6474.82	6420.9	53.925
11	607.99	750	660	640	930	1100	6514.91	6460.73	54.176
12	521.81	670.55	660	640	930	1100	6216.85	6163.47	53.376
13	565.99	715.92	660	640	930	1100	6370.13	6316.64	53.492
14	574.92	725.14	660	640	930	1100	6401.19	6347.6	53.591
15	579.66	730.04	660	640	930	1100	6417.66	6364.01	53.653
16	549.67	699.11	660	640	930	1100	6313.45	6260.07	53.377
17	556.3	705.93	660	640	930	1100	6336.46	6283.05	53.413
18	514.96	663.56	660	640	930	1100	6193.14	6139.73	53.414
19	459.82	607.56	660	640	930	1100	6002.55	5948.27	54.277
20	445.74	593.34	660	640	930	1100	5944.69	5889.95	54.74
21	442.21	589.78	660	640	930	1100	5941.77	5887	54.766
22	441.58	589.14	660	640	930	1100	5939.6	5884.81	54.785
23	441.58	589.14	660	640	930	1100	5939.6	5884.81	54.785
24	441.58	589.14	660	640	930	1100	5939.6	5884.81	54.785

Table 5.7 hourly results when load is connected to bus 23

The results tabulated in the Table 5.2 – 5.7 are obtained by solving optimal power flow using the interior point optimization described in Section 3.5 and is integrated in the Matpower tool of Matlab environment.

With the cogeneration facility of the Industrial plant attached to the selected load bus, the IEEE 39-Bus Test System which had ten generating units will now have eleven units (considering the cogeneration as a reliable source of electrical energy). If we assume that the plant considered for the study has a capability to produce 100MW of power through cogeneration, then the plant can make use of this electricity during lower peaks of the load (when it is less than 100MW) or when the price of electricity for which it buys from utility is large comparatively. And, after satisfying the need at the lower peaks of the load profile, plant can sell the leftover electricity produced through cogeneration to the utility. This transaction is based on the value of Lambda at each hour which is generally considered constant for normal daily utility operation. But, with the variable load and with the values of lambda varying for every hour, the transactions are made based on the actual hourly cost rather than considering the estimated values for Lambda and constant load profile throughout the day. The hourly benefit to the plant connected to the selected bus # 21 # 7, #23 are tabulated in Table 5.8, 5.9, 5.10 respectively.

Hours	Load at Bus-21	Lambda($/MWh)	Excess Cogen MW	Benefit ($/h)
1	29.92	14.71	70.08	1030.57
2	29.92	13.86	70.08	971.35
3	29.92	13.86	70.08	971.35
4	32.34	13.86	67.66	937.78
5	31.49	13.87	68.51	950.08
6	59.35	13.87	40.65	563.62
7	265.25	13.96	-165.25	-2307.11
8	599.55	14.67	-499.55	-7330.35
9	639.52	15.86	-539.52	-8554.04
10	632.25	16.08	-532.25	-8559.10
11	676.34	16.02	-576.34	-9234.08
12	347.25	16.38	-247.25	-4050.49
13	516.82	14.96	-416.82	-6236.07
14	551.10	15.56	-451.10	-7019.10
15	569.27	15.68	-469.27	-7359.04
16	454.20	15.75	-354.20	-5577.62
17	479.64	15.34	-379.64	-5822.88
18	320.97	15.43	-220.97	-3409.12
19	109.01	14.87	-9.01	-133.95
20	44.45	14.13	55.55	785.01
21	41.18	13.91	58.82	818.17
22	38.76	13.90	61.24	851.19
23	38.76	13.89	61.24	850.64
24	38.76	13.87	61.24	849.42
	274.00			-66013.74

Table 5.8 Hourly benefit to the plant when load is connected to bus 21

The forth column of the Table 5.8 is the MW leftover from cogeneration (100MW minus hourly load). The positive values indicate that the plant can sell this electricity to the utility and the negative values indicate that the plant has to buy this electricity from the utility. The fifth column is the hourly benefit to the plant. Adding all the values in this column gives the price of electricity for the day.

Table 5.9 is when the plant is connected to the Bus 7 and gives the hourly details for the Cogeneration electricity leftover and the benefit to the plant by selling this cogenerated electricity to the utility.

Hours	Load at Bus-7	Lambda($/MWh)	Excess Cogen MW	Benefit ($/h)
1	25.53	13.94	74.47	1038.37
2	25.53	13.94	74.47	1038.37
3	25.53	13.94	74.47	1038.37
4	27.59	13.95	72.41	1010.20
5	26.87	13.95	73.13	1020.08
6	50.64	14.05	49.36	693.53
7	226.34	16.36	-126.34	-2066.62
8	511.58	22.77	-411.58	-9373.01
9	545.69	24.60	-445.69	-10963.97
10	539.49	24.29	-439.49	-10674.74
11	577.11	26.24	-477.11	-12517.89
12	296.31	17.63	-196.31	-3460.47
13	441.00	20.32	-341.00	-6928.35
14	470.24	21.04	-370.24	-7789.93
15	485.75	21.51	-385.75	-8297.80
16	387.56	19.31	-287.56	-5551.42
17	409.27	19.72	-309.27	-6097.51
18	273.88	17.22	-173.88	-2994.36
19	93.02	14.23	6.98	99.41
20	37.93	14.00	62.07	868.74
21	35.14	13.99	64.86	907.08
22	33.07	13.98	66.93	935.38
23	33.07	13.98	66.93	935.38
24	33.07	13.98	66.93	935.38
	233.80			-76195.78

Table 5.9 Hourly benefit to the plant when load is connected to bus 7

According to Table 5.6, for the base case with fixed load of 233.8MW hourly throughout the day, the lambda value to purchase electricity from the utility is 16.493$/MWh. But, with the variable load for this average 233.8MW at every hour, there is variation in the value of lambda.

This variation in lambda results in the hourly costs, i.e., after satisfying the need, the cogenerated electricity leftover at the plant is sold to the utility at this price.

Table 5.10 details about the electricity consumed at every hour and the costs associated with MW utilized and generated when the plant is connected to load bus 23.

Hours	Load at Bus-23	Lambda($/Mwh)	Excess Cogen MW	Benefit ($/h)
1	27.02	13.78	72.98	1005.91
2	27.02	13.78	72.98	1005.91
3	27.02	13.78	72.98	1005.91
4	29.21	13.79	70.79	976.24
5	28.45	13.79	71.55	986.66
6	53.61	13.88	46.39	643.72
7	239.60	14.52	-139.60	-2027.41
8	541.56	15.59	-441.56	-6885.27
9	577.67	15.73	-477.67	-7511.29
10	571.10	15.70	-471.10	-7396.29
11	610.93	15.91	-510.93	-8129.84
12	313.67	14.78	-213.67	-3158.65
13	466.84	15.33	-366.84	-5622.14
14	497.80	15.44	-397.80	-6140.82
15	514.21	15.50	-414.21	-6418.18
16	410.27	15.13	-310.27	-4692.89
17	433.25	15.21	-333.25	-5067.39
18	289.93	14.70	-189.93	-2791.93
19	98.47	14.03	1.53	21.53
20	40.15	13.86	59.85	829.55
21	37.20	13.82	62.80	867.86
22	35.01	13.81	64.99	897.58
23	35.01	13.81	64.99	897.58
24	35.01	13.81	64.99	897.58
	247.50			-55806.09

Table 5.10 Hourly benefit to the plant when load is connected to bus 23

At every selected load bus, a comparison for the daily costs is done based on the three cases and is tabulated in Table 5.12 –

a) The lambda at the plant is more than the lambda at the utility, and to increase the margin, the plant shuts off the cogeneration and buys the electricity from the utility (the plant lambda and the utility lambda are equal in the study). In this case, the load on the bus is fixed throughout the day and the lambda value is constant, Table 5.11.

b) The lambda value is constant, the load is fixed throughout the day, but the plant utilizes the cogenerated electricity of 100MW and the remaining MW is bought from the utility, Table 5.11.

c) For this case, the cogenerated electricity is constant with 100MW throughout the day, but the load varies hourly.

Bus No.	Load	Lambda	MW needed	w/o Cogen fixed load	w/ Cogen Fixed Load
21	274.00	14.71	174.00	96700.08	61408.08
7	233.80	16.49	133.80	92545.52	52962.32
23	247.50	14.55	147.50	86432.94	51510.54

Table 5.11 Price of Electricity with fixed load

Table 5.11 shows the decrease in the price of electricity when there is cogeneration facility, but the prices are the estimated values which are based on fixed load throughout the day. For the actual price, the variable load over 24-hour period is to be considered. The price of electricity for each case (a), (b), and (c) is tabulated in Table 5.12.

Bus No.	w/o Cogen fixed load	w/ Cogen fixed load	w/ CogenVar Load
21	96700.08	61408.08	66013.74
7	92545.52	52962.32	76195.78
23	86432.94	51510.54	55806.09

Table 5.12 Comparison for case (a), (b), (c)

The last column of the Table 5.12 is the price of electricity for 24-hour period at the selected bus # 21, # 7, #23 with variable load profile for the Industrial Plant. The prices in case (c) may be a little higher when compared with those of case (b), but with the hourly data, the Smart Grid Transaction is modeled, and this hourly variable load and the varying values of lambda are available at the plant and the utility so that the utility and the industrial plant may exchange the electricity in a beneficial way. Continuing this process will eventually reduce the price of electricity that is purchased from the utility and also the higher peaks of load on the utility.

6. Concluding Remarks and Future Work

6.1 Conclusions

The thesis proposed a methodology which can identify the benefit of designing a user – (utility and industry) friendly system that increases the efficiency and reliability by promoting two-way communication to optimally exchange the available electricity with the help of smart grid technologies. System lambda which is the minimum cost of producing the next megawatt-hour by a typical utility is determined by running OPF program on the IEEE 39-Bus Test System connected with an industrial plant with load variation using Matpower. The Industrial activities, their ranking based on energy consumption, statistical mean and variance of the data which is proposed previously were used to generate the hourly load profile of a typical Industrial plant used in the study.

Chapter 1 addressed the information about Utility and Industry operations, and the meaning of Integrated Industrial Electric System. Brief notes on Smart Grid, its Technologies and the anticipated saving with the use of these technologies is presented in the later parts of the chapter.

In Chapter 2, the industries operating in Louisiana, their load profiles and electric energy consumption patterns were investigated with a little higher concentration on fuel and energy consumption costs of Pulp and Paper manufacturing plant.

A typical 120MW pulp and paper manufacturing plant is modeled in Chapter 3 by considering the mean and variance of a low voltage industrial manufacturing plant. The mathematical formulation of OPF problem to calculate the lambda by minimizing the fuel cost, and the load flow program to calculate the losses in the system are presented in the chapter. Based on the variable load of the industrial plant and the lambda values, the Smart Grid Transaction proposal is described where utility and industry can exchange electricity in a beneficial way.

The description of test system represented by IEEE 39-Bus System is given in Chapter 4 along with the collected data for simulation.

In Chapter 5, a methodology for smart grid transaction was proposed, and combination of the developed 24-hour load profile of Chapter 3 and optimal power flow programs were used to determine the minimum dollar per mega-watt hour of energy produced by the IEEE 39-Bus Test System connected with industrial load at one of the selected load buses. To calculate the lambda at each hour, the proposed test system is simulated using MatPower and the results obtained were tabulated to compare the difference between the cost associated with fixed and variables daily loads.

Chapter 6 is devoted to summarizing the work and to make concluding remarks for extension of the ideas presented in the thesis for study of large scale systems such as Entergy Transmission System.

The load profile of the industrial plant which is considered constant throughout the day is converted to 24 hour variable load based on the average daily load and the mean, standard deviation of the low voltage plant resulting in the hourly values of lambda for the selected load buses. The IEEE 39-Bus Test System which had ten generating units will have eleven units because of the cogeneration facility of the Industrial plant attached to the selected load bus. This excess cogenerated electricity can be sold to the utility when the cost to purchase electricity from the utility is high comparatively. The cost to purchase electricity from the utility based on three cases – fixed load without cogeneration facility, fixed load with cogeneration facility and variable load with cogeneration facility were compared. A Smart Grid Transaction Display when modeled and installed in the utility and the industrial plant will have the hourly values fed into it so that they are available at both ends to optimally exchange the electricity.

6.2 Future Work

A typical Industrial plant shall be modeled by considering different activities and their percentage of energy consumption from the total available generation. While we only considered one bus as the load bus (one industrial plant) in the study, many load buses with varying profiles may be considered in future studies. Likewise, while we only considered one utility in the study, utilization of smart grid technologies may be implemented between utilities for further development of the work. The results obtained can be compared with different optimization techniques and/or an optimization technique can be developed to improve the accuracy.

A Smart Grid Transaction Display need to be developed and installed at Utility and the Plant so that the hourly information is available at both ends and they can adopt the profitable scheme for exchanging the electricity.

As a first step for the proposed methodology, the approximate load profile of the plant is considered based on the mean and variance of the low voltage industrial activities. Instead, creation of actual load profile of the typical industrial plants – one profile for each type of industry, should be modeled by looking at the previous records of the of the utility and plant.

The Optimal Power Flow program on IEEE 39 bus system is run using MatPower to calculate the Lambda at every hour. In future, inclusion and study of different OPF programs should be done in order to choose the best technique that is more efficient among those that are available.

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Definitions

1. Barrel: A volumetric unit of measure equivalent to 42 U.S. gallons.
2. British thermal unit (Btu): The quantity of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit. Once generated, one kWh is equivalent to 3,412 Btu
3. Census Division: A geographic area consisting of several States defined by the U.S. Department of Commerce, Bureau of the Census (see the map in Appendix E). The States are grouped into four regions and nine divisions.

Region	Division	States
Northeast	New England	Connecticut, Maine, Massachusetts, New Hampshire, Vermont, and Rhode Island
	Middle Atlantic	New Jersey, New York, and Pennsylvania
Midwest	East North Central	Illinois, Indiana, Michigan, Ohio, and Wisconsin
	West North Central	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota
South	South Atlantic	Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia
	East South Central	Alabama, Kentucky, Mississippi, and Tennessee
	West South Central	Arkansas, **Louisiana**, Oklahoma, and Texas
West	Mountain	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming
	Pacific	Alaska, California, Hawaii, Oregon, and Washington

4. Cogeneration: The production of electrical energy and another form of useful energy (such as heat or steam) through the sequential use of energy.

5. Demand-Side Management (DSM): A term used to describe a variety of programs sponsored by utility companies to encourage customers to modify their energy use. In general, DSM programs are designed to reduce demand or to modify patterns of demand as an alternative to adding new capacity.
6. Electricity Demand: Electricity demand is the amount of electricity actually consumed onsite, regardless of where or how it was produced. It is a useful measure of electricity consumption without regard to the consumption of other energy sources. Electricity demand is estimated as the sum of electricity purchases, transfers in, and total onsite generation minus the quantities of electricity sold or transferred offsite.
7. Electric Utility: A legal entity engaged in the generation, transmission, distribution, or sale of electric energy, primarily for use by the public; legally obligated to provide service to the public within its franchised area; and required to file forms listed in the Code of Federal Regulations, Title 18, Part 141. Independent power producers and facilities that qualify as co-generators or small power producers under the Public Utility Regulatory Policies Act are not considered electric utilities. See Nonutility Power Producers.
8. End Use: A use for which total input energy for heat, power, and electricity generation is consumed at the manufacturing establishment. In end-use estimates presented in this report, nonfuel uses of energy sources are not considered. End users in this report include three broad categories: indirect uses, direct uses, and direct non-process.
9. Fuel: Any substance that can be burned to produce heat or power.
10. Fuel-Switching Capability: The short-term capability of a manufacturing establishment to have used substitute energy sources in place of those actually consumed. Capability to use substitute energy sources means that the establishment’s combustors (for example, boilers, furnaces, ovens, and blast furnaces) had the machinery or equipment either in place or available for installation so that substitutions could actually have been introduced within 30 days without extensive modifications. Fuel-switching capability does not depend on the relative prices of energy sources; it depends only on the characteristics of the equipment and certain legal constraints.
11. Industrial Sector: Comprises manufacturing industries that make up the largest part of the sector along with mining, construction, agriculture, fisheries, and forestry. Establishments in this sector range from steel mills, to small farms, to companies assembling electronic components. The SIC codes used to classify establishments as industrial are 1 through 39.
12. Local Distribution Company (LDC): A legal entity engaged primarily in the retail sale and/or delivery of natural gas through a distribution system that includes mainlines (that is, pipelines designed to carry large volumes of gas, usually located under roads or other major right-of-ways) and laterals (that is, pipelines of smaller diameter that connect the end user to the mainline). Since the restructuring of the gas industry, the sale of gas and/or delivery arrangements may be handled by other agents, such as producers, brokers, and marketers that are referred to as "non-LDC."
13. Manufacturing Division: One of 10 fields of economic activity defined by the Standard Industrial Classification Manual. The manufacturing division includes all establishments engaged in the mechanical or chemical transformation of materials or substances into new products. The other divisions of the U.S. economy are agriculture, forestry, fishing, hunting, and trapping; mining; construction; transportation, communications, electric, gas, and sanitary services; wholesale trade; retail trade; finance, insurance, and real estate; personal, business, professional, repair, recreation, and other services; and public administration. The establishments in the manufacturing division constitute the universe for the MECS.
14. Nonutility Power Producer: A legal entity that owns electric generating capacity and is not an electric utility. Includes qualifying co-generators, qualifying small power producers, and other nonutility generators (including independent power producers) with a franchised area and not required to file forms listed in the Code of Federal Regulations. See Electric Utility.
15. North American Industrial Classification System (NAICS): A new classification scheme, developed by the Office of Management and Budget to replace the Standard Industrial Classification (SIC) System, that categorizes establishments according to the types of production processes they primarily use.
16. Public Utility Regulatory Policies Act of 1978 (PURPA): One part of the National Energy Act of 1978, this legislation contains measures designed to encourage the conservation of energy, more efficient use of resources, and equitable rates. Principal among those measures were suggested retail rate reforms and new incentives for production of electricity by co-generators and users of renewable resources. The authority for implementing several key PURPA programs is held by an independent regulatory agency within the U.S. Department of Energy.

17. Quad: Quadrillion BTU - Equivalent to 10^{15} Btu. This is the final demand, for which Electricity use is computed at 3,412 Btu/kWh. It includes petroleum products, natural gas, coal and non-purchased fuels such as – biomass. Including conversion losses in producing the electricity, Industry can be said to have used over 29 Quads of primary energy.
18. Renewable Energy: Energy obtained from essentially inexhaustible sources, which are not necessarily combustible. Combustible sources of renewable energy include wood harvested directly from trees, tree bark, and wood waste. Noncombustible sources include solar power, wind power, hydropower, and geothermal power.
19. Smart-Meters:-Smart Meters are among the fundamental building blocks of smart grid deployments. They track and report energy usage by time of day, enabling utilities to charge less for electricity used during off-peak hours.
20. Smart-Sensors refer to smart equipment places at key locations on the power grid. They sense what is happening with the electric load or with the assets on the grid and communicate this status back to the utilities.
21. Spot Market (natural gas): A market in which natural gas is bought and sold for immediate or very near-term delivery, usually for a period of 30 days or less. The transaction does not imply a continuing arrangement between the buyer and the seller. A spot market is more likely to develop at a location with numerous pipeline interconnections, thus allowing for a large number of buyers and sellers. The Henry Hub in southern Louisiana is the best known spot market for natural gas.
22. Standard Industrial Classification (SIC): A classification scheme, developed by the Office of Management and Budget that categorizes establishments according to the types of goods they primarily produce.
23. Storage Capacity: Includes, for the purposes of the MECS, any volumetric capacity (including tank tops and tank bottoms) that is on the establishment site even if it is dedicated or leased for the storage of an energy source by other establishments.
24. Value of Production: Calculated as the value of shipments plus inventory change during the year (subtract prior year-end from current year-end inventories) in constant 1992 dollars.
25. Value of Shipments: Received or receivable net selling values (exclusive of freight and taxes) of all primary and secondary products shipped, as well as all miscellaneous receipts for contract work performed for others, installation and repair, sales of scrap, and sales of products bought and resold without further processing. Deflated to constant 1992 dollars.

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