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Vishwanatha Raju Brahmandhabheri

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TECHNICAL AND ECONOMIC FEASIBILITY CONSIDERATIONS OF ALTERNATIVE ENERGY DISTRIBUTED GENERATION

By

Vishwanatha Raju Brahmandhabheri

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TECHNICAL AND ECONOMIC FEASIBILITY CONSIDERATIONS OF ALTERNATIVE ENERGY DISTRIBUTED GENERATION

By

Vishwanatha Raju Brahmandhabheri

Approved:

Noel N. Schulz
Associate Professor of
Electrical and Computer
Engineering
(Director of thesis)

Stanislaw Grzybowski
Professor of
Electrical and Computer
Engineering
(Committee Member)

John Plodinec
Director
Diagnostic Instrumentation
&Analysis Laboratory
Mississippi State University
(Committee Member)

Nicholas H. Younan
Professor of
Electrical and Computer
Engineering
(Graduate Coordinator)

A. Wayne Bennett
Dean of College of Engineering

Name: Vishwanatha Raju Brahmandhabheri

Date of Degree: May 8, 2004

Institution: Mississippi State University

Major Field: Electrical Engineering

Major Professor: Dr. Noel N Schulz

Title of Study: TECHNICAL AND ECONOMIC FEASIBILITY CONSIDERATIONS OF ALTERNATIVE ENERGY DISTRIBUTED GENERATION

Pages in Study: 109

Candidate for Degree of Master of Science

The pressing needs for cost effective electric power that provides both high reliability and high quality is creating an opportunity for alternative energy distributed generation (DG). To determine the economic and technical feasibility of such alternative energy distributed generation facilities, electric power customers must understand their electric usage patterns, economic considerations, local alternative fuel supplies and available DG technologies. This thesis discusses the economic and technical feasibility of establishing a distributed generation installation.

As a part of technical feasibility, an evaluation has been done to compare DG size and location impact on the operation of the IEEE 13 node test distribution systems. This evaluation was carried out by performing the distribution power flow that provides the information about voltage profile, losses in the system and feeder power factor. This information was used to determine the optimal location of DG in the test distribution

system. Additionally, this part focuses on the importance of power utilization assessment in distributed generation planning. It also discussed the load utilization assessment that focus on step-by-step analysis of load profiles of different facilities such as Choctaw Laundromat, Choctaw Geyser Falls (water park) and Golden Moon Casino.

The second part of this thesis's work resulted in an informative and useful economic analysis tool, DG-ECON with which the user can document the study results and analyze them for economic feasibility with minimal effort. The economic feasibility of a biomass-based renewable energy installation is clearly shown by developing a user interface spreadsheet in Microsoft Excel. The spreadsheet calculates project-screening information in the form of a 20-year life cycle cost analysis. This cost analysis that enables users to define projects that are most energy efficient and offer the greatest financial benefit. The emphasis is on the user interface features of the application to make the application as user friendly as possible. The application has both numerical and graphical data representation using some of the features of Microsoft Visual Basic.

DEDICATION

Ma – to you

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I would like to take this opportunity to express my deepest sense of gratitude to my research advisor and academic advisory committee chairperson, Dr. Noel N. Schulz for her support, guidance, and encouragement throughout this research. I would also like to extend credit to the other committee members, Dr. John Plodinec and Dr. Stanislaw Grzybowski for their valuable suggestions to improve this work.

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LIST OF ABBREVIATIONS

ABBREVIATIONS	
DG/DR…………..	Distributed Generation/Distributed Resource
MBCI……………	Mississippi Band of Choctaw Indians
TLP……………..	Typical Load Profile
RDAP…………..	Radial Distribution Analysis Package
DOE…………….	Department of Energy
HVDC……………	High Voltage Direct Current
DER……………..	Distributed Resources
TVA……………..	Tennessee Valley Authority
PV……………….	Photo Voltaic
PWA…………….	Present Worth Analysis
LCC……………..	Life Cycle Cost
VBA……………..	Visual Basic Application
CHP……………..	Combined Heat and Power
O & M…………....	Operation and Maintenance

CHAPTER I

INTRODUCTION

1.1 Introduction

Traditional power systems were divided into three parts, generation, transmission and distribution to the load. Due to economics of scale and environmental concerns, generation facilities have been large power plants (100s of MW) and were located in non-populated areas away from loads. However improvements in technology, increased demand for high reliability and deregulation have created a new paradigm for generation of electricity.

Enhanced competition in the electrical market, recent advances in technology-including higher efficiency power production, new legislative and regulatory initiatives and the possibility of effectively exploiting the renewable energy and cogeneration are the principal factors that motivate the use of distributed generation. Distributed Generation (DG) is power generation on the distribution level of power system. Replenishable resources that are available abundantly in nature produce renewable energy. Some renewable energy resources include hydro, geothermal, wind, solar and biomass. Distributed generation is well-suited to the use of these renewable energy technologies, because it can be located close to the user and can be installed in small units to match the load requirements of the customer.

Traditional central station generation became cost effective due to economics of scale. In the past, renewable energy systems were not cost effective due to varied fuel supplies (wind, solar and geothermal), lower conversion efficiencies and uncontrollable electrical output. However, these major factors have contributed to increased opportunities for renewable energy systems. The first one is improvement in technologies including conversion efficiencies and power electronics for electrical power conditioning. The second factor is renewed interest in environmentally friendly power sources. This has included state and federal subsidies for renewable pilot projects. The third factor relates to increased expectations for power reliability. Today's consumers expect power delivered 24/7. The alternative power systems as distributed generation can provide backup generation during outages for critical loads.

Background

1.2 Need of Renewable energy

An energy resource that is replaced rapidly by natural processes is defined as a renewable energy source. Some examples of renewable energy resources are hydro, geothermal, wind, solar and biomass. Bio-energy technologies use renewable biomass resources to produce an array of energy-related products including electricity; liquid, solid, and gaseous fuels; heat; chemicals, and other materials. There are many types of biomass, including pulp and paper operation residues, forest residues, agricultural residues, urban wood waste, animal waste, landfill gas and energy crops.

In the U.S., biomass contributes the most to the nation's non-hydro renewable energy supply. According to the U.S. Energy Information Administration [1], biomass supplied 10,500MW(3% of the total electricity supply) of power in 1999. The following figure shows the contribution of renewable energy in total US primary energy consumption.

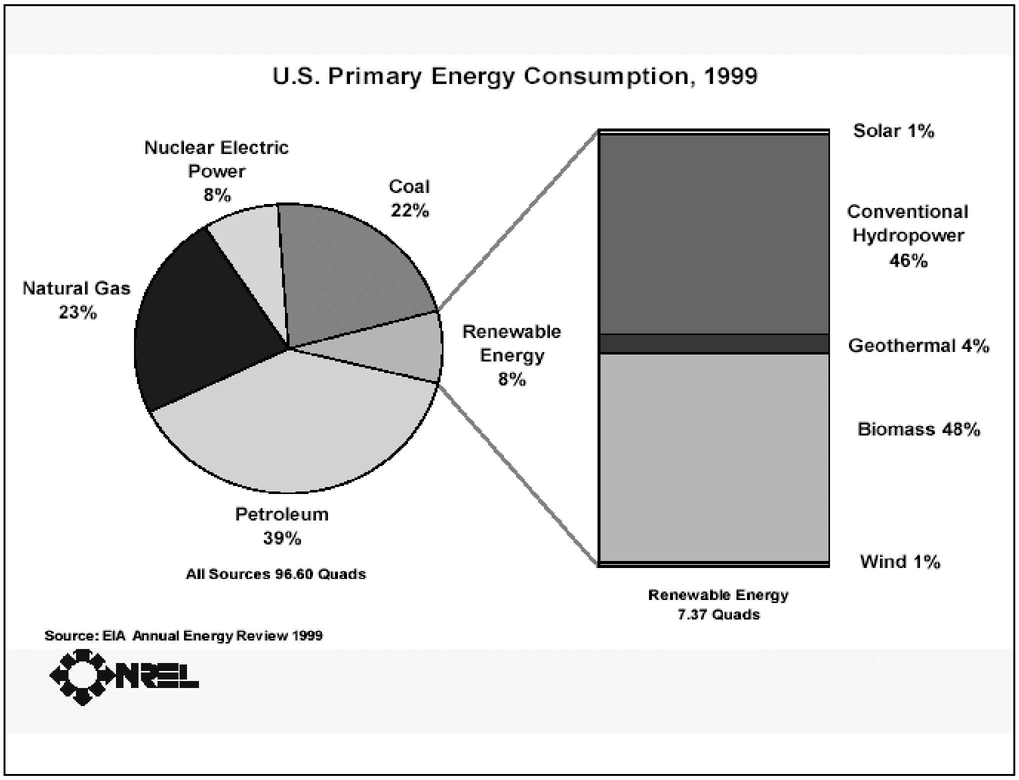


Figure 1.1 Contribution of Renewable energy and biomass in total US energy consumption (Year 1999) [1]

1.3 Potential Advantages of Renewable Energy

Renewable energy has several advantages over the currently used energy sources such as gas, oil, coal and uranium.

- Unlike fossil fuels, the fuel supply for renewable power systems is replenished.
- One of the largest advantages of energy from most renewable sources is that they are relatively clean. They have a minimal impact on the natural environment. Most

renewable energy systems have no emission of CO_2, the gas formed by burning of fossil fuels such as coal, oil and natural gas.

- Use of renewable energy leads to a higher security of supply of energy, so it can be seen as a safe power source. Renewable energy can be found in any nation on earth. Thus, it reduces dependence on current power sources.
- There are also advantages of renewable energy for the economy. In general renewable energy provides more jobs per dollar invested than other energy technologies.

1.4 Overview of thesis and Organization

In this thesis, the research work consists of two parts: The first part focused on the technical evaluation of distributed generation. The second part emphasizes the economic feasibility. On the technical side, an evaluation has been done to compare DG size and location impact on the operation of the IEEE 13 node test distribution systems. Actually using this test feeder first order technical evaluation has been done so that future work may include the same kind of evaluation on real time distribution systems. Additionally using actual load data from a casino, water park, and laundry, discussions on load following and other technical issues are addressed.

Second part of this thesis focused on the economic feasibility of poultry litter powered distributed generation installation including start-up, annual costs and savings. An economic analysis tool was developed to perform the economic feasibility study. The Mississippi Band of Choctaw Indians' (MBCI) proposal to locate a renewable energy installation on the tribal lands under the Tribal Energy Program was taken as a case study to show the results of feasibility study.

The theoretical concepts used and the works done to evaluate technical and economic feasibility are discussed in this document. In this chapter renewable distributed generation technology was introduced with its cons and issues. Next, the need for renewable energy and the potential advantages are explained. Chapter 2 will provide the background information about the project. This includes the discussion of types of DG technologies, potential challenges with and also includes the preliminary discussion on the topics covered in this thesis. Chapter 3 will focus on issues to be studied and literature review on small-distributed generation technologies and its characteristics, load profiling of different facility types, location impact of DG on distribution systems and finally economics analysis of DG. Chapter 4 includes the load profiling analysis of a few different sites of MBCI. Chapter 5 explains the complete technical evaluation of impact of size and location of DG on IEEE radial test feeder. Chapter 6 focuses on the development of economic analysis tool for the feasibility study of poultry litter powered DG. Chapter 7 includes conclusions and future work.

CHAPTER II

BACKGROUND

2.1. Introduction of Power Systems

Electric power is the prime source of energy that supports most existing technologies. The power systems consist of three major components: power generation, transmission and distribution systems. Figure 2.1 shows the concept of typical power systems.

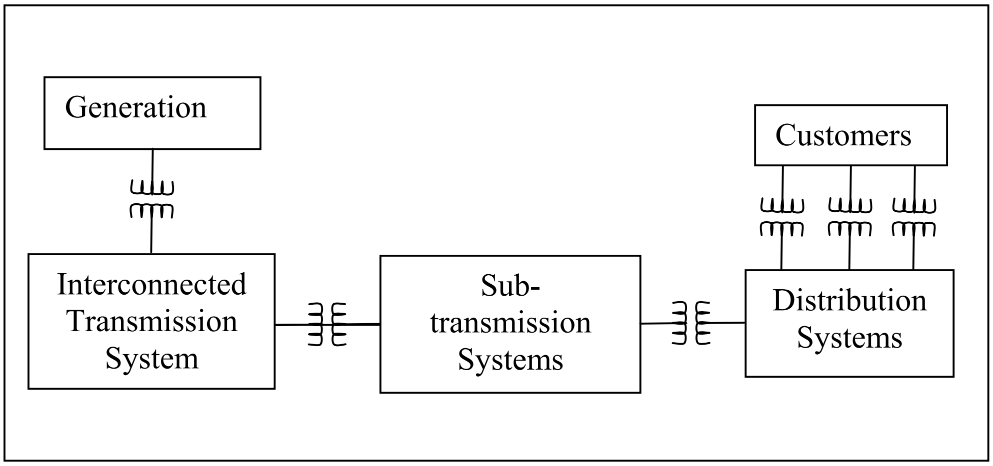


Figure 2.1 Typical Power System Components [2]

2.1.1 Overview

The power generation begins at a power plant with the conversion of the energy stored in the water, gas, oil, wind, nuclear fuel and other resources into electric energy. The most frequently used power plants are thermal power plants, nuclear power plants, and hydroelectric power plants. The power plant produces AC power. However, it produces three different phases of power simultaneously, and the three phases are offset 120 degrees from each other. There are four wires coming out of every power plant: the three phases plus a neutral or ground common to all three. The generating voltage is in the range of 15-25kV.

The three-phase power then enters the transmission substation at the power plant leaving the generator. The voltage of the generated power is relatively low, and it is not suitable to transmit the electric energy over a long distance at this voltage level to meet the needs of customers at a long distance. The transformers at the substations are used to convert the generators voltage into extremely higher voltages for long distance transmission on the transmission grid. The voltage range for long distance is in the range of 155kV-765 kV with a maximum transmission distance of around 400-500 miles. The transmission on HVDC (High Voltage Direct Current) lines can carry voltages above 500kV. The power is transmitted at higher voltages in order to reduce the transmission losses. The power system also has sub-transmission lines that interconnect the high voltage transmission substations with distribution substations within a city or near a load center. This is a looped system with more than one path between the generation and substation.

The power distribution systems directly deliver the power to the end users (customers). The distribution systems start from the distribution substations. A typical radial distribution system consists of one distribution substation with one or more primary feeders and many laterals. The distribution system carries electrical power from the distribution substation to the individual customer at voltages that range between 34.5 kV and 4.2 kV. The distribution system usually has only one path between the substation and customer. This is called a radial system.

2.2 New Power System Paradigm

Electric utilities have historically satisfied customer demand by generating electricity centrally and distributing it through an extensive transmission and distribution system. As demand increases, the utility generates more electricity. Once demand increases beyond a certain level, however, the capacity of the generation, transmission, and distribution systems can become constrained. This situation has led to power shortages, power quality issues, and unreliable and costly power.

The traditional utility response to these constraints was to build new facilities such as more central generations and transmission lines. This response is changing with emergence of Distributed Generation (DG) technologies. Distributed Generation, locating electricity generators close to the point of consumption, provides some unique benefits to power companies and customers that are not available from centralized electricity generation.

Figure 2.2 shows how a traditional, central-station generating system looks after the addition of distributed resources to the power grid. While the central generating plant continues to provide much of the power to the system, the distributed resources meet the peak demands of local feeder lines or major customers. These distributed resources can be run either in parallel with the grid, or as an isolated local generation as shown in the following figure. In parallel operation, both grid and DG act as two sources to meet the load demand where as in local generation distributed resources act as local generation supplying power to critical loads. These distributed resources can be distributed generation sources such as microturbines, combustion turbines, reciprocating engines, fuel cells and also alternative energy sources such as bioenergy, wind, solar, geothermal, hydrogen and ocean.

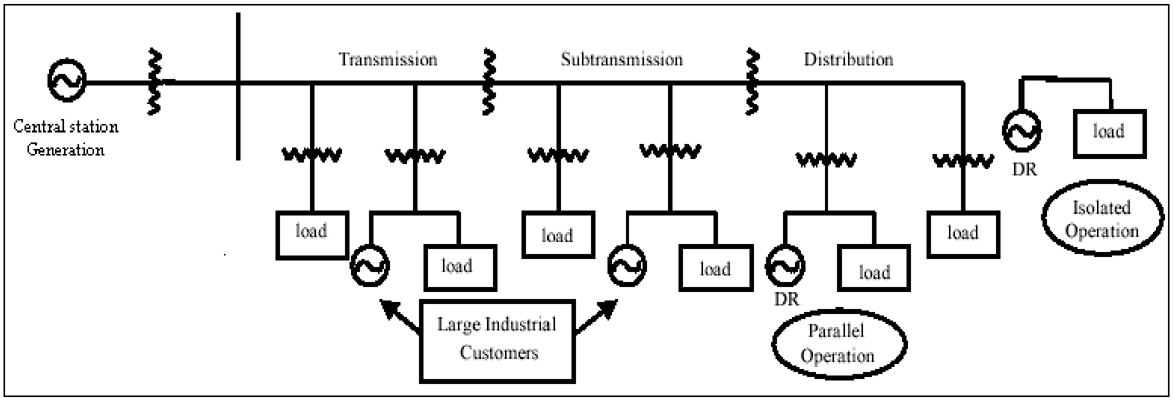


Figure 2.2 Central Station Generation and T &D with Distributed Resources [4]

DG includes the application of small generators, typically ranging in capacity from 15 to 10,000 kW, scattered throughout a power system, to provide the electric power needed by electrical consumers. As ordinarily applied, the term DG includes all use of small electric power generators, whether located within the utility system, at the site of a utility customer, or at an isolated site not connected to the power grid.

2.3 DG technology options

Recent advances in efficient and cost effective electricity generation technologies, including advanced combustion turbines and engines have allowed for new system configurations that reduce size yet increase output. Advanced materials and computer-aided design techniques have increased equipment efficiency and reliability dramatically, while reducing costs and emissions. The available small-distributed generation technologies in the market with their applications are shown in Table 2.1.

Table 2.1

Options for small-scale distributed generation [5]

Type	Size range (kW)	Electrical Efficiency (%)	Applications
Reciprocating Engines	5-7000	25-45	Backup power, base load, grid support and peak shaving
Fuel cell	1-10000	40-65	Co-generation, grid support
Photovoltaic Arrays	<1-100	5-15	Base load, peak shaving
Stirling Engines	1-25	12-20	Vehicles, Refrigeration, Aircraft, Space
Wind systems	Several kW-5000	20-40	Remote power, grid support
Micro Turbines	30-500	20-30	Stand-by power, power quality, reliability, peak shaving, and cogeneration
Biomass energy	5-10000	40-50	Co-generation, grid support

The next generation of turbines, fuel cells, and reciprocating engines is the result of intensive, collaborative research and development. More information about individual technologies can be found in references [6].

2.3.1 Renewable energy

The pressing needs of cost effective electric power that provides both high reliability and high quality is creating an opportunity for alternative/renewable energy. Some of these renewable generators are often lumped into the "DG" category because their small size makes them very convenient to connect to the lower voltage (distribution) parts of the electric utility grid. Important renewable generation technologies include photovoltaic generation, wind power generation, geothermal, hydrogen, ocean and bioenergy.

Bioenergy ranks second (to hydropower) in renewable U.S. primary energy production and accounts for three percent of the primary energy production in the United States [7].

Bioenergy (Biomass):

Bioenergy technologies use renewable biomass resources to produce an array of energy related products including electricity; liquid, solid, and gaseous fuels; heat; chemicals; and other materials. Biomass fuels include wood, wood waste (chips), straw, manure, sugar cane, and many other byproducts from a variety of agricultural processes. The latest and upcoming biomass technologies include the technologies that extract energy from poultry litter and wood chips. Biomass can be converted into electricity (or heat) in one of several processes. Today, the majority of biomass electricity is generated using a steam cycle: biomass material is converted to steam in a boiler; the steam then turns a turbine, which is connected to a generator. More information about these biomass technologies can be found in references [7].

2.4 Potential Challenges with Distributed Generation:

There are a number of significant technical, economic and institutional barriers that hinder the deployment of distributed power technologies. These barriers influence the customers who require high efficient electricity and reliable power consistently at all times.

System Impacts of DG: Interconnection of a large number of DGs to a radial designed power system raises many significant concerns. The most significant issue in installing DG technology is the interconnection of the device to the electric utility system and its system impact. A common standard for interconnection of DGs to the electric power system does not exist currently, but the in-progress IEEE Interconnection Standard P1547 specifies various rules for, interconnection of distributed resources with electric power systems, and requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection [8-10]. Some of the system impacts are:

1. The current power system is designed to operate radially without any generation on the distribution line or customer side. The introduction of any generation sources such as DGs on the utility system can significantly impact the operations of the system, and the reverse power flow is a major concern.
2. Strategic placement of DG can provide system benefits and preclude the need for expensive upgrades. Otherwise improper placement results in a system with high losses, a poor power factor and a voltage profile out of the specified limits [11-12]. The determination of optimal location of DG in a distribution system is discussed in Chapter 4 of this document.
3. DG can potentially support unintentional system islands, which occur when the distributed generator (or group of distributed generators) continues to energize a portion of the utility system that has been separated from the main utility system. This separation could be a part of an operation when a fault occurs in the upstream, utility side. In most cases this situation is not desirable for a DG to island with any part of the utility system because this can lead to safety and power quality problems that will affect the utility systems and loads. It also can hinder service restoration by requiring line crews to spend extra time disabling the island conditions. This will impact reliability of the system [13-14].
4. Protection requirements will generally vary based upon the size of the DG, its load and the impact it may have on the connected feeder. If the DG is small, treated as a

negative load and when there is no export of power onto the utility feeder, the protection may be minimal. However, for few larger DGs where power is delivered to the utility system, the protection requirements and associated control equipment can become more complex [15]. The protection system from distributed generation side should be coordinated properly with the protection system associated with the utility system, otherwise this may result in lower reliability and power quality, possible damage to the DG and utility equipment [16].

5. The distribution system is generally designed to operate radially and the voltage conditions within a permissible range are normally achieved using LCT (Load-tap Changing Transformer) and LDC (Line Drop Compensator) at substation bus. This practice is based on radial power flows from the substation to the loads without generation on the distribution line or customer side. The advent of distributed generation can significantly impact the voltage profile at customers and utility equipment. If significant DGs are introduced into the distribution system that is using the LDC method, they begin to introduce meshed power flows that interfere with the effectiveness of standard voltage regulation practice. Then the distribution system will lose the function of proper voltage regulation [18].
6. With the rapid proliferation of penetration of DG into distribution system, impact of DG on the distribution power quality has become the major concern. While the energy conversion technology may play some role in the power quality, most power quality issues relate to the type of electrical system interface. The power variation from renewable sources such as wind and solar can cause voltage fluctuations. Some fuel cells and microturbines do not follow step changes in load

well and must be supplemented with battery or flywheel storage to achieve improved reliability. Misfiring of reciprocating engines can lead to a persistent and irritating type of flicker, particularly if it is magnified by the response of the power system. On the whole, the main power quality issues affected by DG are sustained interruptions, voltage regulation, harmonics and voltage sags [19].

Although much excellent work has been done to solve the above-said technical issues associated with DG, there continue to be many excellent technical challenges to tackle.

2.5 Economics of Distributed Generation

An understanding of the fundamental economics of DG is essential to address all concerns and to arrive at sound decisions regarding the future of DG. One approach to examining the economics of DG is to compare the costs of the options that utilities have to meet new customer demand. The first step in evaluating the economics of a DG project is to understand the various costs and potential savings involved in establishing distributed generation sources. The economics of owning and operation of DG can be described by the important components such as capital investment and installation, operation and maintenance, and costs of generation. The definition of the parameters related to the costs and savings for using localized distributed generation are explained and an economic analysis tool that gives a snapshot of all economics was developed in this thesis using a renewable energy installation at Mississippi Band of Choctaw Indians (MBCI) as a case study. More details will follow in chapter 6 of this document.

2.6 Load behavior

When deciding the size of distributed generation, it is important to know the capacity of local loads present in the system in which a DG is placed. This information can be used to plan its generation around that load profile. An individual customer's load profile can determine where exactly DG fits for serving the load demand. When the load profile of thousands of customers is aggregated, it becomes predictable to decide the capacity of DG such that the customer's demand can be met by its local generation.

One part of this project focuses on load utilization assessment that focus on step-by-step analysis of load profiles of different facilities such as Choctaw Laundromat, Choctaw Geyser Falls (water park) and Golden Moon Casino. The installation of renewable energy at MBCI was taken as a case study to assess the importance of load behavior in planning the capacity of distributed generation.

2.7 Summary

This chapter provided an introduction of traditional power systems and a brief overview about its operation from generation to distribution. It also discussed a new power system paradigm with distributed generation in the system. A detailed summary related to the present types of available DG technologies is given. This chapter also discusses the various challenging technical issues associated with the use of DG in power systems. The final sections highlight the importance of load behavior and economics in DG planning.

CHAPTER III

LITERATURE REVIEW

3.1 Introduction

This chapter reviews the previous work done in economic analysis of Distributed Generation (DG) with a focus on renewable energy technologies and load profiling for typical load patterns. It also includes the literature review on the optimal placement of distributed generation and its impact on radial distribution feeder.

3.2 Economic Analysis of Distributed Generation

DG has the potential to play a major role as a complement or alternative to the electric power grid and fundamentally distinct from the traditional central plant model for power generation and delivery in that it can deliver energy close to loads within the power distribution network. Also, DG facilities are smaller than central plants, can be operated remotely, and provide a broad range of applications for customers. The range of DG technologies and the variability in their size, performance, and suitable applications suggest that DG could provide power supply solutions in many different industrial, commercial, and residential settings across the United States. An understanding of the fundamental economics of DG is essential for utility/DG owner to arrive at sound decisions regarding the future of DG.

One approach to examining the economics of DG is to compare the costs of the options utilities have to meet new customer demand. Essentially, if the difference between the DG operating costs and avoided electricity costs is large enough relative to the investment required to meet the customer's investment-return criteria, the project will go forward [20]. The following section highlights some of the key work that has been done in the economics and feasibility of DG.

In paper [21], the authors studied the feasibility of constructing a wind generating facility in the Medicine Hat, Alberta region in order to meet the city's growing needs. Finally this paper presented a feasibility of this facility by taking all the costs into consideration.

Authors Mann, Spath and Craig in paper [22] highlighted the cost and performance potential of a biomass-based integration gasification combined cycle (IGCC) system. The techno-economic feasibility study focused on economic viability and thermodynamic efficiency of this biomass-based IGCC technology.

In paper [23], Cosgrove-Davies and Cabraal proposed a methodology for evaluating dispersed and centralized rural energy options on a least cost basis. The financial requirements demand that each proposed energy project offer the least cost option and show a net positive benefit. These requirements apply to potential energy projects as well as more conventional technologies. Lastly, a net present value analysis (including capital, installation, Operation & Maintenance (O&M), fuel, and replacement costs, etc) was performed to identify the least cost option. A spreadsheet-based analytical tool was developed to compare the costs of different energy options.

Ackermann in paper [24] focused on the significant differences in cost, performance, and commercial readiness among DG technologies. This paper highlights small DG systems that are already commercial and becoming increasingly cost effective. These systems involve significant one-off project design costs and are usually single technology based, such as hydro, steam co-generation, gas turbine, wind generator or geothermal. They often include local use of a heat energy component (co-gen). These systems compete with grid supplied wholesale electricity, so they must be able to demonstrate low energy costs. The following table shows the options for small-distributed generation technologies.

Table 3.1
Cost of small-scale distributed generation [24]

Type	Size range (kW)	Electrical Efficiency (%)	Current equipment Cost ($/kW)
Reciprocating Engines	5-7000	25-45	200-800
Micro Turbines	30-500	20-30	250-1250
Fuel cell	1-10000	40-65	4000-5000
Photovoltaic Arrays	<1-100	5-15	5000-10000
Stirling Engines	1-25	12-20	2000-50000
Biomass energy	5-10000	40-50	2000-4000

Summary of work

The economics of owning and operation of DG can be describes by the important components such as capital investment and installation, Operation& Maintenance costs and cost of generation. The definition of the parameters related to the costs and savings for using localized distributed generation are explained and an economic analysis tool that gives a snapshot of all economics is developed in this thesis using a renewable energy installation at Mississippi Band of Choctaw Indians (MBCI) as a case study.

3.3 Load profiling

When planning a Distributed Generation (DG) system it is important not to lose sight of what our needs actually are. Once needs are defined, we can then begin to design a Renewable Energy system to meet them. Out of those needs, the important one is to determine and analyze how much energy it takes to meet the load demand of each facility. This can be procured by step-by-step analysis of a load profile. The term load profile describes the pattern of electricity usage for a customer or a group of customers over a given period. Similarly, the term load profiling is defined as estimated load shapes that are developed from historical or current data and balanced to actual meter reading on a daily or monthly basis [27].

In paper [25], the authors proposed a daily load profile determination. For that purpose, the author suggests the use of hierarchical clustering method. The goal of hierarchic clustering method is to classify customer profiles into coherent groups – Typical Load Profiles (TLP). Results obtained demonstrate the ability of the suggested method to overcome problems concerning formation of TLP. This paper also presented the TLPs of different facilities such as casinos and small commercial loads by using the above said method.

Authors Jardini, Tahan, Gouvea, Ahn and Figueiredo in paper [26] proposed a methodology for the aggregation of residential, commercial and industrial loads to determine the expected loading in equipment or in a preset part of the distribution network by using the representative daily curves of each consumer's activity and the monthly energy consumption of the connected consumers. The consumers' representative curves can be used to obtain daily load curves in any point of the network by aggregation of the consumers' load.

Summary of work

The part of this thesis focus on load utilization assessment that focus on step-by-step analysis of load profiles of different facilities such as Choctaw Laundromat, Choctaw Geyser Falls (water park) and Golden Moon Casino. The project on installation of renewable energy at Mississippi Band of Choctaw Indians (MBCI) was taken as a case study to assess the importance of load behavior in planning the capacity of distributed generation.

3.4 Impact of placement of Distributed Generation in distribution system

Conventionally, it is assumed that electric power in distribution systems always flows from substations to the end of feeders in planning and operation. However, introduction of distributed generators under de-regulated environment causes reverse power flow and complicated voltage profiles in the distribution systems. This type of complication in the systems depends on the strategic placement of DG. Therefore it is required to focus on optimal placement of distributed generation in the distribution systems.

In distribution systems, key information includes system state variables such as voltage, current magnitudes and corresponding phase angles at every node of the feeder. Once the system state variables are known, the flows on the distribution system can be acquired, which is very important in keeping the system operating in a secure and economical state. This state variable can be obtained by the analysis of power flow in distribution systems. But the placement of DG changes these system variable and losses. The following section highlights some of the key work that has been done in the optimal placement of DG in distribution system.

In paper [28], the authors demonstrated a methodology for deploying dispersed fuel cell generators throughout a power system to allow for more efficient operation. This works presented an algorithm to determine the near optimal, with respect to system losses, placement of these units on the power grid. Further, the impacts of dispersed generation at the distribution level were performed with an emphasis on resistive losses, and capacity savings.

Wang and Nehrir in paper [11] presented analytical methods to determine the optimal location to place DG in radial as well as interconnected distribution systems to minimize the power loss of the system. This paper also carried out the simulation studies to verify the results obtained analytically for both radial and network connected systems.

In paper [12], Rau and Yih-heui Wan proposed a method to allocate optimal quantities of distributed resources in selected nodes of distribution system such that system will have reduction of network losses, var losses, or loadings on selected lines. An optimization method was presented to minimize the losses in distribution system.

Summary of work

This thesis discusses the impact of location of DG on distribution system when placed in the radial distribution system. The results of distribution flow such as line flows, losses and power factor are taken as a basis to determine the impact of location of DG in distribution system. These results are also used to identify the optimal placement of DG sources in a radial distribution feeder. The 4.16 kV IEEE 13 node test feeder was taken as a test radial distribution feeder for the analysis of impact of DGs on the distribution system, simulation was carried out using Radial Distribution Analysis (RDAP). However, the same type of evaluation can be carried out on the real time distribution systems for the determination of optimal placement of DG.

3.5 Summary

This chapter reviews the previous work done in economic analysis of Distributed Generation (DG) with a focus on renewable energy technologies and load utilization assessment for typical load patterns. It also included the literature review on the optimal placement of distributed generation and its impact on radial distribution feeder. This chapter also summarized the work done in this thesis.

CHAPTER IV

POWER UTILIZATION ASSESSMENT

4.1 Introduction

The most important task in planning a distributed generation site is to determine and analyze how much energy DG should supply to meet the load requirements of each facility. This task can be accomplished by step-by-step analysis of a load profile. The term load profile describes the pattern of electricity usage for a customer or a group of customer over a given period. Similarly, the term load profiling is defined as estimated load shapes that are developed from historical or current data and balanced to actual meter reading on a daily or monthly basis [25].

Load profile involves two main processes:

- Determining an estimate of the average load profile for a class of customers over a given period.
- Allocating that load profile to all customers in that customer category.

4.1.1. Importance of Power Utilization Assessment

A customer's consumption pattern in the underegulated power system is of primary importance. Such information has been used for demand side management and Distributed Resource (DER) planning. For distributed generation system planning, the most important one is to determine and analyze how much capacity of DG is to build in order to meet the load demand of surrounding facilities attached with DG. When deciding a size of distributed generation, it is important to know the capacity of local loads present in the system in which DG is placed. This information can be used to plan its generation around that load profile. An individual customer’s load profile can determine where exactly DG fits into it in serving the load demand. When the load profile of thousands of customers is aggregated, it becomes very predictable to decide the capacity of DG such that customer's demand can be met by its local generation.

The following sections highlight the power utilization assessment that focus on step-by-step analysis of load profiles of different facilities such as Choctaw Laundromat, Choctaw Geyser Falls (water park) and Golden Moon Casino. The project on feasibility study of renewable energy installation at Mississippi Band of Choctaw Indians (MBCI) was taken as a case study to assess the importance of load behavior in planning the capacity of distributed generation. Information about the customers' consumption pattern at MBCI is critical for the feasibility study. Finally, the load curve data of individual facilities at MBCI is used in the economic analysis tool (Chapter 6) to determine the economic feasibility of installing DG at that facility when all other cost parameters were taken into account.

4.2 Details of Load Curve Measurement – Terminology

Demand and demand periods

Demand, as normally used in electric load analysis and engineering, is the average value of electric load over a period of time known as the *demand interval.* Very often, demand is measured on an hourly basis but it can be on any interval basis-seconds, minutes, 30 minutes, daily, and monthly. The average value of power during the demand interval is given by dividing the kilowatt-hours accumulated during the demand interval by the length of the interval. Demand intervals vary among power companies, but those commonly used in collecting data and billing consumers for "peak demand" are 15, 30, and 60 minutes.

Load curves may be recorded, measured, or applied over some specific time, for example, a load curve might cover one day. If recorded on an hourly demand basis, the curve consists of 24 values, each the average demand during one of the 24 hours in the day, and the peak demand is the maximum hourly demand seen in that day. Load data can be and are gathered and used on a monthly basis and on an annual basis.

Average

"Average", is the energy used during the entire period (e.g., a day, a year or month) divided by the number of demand intervals in the period (e.g., 24 hours, 8,760 hours).

Mean Deviation

"Mean Deviation", is the difference between the load values and its average or the deviation of load values from its average.

Standard Deviation

"Standard deviation (σ)", is computed as the square root of average squared deviation of each load value from its mean. It is expressed as:

$$\sigma = \sqrt{\frac{\sum (X - AverageDemand)^2}{N}}$$

where X is the load value and N is the total number of load values during a day, a year or month.

Load factor

Load factor is the ratio of the average to the peak demand. The average load is the energy used during the entire period (e.g., a day, a year) divided by the number of demand intervals in the period (e.g., 24 hours, 8,760 hours). The average is then divided by the maximum demand to obtain the load factor, as:

$$\text{Load factor} \quad = \quad \frac{AverageDemandkW}{PeakDemandkW} \text{x}100 \;=\; \frac{kWhr}{(kWDemand)*(Hr)} \text{x}100$$

Load factor gives the extent to which the peak load is maintained during the period under study. Load factor can be computed for daily or for monthly load. The maximum load factor possible is 100 percent. The load factors associated with the current energy usage and historical energy usage were evaluated to analyze the peak load maintained during that period.

4.3 Load profiles of Different Facilities in MBCI

The facilities chosen for assessing the power utilization were the Choctaw Laundromat, Choctaw Geyser Falls (water park) and Golden Moon Casino. This section presents the typical load profiles of above said facilities during week and weekend days. It also explains the observed patterns with the load for every facility during week and weekend days with some statistical analysis. The local utility personnel and Tennessee Valley Authority (TVA) provided the load information of these facilities. The installed meters provided the real and reactive power consumption of test facilities for every 30 minutes during the study period. Appendix A.3 gives the raw data provided by monitoring the load.

Derivation of typical customer load patterns

After collecting the raw data of customer's power consumption from meters, the average value (•) and standard deviation (•) of the customer power consumption are solved by using statistical analysis. Using the mean value of load for 30 minutes interval, the deviation of load values from average (mean) is calculated while the deviation (• •) between two regular intervals is calculated. These numbers are helpful to the derived load patterns to represent the customer load behavior very effectively. The following sections highlight the load patterns of above said facilities during both weekday and weekend day to compare the load behavior effectively.

A. Load profile of Choctaw Geyser Falls

Geyser Falls, a water theme park, is a development of the Mississippi Band of Choctaw Indians (MBCI) located in Philadelphia under the management of Pearl River Resort in Choctaw, Mississippi. The various loads of the Choctaw Geyser Falls includes the water pumps for various water rides, a Hard Rock Beach Club restaurant and lightings all around the park. The load data was collected during the days starting from 06/27/03 to 07/07/03. The padmount transformer for Geyser Falls has a 277/480 volt 4 –wire/wye secondary. The power monitor was set inside the padmount on the secondary side of the transformer and recorded the power consumption at the end of each 30-minute interval for load profile. The following load curves show the typical load patterns of Geyser Falls.

Typical load profiles:

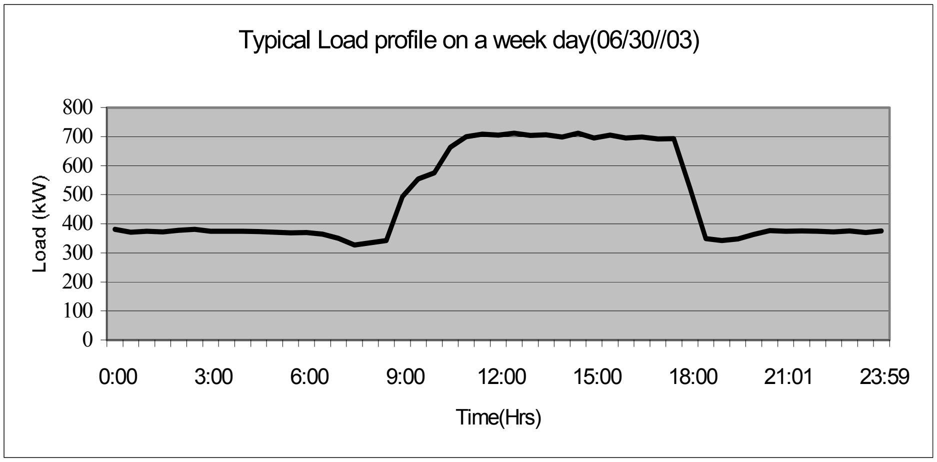


Figure 4.1 The typical load profile of Geyser Falls on weekday

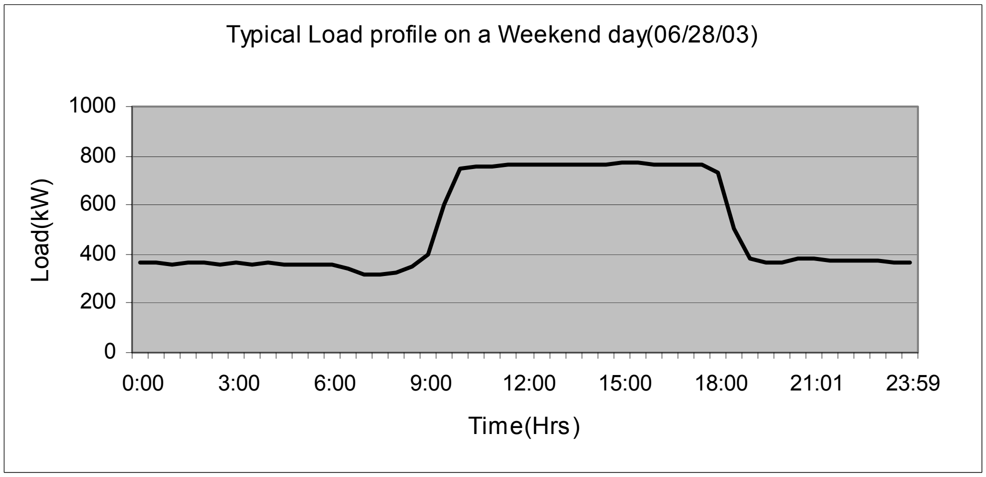


Figure 4.2 The typical load profile of Geyser Falls on a weekend day

Table 4.1

Loading information of Geyser falls during 06/27/03 to 07/07/03

No	Day Type	Average load/30 min	Std.Deviation	Max.Deviation	Max. Δ	Load factor
1	Weekend Day	466.41	160.17	258.69	317.3	0.65
2	Weekend Day	482.16	153.72	229.84	173.8	0.68
3	Week Day	508.56	190.71	263.44	230.9	0.66
4	Week Day	469.75	141.8	218.25	-178.7	0.68
5	Week Day	465.66	182.96	332.76	270.5	0.63
6	Week Day	557.37	144.32	197.67	270.6	0.75

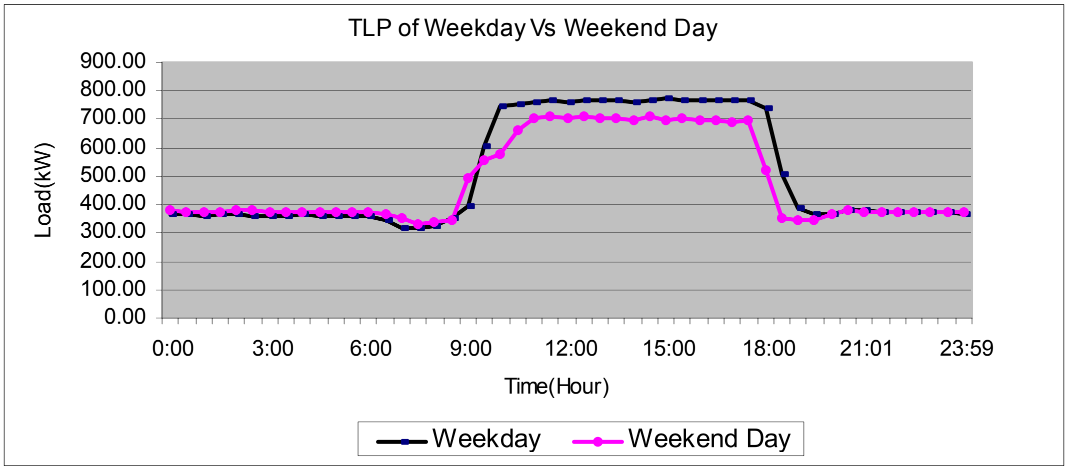


Figure 4.3 Comparison of typical load profile of weekday and weekend day

The casino has plenty of back-up generation to hold it through outages. However, Geyser Falls does not have this backup as demonstrated by the outage during load profiling time. An outage occurred at Geyser Falls on 07/02/03 and had a severe effect on the normal load pattern and the behavior of the load profile changed considerably. The following Figure 4.4 shows the difference in the load behavior on an outage day and a normal weekday.

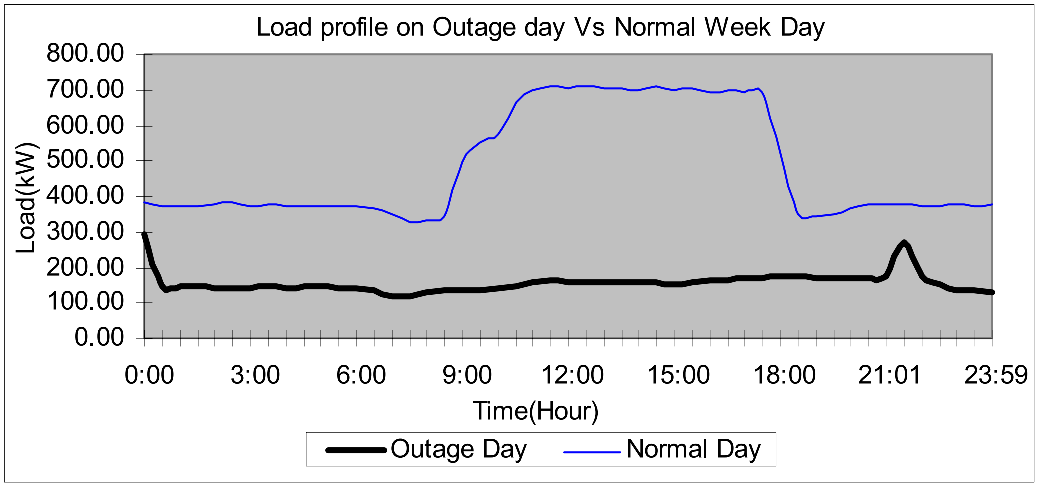


Figure 4.4 Load pattern observed at Geyser Falls during outage on 07/02/03

B. Load profile of Choctaw Laundromat

The Choctaw Laundromat is a development of the Mississippi Band of Choctaw Indians (MBCI) located in Choctaw in Philadelphia, Mississippi. The various loads of the Choctaw Laundromat include various washers, drying machines and other types of machines used for pressing or folding of clothes. The load data was collected during the days starting from 07/07/03 to 07/21/03. The laundry has a 500-kVA-padmount transformer with a 277/480-volt secondary. The power monitor was set inside the padmount on the secondary side of the transformer and recorded the voltage magnitudes at the end of each 30-minute interval for a load profile. The following load curves show the typical load patterns of the Laundromat on both weekday and weekend day during the study.

Typical load profiles:

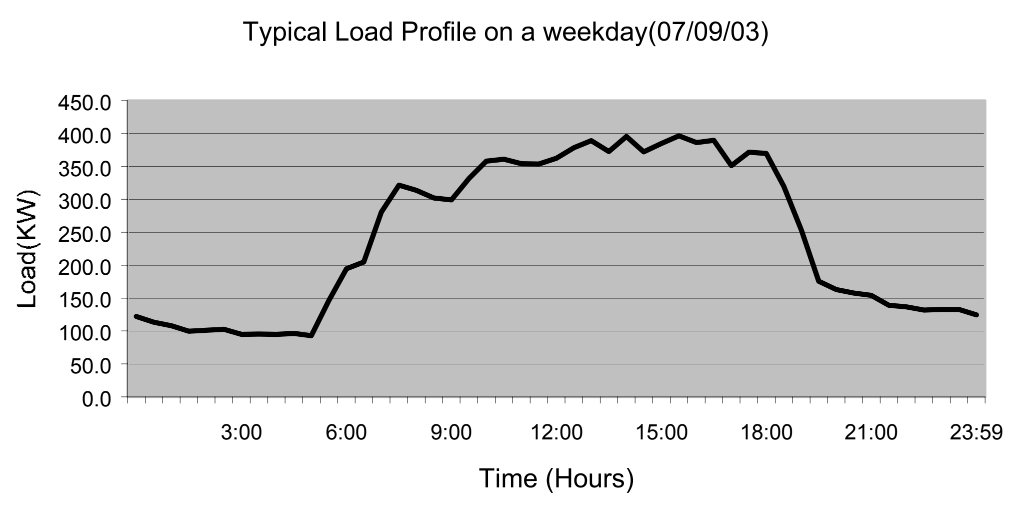


Figure 4.5 The typical load profile on a weekday

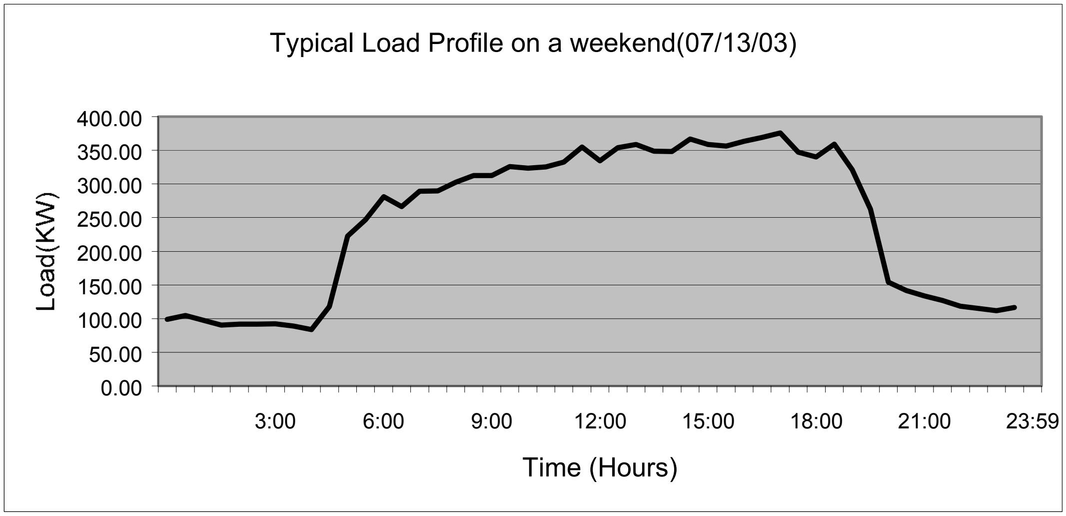


Figure 4.6 The typical load profile on a weekend day

Table 4.2

Loading information of Laundromat during 07/07/03 to 07/21/03

No	Day Type	Average load/30 min	Std.Deviation	Max.Deviation	Max. Δ	Load factor
1	Week Day	241.26	125.27	160.14	81.5	0.61
2	Week Day	242.5	117.05	153.9	77.5	0.61
3	Week Day	237.12	110.25	143.88	82.9	0.62
4	Week Day	232.45	120.33	150.35	115.4	0.61
5	Week Day	280.03	103.66	187.63	-76.2	0.7
6	Week Day	299.38	107.11	204.68	94.9	0.76
7	Week Day	298.74	85.4	183.04	98.8	0.75
8	Week Day	280.97	75.67	156.47	-73.5	0.72
9	Week Day	299.77	85.04	184.27	78.1	0.76
10	Weekend Day	239.74	106.2	141.74	82	0.63
11	Weekend Day	244.29	110.4	160.79	108.2	0.65
12	Weekend Day	276.99	68.38	154.99	99.5	0.77
13	Weekend Day	235.11	99.81	141.01	83.3	0.65

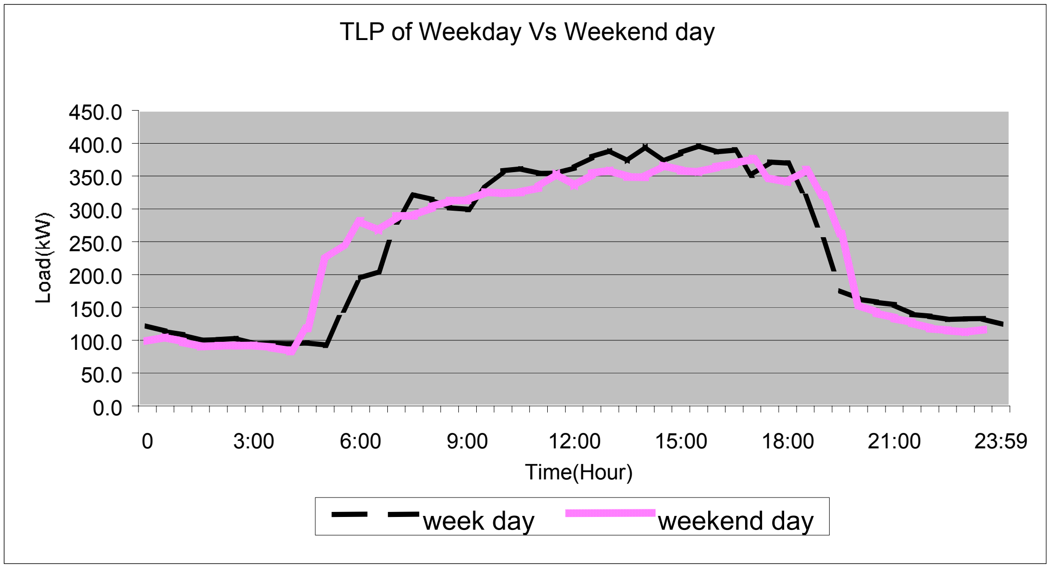


Figure 4.7 Comparison of typical load profile of weekday and weekend day

C. Load profile of Golden Moon Casino

The Golden Moon Hotel and Casino is Pearl River Resort's newest addition. Golden Moon Hotel and Casino's loads are gaming machines, five restaurants, five lounges**,** five retail shops**,** indoor and outdoor pools and a modern fitness facility**.** The load data was collected during the days starting from 07/22/03 to 08/01/03. For the Golden Moon Casino, the power monitor was set at the primary meter, on the secondary side of the potential and current transformers. The primary phase-to-phase voltage at that location is 25 kV. The meter records the voltage magnitudes at the end of each 30-minute interval for the load profile.

Typical load profiles:

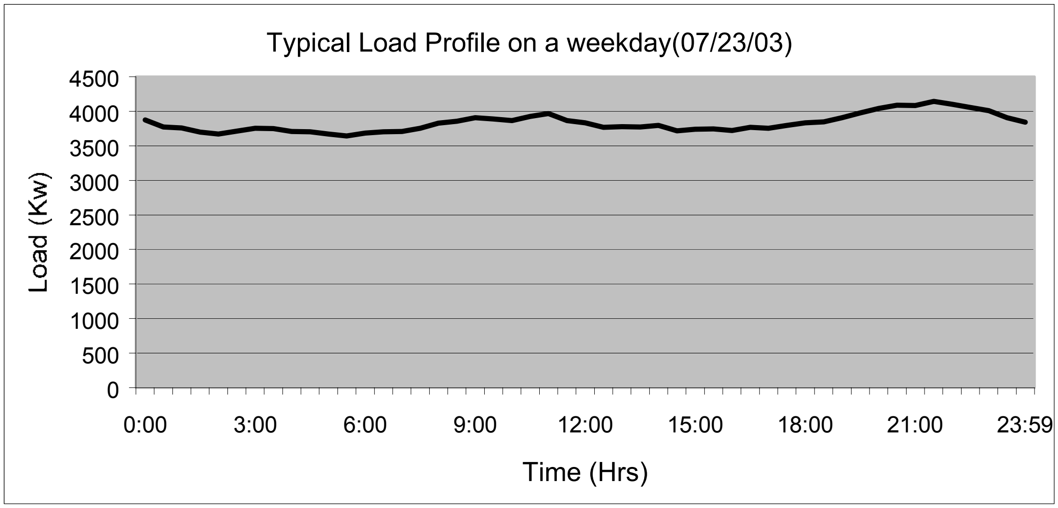


Figure 4.8 The typical load profile on a weekday

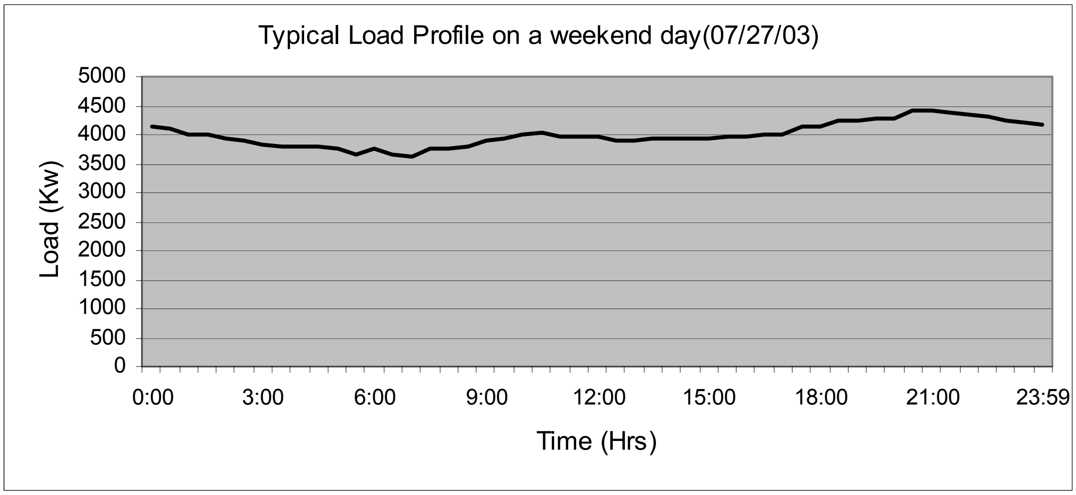


Figure 4.9 The typical load profile on a weekend day

Table 4.3

Loading information of Casino during 07/22/03 to 08/01/03

No	Day Type	Average load/30 min	Std.Deviation	Max.Deviation	Max. Δ	Load factor
1	Week Day	3936.69	146.63	304.79	128.8	0.94
2	Week Day	3830.27	128.46	269.73	104.8	0.92
3	Week Day	3611.48	194.79	414.68	120.2	0.91
4	Week Day	3626.56	211.33	411.16	283.7	0.91
5	Week Day	3946.71	159.24	-362.39	170.8	0.92
6	Week Day	3978.01	195.25	366.01	-165.4	0.92
7	Week Day	3940.54	149.72	-279.66	-156.8	0.93
8	Week Day	3901.9	134.66	258.1	181.6	0.95
9	Weekend Day	3817.51	245.81	410.81	-146.4	0.91
10	Weekend Day	3999.31	208.35	415.09	-146.8	0.91

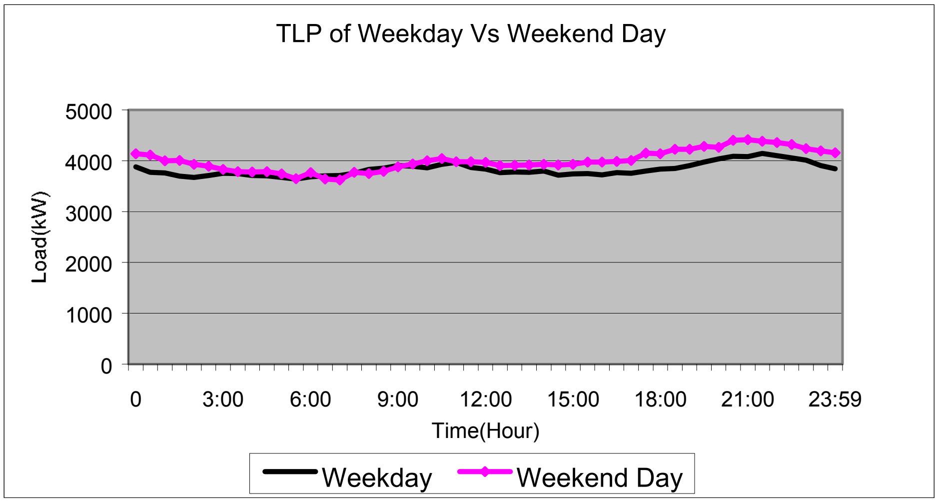


Figure 4.10 Comparison of typical load profile of weekday and weekend day

4.4 Discussion on Load Profiles

Some general information relating to the load profiling data follows. The load profiles of the laundry facility and Geyser Falls have a much different shape. The water park has an extremely sharp increase and decrease based on its operating times. The difference between the minimum and peak values during the day is approximately 64 % of the peak value. Additionally the load during the day is greater than twice the power required when the part is not open. The laundry also has a large difference between off-shift and daily power requirements, the difference between the minimum and peak value during the day is approximately 75 % of the peak value. The difference for the laundry is three to four times higher during peak times than overnight requirements. The solar Photo Voltaic (PV) cells would be an excellent possibility to supply power during the daytime to meet the peak demand.

The Golden Moon Casino has an extremely flat load curve. The difference between the minimum and peak values during the day is approximately 16 % of the peak value. The casino load curve lends itself better to a constant distributed generation supply. The load does not have huge percentage fluctuations that might impact local distributed generation operation, reliability and stability. For this type of load, a fuel cell may be the best constant power supply source.

Besides the magnitude of the power requirements, another important issue is the how fast the power demand changes. The steep slope of the water park load profile means a rapid change in a short time. The power system needs to be able to follow this closely. The distributed generation would need to be part of the base load because following the changes in either the laundry or the water park would require tighter controls, increase maintenance and decrease operational stability. The summary of load information of all facilities chosen for load utilization assessment are given in Table 4.4.

Table 4.4
Summary of load information for all load facilities

No	Load Facility	Average load/30 min		Average Std.Deviation		Average Max.Deviation		AverageMax Δ (% of Peak value)		Average Load factor	
		WD	WE	WD	WE	WD	WE	WD	WE	WD	WE
1	Geyser Falls	500.3	474.3	165	157	253.0	244.3	63.8	57.3	0.68	0.665
2	Laundromat	268.0	249.0	103.3	96.20	169.4	149.63	74.6	73.0	0.68	0.68
3	Casino	3846	3908	165.0	227.08	172.8	412.95	15.1	18.9	0.93	0.91

Note: Δ = Maximum value-Minimum value

4.5 Summary

This chapter discussed the importance of power utilization assessment in Distributed Resource planning. It also discussed the load utilization assessment that focus on step-by-step analysis of load profiles of different facilities such as Choctaw Laundromat, Choctaw Geyser Falls (water park) and Golden Moon Casino. The project on a feasibility study of renewable energy installation at MBCI was taken as a case study to assess the importance of load behavior in planning the capacity of distributed generation. The following chapter discusses the impact of DG placement on radial distribution feeder.

CHAPTER V

IMPACT OF DG PLACEMENT ON RADIAL DISTRIBUTION FEEDERS

5.1 Introduction

A distribution system is generally designed to operate radially without any generation on the distribution line or customer side. The introduction of any generation sources such as DGs on the distribution system can significantly impact the flow of power and voltage conditions at customers and utility equipment. It is paramount to focus on location impacts on a distribution system to keep the system in an economical and secured state. This chapter discusses the first order technical evaluation to compare DG size and location impact on the operation of the IEEE 13 node test distribution systems. This evaluation study is based on the small capacity chicken litter powered DG and its placement on the radial distribution feeder. However, for the placement of other DG sources, the evaluation needs to consider various constraints such as fuel statistics, local load conditions, generation capacity and inter-tie connection. The following sections highlight the impact of DG on a test distribution system when distribution power flow is performed. The results of distribution flow such as line flows; losses and power factor are taken as a basis to determine the impact of DG on a distribution system. These results identify the optimal placement of DG sources in a radial distribution feeder.

5.2 Configuration of Test Feeder

The 4.16 kV IEEE-13 node radial distribution feeder was taken as a test feeder for the analysis of impact of DGs on the distribution system; simulation was carried out using Radial Distribution Analysis (RDAP) [29]. The IEEE-13 node test feeder was used as the test system to investigate the radial flow of the distribution system when DG is placed at different nodes of the distribution feeder. This section initiates the distribution power flow study to determine the system voltage profile, power factor and loss. The parameters of this system are given in Appendix A.

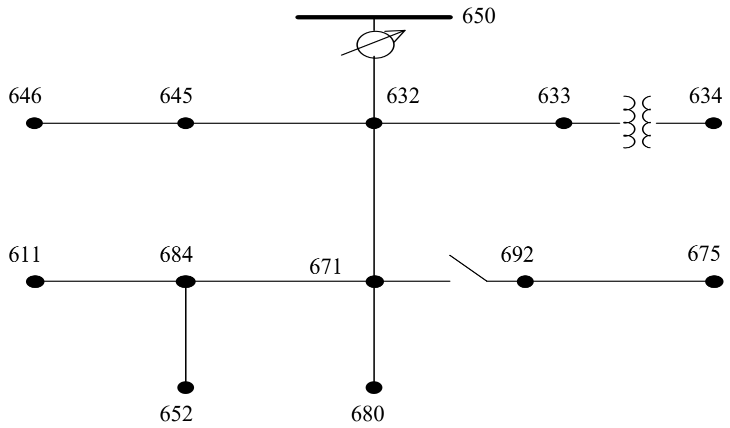


Figure 5.1 IEEE 13 - node radial distribution feeder [30]

5.3 Optimal placement of DG in a radial distribution feeder:

With the rapid penetration of DG into distribution systems, it is critical to assess power system impacts accurately so that these DG units can be applied in a manner that avoids causing degradation of power quality, reliability, and control of the utility system. On the other hand, DG has great potential to improve distribution system performance and it should be encouraged.

The proper location of DG in a distribution system is important for obtaining maximum potential benefits. DG sources are normally placed close to consumption centers and are added mostly at the distribution level. They are small in size (relative to the power capacity of the distribution in which they are placed) and modular in structure. The procedure to determine the optimal node for placing DG considers factors such as power losses, voltage profile and power factor. Optimal placement of DG can minimize system power losses, improve voltage profiles and increase load factors of distribution system [12].

The objective is to find the optimal location for DG in distribution system that results in minimum total power loss and the voltage level at each node is held in the acceptable range (1 ± 0.05 p.u.), while maintaining the power factor near to unity. The analysis is performed for two different sizes of DG, one-third and two-third of total load capacity. The first simulation test setup considers a single DG and the second test two DGs at different feeder nodes. For analysis, it is assumed that only linear loads are present in this distribution system to avoid power quality problems. DG sources with predictable output power (such as fuel cells, microturbines and bioenergy) can be placed at any node in the distribution feeder to achieve optimal result [11].

5.4 Modeling of Distributed Generation in distribution system:

For a radial analysis, by definition, distributed generation cannot be modeled as a source in parallel with the utility source. To do so would create a non-radial system incapable of being analyzed by radial algorithms. The simplest solution is to model DG as a negative load that injects real and reactive power into the system, independent of system voltage [31]. The following figure 5.2 shows how a radial distribution feeder looks with distributed generation modeled as a negative load.

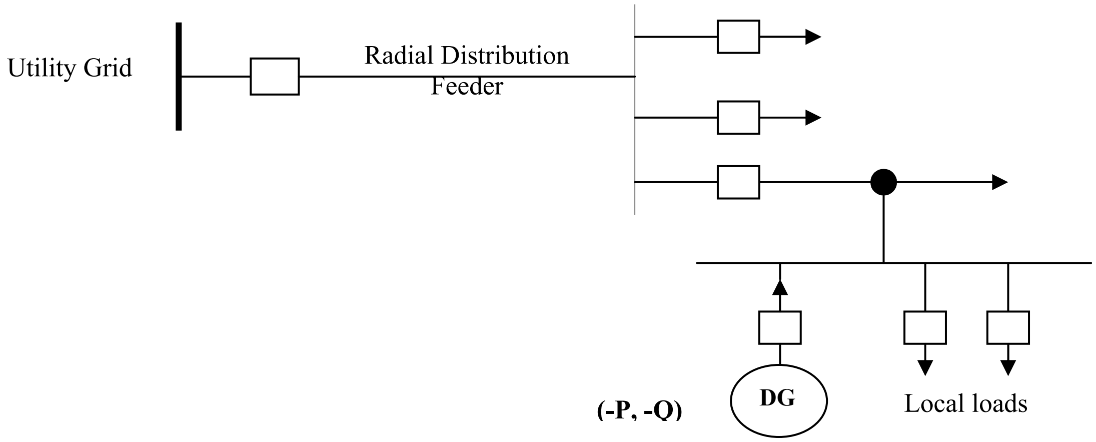


Figure 5.2 Radial Distribution feeders with Distributed Generation modeled as a negative load

Modeling DG as a negative load is reasonable since utilities will probably require DG units to disconnect from the system in the absence of a utility source to ensure safety, allow faults to clear and avoid the problems associated with islanded operation. During normal operation, the negative load reduces overall feeder loading and improves system reliability. Thus modeling DG as a negative load can have a positive impact on reliability.

5.5 Terminology

This section introduces terminology used for the analysis performed in optimal placement of DG. This evaluation resulted in multiple values of losses, voltage profile and feeder power factor. To consider all these values for the optimal location evaluation, scores are calculated for each set of values. The following norms are used to obtain scores of these multiple values.

Error Norm “Error Norm”, is the normalization of error from the base value, and the general form of error norm is give as: $\|\text{Error Norm}\|_p = \left(\sum_{i=1}^{n} |Basevalue - X_i|^p\right)^{\frac{1}{p}}$

Similarly,

$$\|\text{Error 1- Norm}\|_1 = \sum_{i=1}^{n} |Basevalue - X_i|$$

$$\|\text{Error 2- Norm}\|_2 = \left(\sum_{i=1}^{n} |Basevalue - X_i|^2\right)^{\frac{1}{2}}$$

$$\text{Maximum Deviation} = \text{Max}\left(\sum_{i=1}^{n} |Basevalue - X_i|\right)$$

where X is the measured value and Base value is the assumed value.

5.6 Impact of DG placement on radial distribution feeder

This section discusses the different effects of DG placement on radial distribution feeder. The effect on system losses, voltage profile and feeder power factor is discussed in detail. The final section includes the discussion on the optimal placement of DGs in the test distribution feeder based on the single variable optimization. Example outputs are shown in appendix A.2 and a summary of results is given below in each section.

5.6.1 Effect on System Losses

This section addresses the placement of DG units on a selected feeder node with one-third and two-third of capacity of system’s total load. The optimal placement of DG on feeder nodes is determined based on the minimization of losses when DGs are placed at those nodes. Total system power loss was obtained when DG was installed at different feeder nodes in each case (one-third and two-third) are explained in the next sections. The simulation carried out in this project shows that proper placement of the units will reduce losses normally seen by the system, while improper placement may actually increase system losses.

5.6.1.1 Allocation of Single DG with one-third of total load

When a DG of one-third capacity is installed at a feeder node 646, the simulation in RDAP results in power flow values of line flows at every feeder node, total losses in system and power factor per phase. In a similar way, simulation was run by placing DG at different feeder nodes, 633, 611, 671, 692 and 632.

Table 5.1

Losses in system with single DG (one-third capacity) installed at different feeder nodes

Feeder Node/ DG location	Total Losses in System with DG		
	KW	KVAr	KVA
646	196.7	466.1	505.9
633	83.4	225.7	240.6
611	159.0	344.8	379.7
671	35.6	76.0	83.9
692	115.4	331.2	350.8
632	81.9	233.7	238.2

The results in the above table and the following figure shows that total feeder real power losses reach a minimum value when a DG is placed at feeder node 671. The real power loss is minimized as the DG placed at 671 node supplies most of the downstream loads in the test feeder.

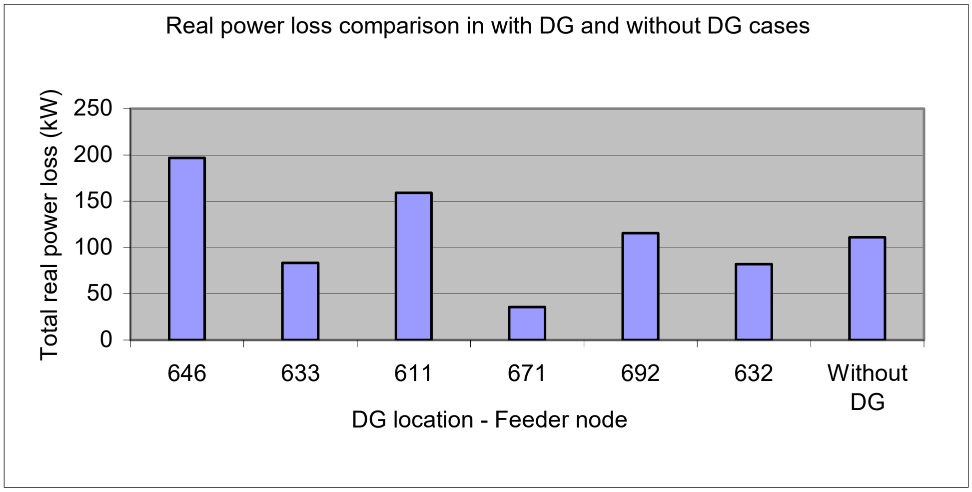


Figure 5.3 Real power loss comparison with DG (one-third) and without DG

5.6.1.2 Allocation of Single DG with two-third of total load

When a DG of two-third capacity is installed at a feeder node 633, the simulation in RDAP results in power flow values of line flows at every feeder node, total losses in system and power factor per phase. In a similar way, distribution power flow was run by taking DG at different feeder nodes, 646, 611, 671, 692 and 632.

Table 5.2

Losses in system with single DG(two-third capacity) installed at different feeder nodes

Feeder Node/ DG location	Total Losses in System with DG		
	KW	KVAr	KVA
646	591.1	1169.5	1310.4
633	76.3	179.7	195.2
611	505.7	1086.2	1198.2
671	25.4	44.3	51.1
692	332.9	912.7	971.5
632	76.3	179.7	195.3

The results in the above table and the following figure shows that total feeder real power losses reach a minimum value when a DG is placed at feeder node 671. The real power loss is minimized as the DG placed at 671 node supplies most of the downstream loads in the test feeder.

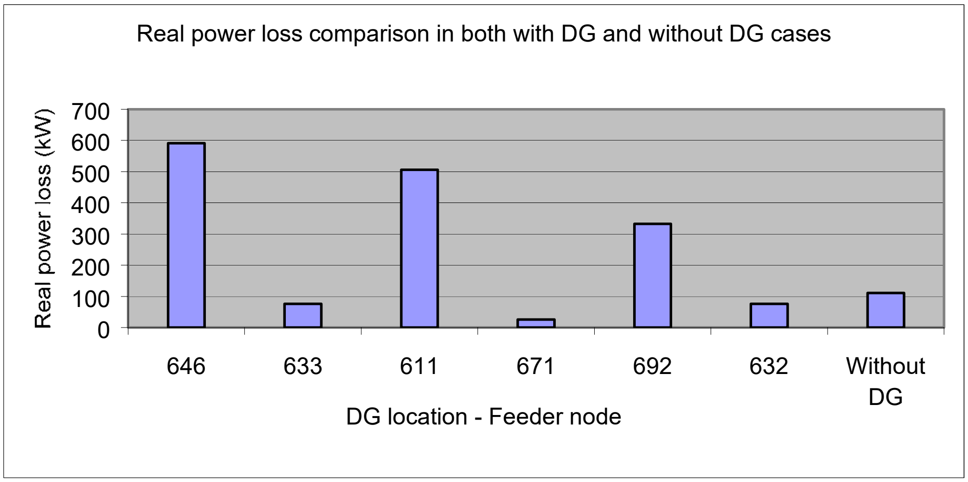


Figure 5.4 Comparison of real power losses of with DG (two-third) and without DG

5.6.1.3 Allocation of two DGs with a total capacity of one-third of total load

To better understand the impact of distributed generation on distribution power flow values such as line flows, system losses and power factor, the second simulation setup considered two DGs at two different feeder nodes to determine the optimal placement of the combination of two Distributed Resources (DR). It is assumed that each of the DGs has a capacity of one-sixth of total load, making the total capacity of combination as one-third of total load. When these DGs with one-third the capacity of the total system's load are installed at two different feeder nodes (671-633), the simulation results in distribution power flow showed the values of line flows at every feeder node, total losses in system and power factor per phase. In a similar way, distribution power flow was run by taking two

DGs of the same one-third total capacity for all combinations such as (632-611), (646-692), (646-671), (633-611) and (632-671).

Table 5.3

Losses in system with two DG (total one-third capacity) installed
at two different feeder nodes

Feeder Nodes/ 2-DG locations	Total Losses in System with DG		
	KW	KVAr	KVA
671-633	36.0	78.6	86.4
632-611	85.0	197.9	215.4
646-692	81.1	201.5	217.2
646-671	61.0	143.5	155.9
633-611	84.3	196.9	214.2
632-671	52.4	122.1	132.9

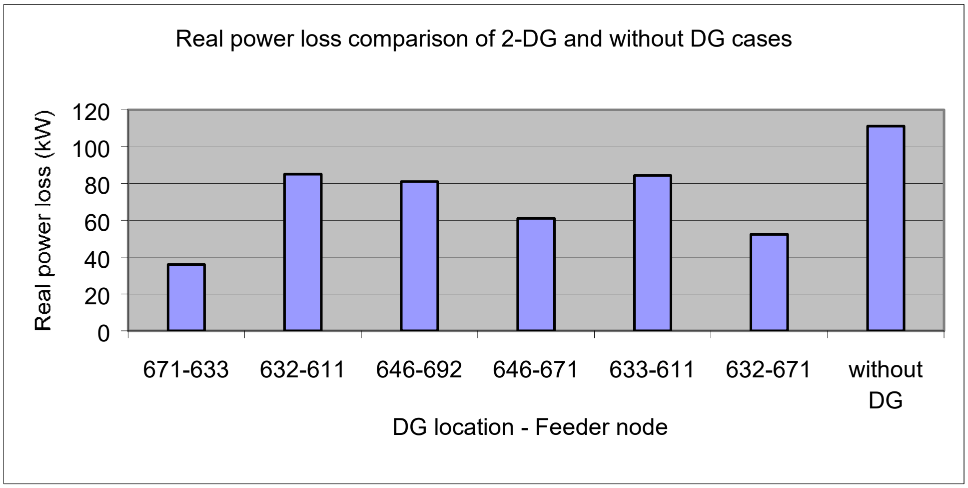


Figure 5.5 Comparison of real power loss with two DGs (one-third) and without DG

The data in the above table and figure shows that total feeder power losses reach a minimum value when two DGs are placed at nodes 633 – 671. This is due to the supply of power from two DGs to all of the downstream loads and some of the upstream loads.

5.6.1.4 Allocation of two DGs with a total capacity of two-third of total load

In another simulation test setup, each DG unit has a capacity of one-third of total load, making the total capacity of combination as two-thirds of the total load. When these DGs with a two-third capacity are installed at two different feeder node (632-611), the simulation results in distribution power flow showed the values of line flows at every feeder node, total losses in system and power factor per phase. In a similar way, distribution power flow was run by taking two DGs with the two-third total capacity for all combinations such as (671-633), (646-692), (646-671), (633-611) and (632-671).

Table 5.4

Losses in system with two DG (total two-third capacity) installed are two different feeder nodes

Feeder Nodes/ 2-DG locations	Total Losses in System with DG		
	KW	KVAr	KVA
671-633	27.2	50.0	57.0
632-611	149.3	315.0	348.6
646-692	163.1	352	388.0
646-671	132.4	269.7	300.4
633-611	149.0	314.6	348.1
632-671	27.5	50.3	57.3

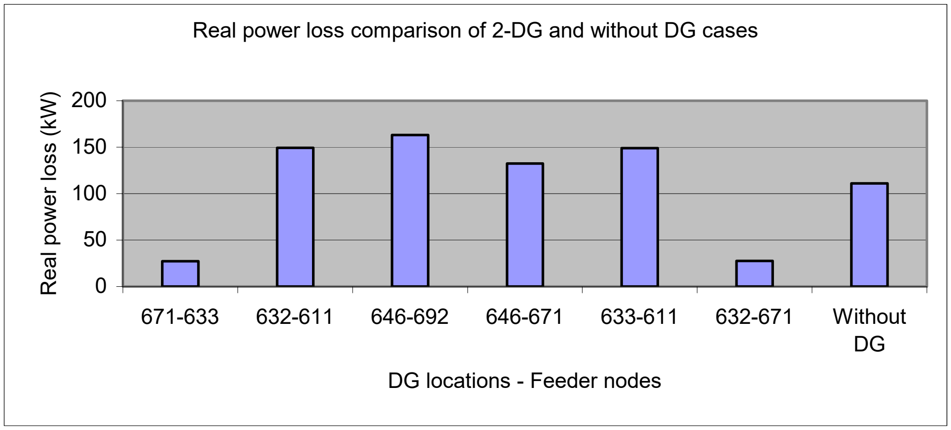


Figure 5.6 Comparison of real power losses in two DG and without DG systems

The data in the above table and figure shows that total feeder power losses reach a minimum value when two DGs are placed at nodes 633 – 671. This is due to the supply of power from two DGs to all of the downstream loads and some of the upstream loads.

5.6.1.5 Comparison of losses based on the number of DGs of the same capacity

For the purpose of analysis, the losses observed in the system are compared for all DG sizes (one-third and two-third) when single and two DGs were considered. This comparison can determine the size of DG (one-third or two-third) and also the number of DGs (one or two) suitable for the minimization of losses in the test system. The following sections show the comparison of losses in both cases.

DG Size: One-third

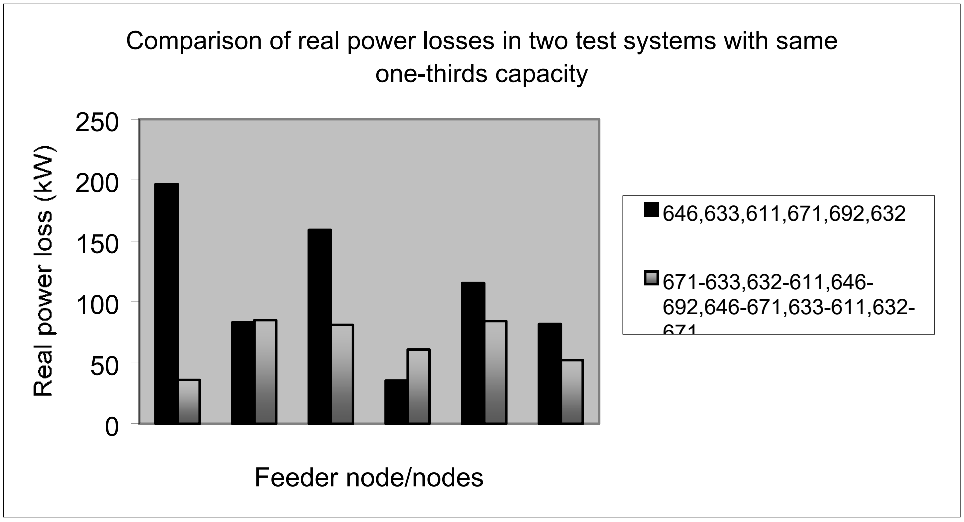


Figure 5.7 Comparison of real power losses with a single and two DGs of same one-thirds capacity

The above figure shows that the losses obtained in the test system when two DGs of capacity one-third are less than the losses observed in the test system with single DG of same capacity. The losses are minimized in the test distribution system, as two DGs were able to supply most of the loads in both the downstream and upstream of the test distribution feeder.

DG Size: Two-third

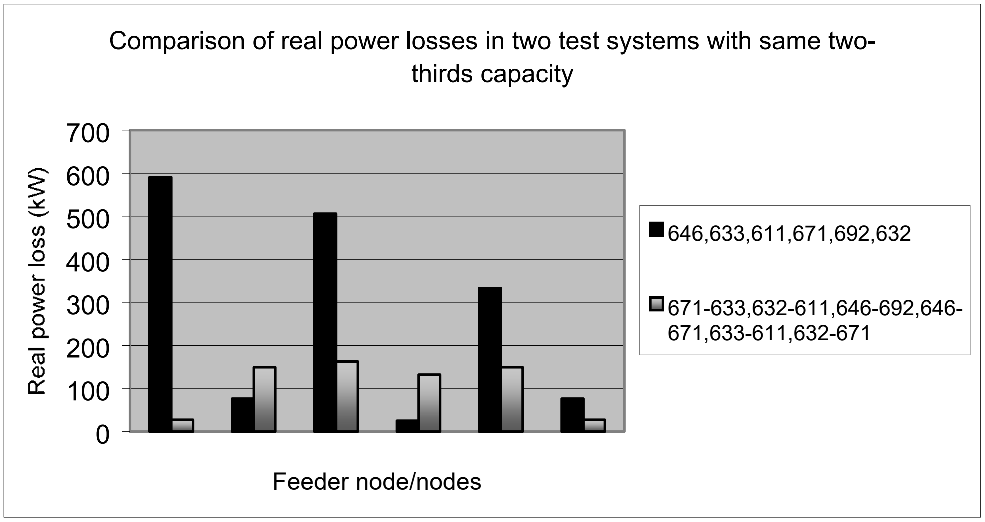


Figure 5.8 Comparison of real power losses with a single and two DGs of same two-thirds capacity

The above figure shows that the losses obtained in the test system with two DGs of two-thirds capacity were less than the losses observed in the test system with single DG of same capacity except in one in case where a DG of two-thirds capacity placed at 671 meets the power requirements of the downstream feeder, which forms the major part of distribution feeder.

5.6.2 Effect on Voltage profile

This simulation also focuses on the optimal placement of DG in a distribution system to produce voltage levels at each node within the acceptable range (1 ± 0.05 p.u.). When a DG of one-third of total system's load is allocated at different nodes of radial distribution feeder, voltage profile changes considerably at some of the nodes along the feeder. While some node voltages fall far out of the acceptable range when there is no DG in the system, all the bus voltages are within 1 ± 0.05 p.u. with the DG added.

In the simulation, voltage profiles at every node were observed when DGs are placed at different feeder nodes along the feeder. This simulation is useful to determine a location to place DGs at feeder nodes where voltage profile is held within limits. In each simulation, DGs are located at different nodes such as 611, 646, 633, 671, 692 and 632. During each simulation with DGs at different feeder nodes, a voltage profile at every node is observed to determine its value within specified limits. For the analysis, the desired magnitude of voltage value at every node is assumed as 1.0 p.u. This section shows the results of one-norm, two-norm and maximum deviation for the voltage values in each case, assuming the desired voltage at every node is 1.0 p.u.

5.6.2.1 Allocation of Single DG with one-third of total load

To observe a voltage profile, a DG of capacity one-third of total load is allocated at different feeder nodes along the feeder. The distribution power flow gives a voltage profile at every node. To determine the range where values are out of acceptable limits, the magnitude of voltage value at every node is assumed as 1.0 p.u. This section shows the results of 1-Norm, 2-Norm and maximum deviation for the voltage values in each case when DG units are allocated at different feeder nodes. The results in the following table shows that a good voltage profile is observed in most of the feeder nodes when a DG unit is placed at 671. The voltage values obtained at every feeder node when a DG is placed at this node are held within limits of 1 ± 0.05 p.u. as it can supply most of the downstream loads in the test feeder.

Table 5.5

The voltage norms and max deviation when a DG of one-third capacity is allocated at different nodes

DG location/ Feeder node	1-Norm			2-Norm			Max Deviation		
	A	B	C	A	B	C	A	B	C
646	0.240	-.750	0.701	0.084	0.247	0.231	-0.011	-0.043	0.088
633	0.120	0.330	0.081	0.061	0.113	0.112	0.005	-0.012	0.039
611	0.733	0.460	0.735	0.251	0.155	0.230	0.107	-0.020	-0.021
671	0.225	0.360	0.159	0.079	0.128	0.065	0.005	-0.009	0.007
692	0.722	0.432	0.677	0.246	0.147	0.206	0.100	-0.018	-0.020
632	0.117	0.321	0.350	0.059	0.111	0.110	0.005	-0.010	0.040

5.6.2.2 Allocation of Single DG with two-third of total load

In this case, a DG unit having a capacity of two-third of total load is allocated at different feeder nodes and distribution power flow is run. The following results show the values of voltage norms and deviation from the assumed value of 1.0 p.u. at every feeder node. The results in the following table shows that a good voltage profile is observed in most of the feeder nodes when a DG unit is placed at 671. The voltage values obtained at every feeder node when a DG is placed at this node are held within limits of 1 ± 0.05 p.u. as it supplies most of the downstream loads in the test feeder. This shows that the optimal placement of DG with two-third capacity is at node 671.

Table 5.6

The voltage norms and max deviation when a DG of two-third capacity is allocated at different nodes

DG location/ feeder node	1-Norm			2-Norm			Max Deviation		
	A	B	C	A	B	C	A	B	C
646	0.587	1.08	1.316	0.188	0.373	0.406	-0.050	-0.050	0.142
633	0.121	0.279	0.378	0.062	0.098	0.116	0.007	-0.005	0.041
611	1.355	0.834	1.332	0.464	0.284	0.448	0.194	-0.045	-0.028
671	0.268	0.276	0.203	0.092	0.108	0.071	0.004	0.002	0.002
692	1.331	0.862	1.264	0.454	0.303	0.410	0.182	0.174	-0.034
632	0.121	0.279	0.378	0.062	0.098	0.116	0.007	-0.005	0.041

5.6.2.3 Allocation of two DGs with a total capacity of one-third of total load

The following table shows the values of voltage norms and deviation when two DGs of each one-sixth of capacity are installed, and distribution power flow was simulated to observe the voltage profile at every feeder node. It shows that the optimal placement for the two DGs is at nodes (671-633) as the voltage profiles at every node are within the specified limits as shown below. The voltage profile obtained was within the desired limits as two DGs at nodes 671-633 were able to supply most of the downstream loads and part of upstream loads in the test feeder.

Table 5.7

The voltage norms and max deviation when two DGs of total one-third capacity are allocated at two different nodes

DG location/ feeder node	1-Norm			2-Norm			Max Deviation		
	A	B	C	A	B	C	A	B	C
671-633	0.220	0.318	0.203	0.079	0.116	0.072	0.000	-0.006	0.012
632-611	0.410	0.380	0.461	0.145	0.129	0.151	0.062	0.015	0.035
646-692	0.392	0.640	0.116	0.139	0.207	0.055	0.057	-0.036	0.014
646-671	0.317	0.413	0.383	0.105	0.180	0.118	-0.008	-0.024	0.041
633-611	0.405	0.385	0.469	0.144	0.130	0.140	0.062	-0.017	-0.019
632-671	0.394	0.278	0.262	0.127	0.107	0.091	-0.017	-0.0003	0.033

5.6.2.4 Allocation of two DGs with a total capacity of two-third of total load

The following table shows the values of voltage norms and deviation when two DGs of each one-third capacity are installed, and distribution power flow was simulated to observe the voltage profile at every feeder node. The voltage values obtained at every feeder node when DGs are placed at (671-633) nodes are held within limits of 1 ± 0.05 p.u. The following results show that the optimal placement of two DGs of two-thirds capacity is at nodes (671-633). The voltage profile obtained was within the desired limits as two DGs at nodes 671-633 were able to supply most of the downstream loads and part of upstream loads in the test feeder.

Table 5.8

The voltage norms and max deviation when two DGs of total two-third capacity are allocated at two different nodes

DG location/ feeder node	1-Norm			2-Norm			Max Deviation		
	A	B	C	A	B	C	A	B	C
671-633	0.226	0.273	0.164	0.080	0.105	0.067	0.001	-0.0004	0.006
632-611	0.7278	0.493	0.728	0.250	0.166	0.228	0.091	-0.069	-0.070
646-692	0.576	0.780	0.309	0.204	0.257	0.105	0.084	-0.043	0.018
646-671	0.478	0.687	0.538	0.154	0.228	0.158	-0.024	-0.031	0.053
633-611	0.721	0.499	0.739	0.248	0.168	0.229	0.091	-0.069	-0.070
632-671	0.225	0.270	0.156	0.079	0.105	0.066	0.005	0.001	0.006

5.6.3 Effects on feeder power factor

Capacitors are widely used in distribution systems that produce a varying proportion of the reactive energy that the system consumes itself to achieve a good power factor. It also achieves power loss reduction, system capacity release and maintain a voltage profile within permissible limits. Shunt capacitor banks installed in the test feeder are three-phase wye connected. To maintain the desired power factor at the substation at unity, shunt capacitors were installed in the test feeder at nodes 675 and 611 respectively. These capacitors are modeled as constant susceptance and specified at nameplate rated KVAr. The total KVAr of capacitors installed was 700 KVAr.

The distribution power flow of the test feeder without DG results in the power factor as shown in Table 5.9. The results show that there is a need to improve the power factor for the better operation of radial distribution feeders. This section considers the impact of DG on feeder power factor without considering the changing of ratings of capacitors installed in the test feeder.

Table 5.9

Power factor of the IEEE 13-test radial distribution feeder

Phase-A	Phase-B	Phase-C	Total
0.9101	0.9044	0.8873	0.9001

5.6.3.1 Allocation of Single DG with 1/3 of total load

Apart from the factors such as minimization of losses, having a good voltage profile that contributes to the determination of optimal allocation of DG in distribution system, another important factor is a feeder power factor. To determine the impact of DG on feeder power factor, simulation considers the DG with capacities of one-third and two-thirds of system's total load. The simulation (distribution power flow) was used to determine the optimal placement for DG that results in a good feeder power factor. For analysis, a power factor of 0.95 per phase and total feeder power factor was assumed. The following table shows the power factor values and their deviation from the original values when a DG of one-third capacity is placed at different nodes, 646, 633, 611, 671, 692 and 632.

Table 5.10

The Power factor values and deviation when a DG of one-third capacity is allocated at different nodes

DG location/ feeder node	Power Factor				Deviation			
	A	B	C	Total	A	B	C	Total
646	0.89	0.90	0.88	0.88	0.060	0.055	0.066	0.066
633	0.92	0.91	0.90	0.91	0.027	0.037	0.047	0.037
611	0.91	0.88	0.69	0.91	0.043	0.068	0.257	0.042
671	0.99	0.94	0.96	0.96	-0.028	0.005	-0.008	-0.012
692	0.90	0.88	0.51	0.92	0.041	0.070	0.441	0.030
632	0.92	0.91	0.90	0.91	0.027	0.037	0.047	0.037

From the data in the above table, node 671 can be considered as the optimal placement for DG as the placement results in a power factor ranging from 0.94-0.99 per phase and total feeder power factor being 0.96. The allocated DG at 671 can provide the reactive power requirements for most of the downstream loads of the test feeder. Though the power factor values are better than the original system values, improvement in power factor is anticipated for the better monitoring and control of radial distribution feeder. The improvement can be obtained by following a procedure explained in further sections.

5.6.3.2 Allocation of Single DG with two-third of total load

When a DG of two-thirds capacity is placed at different feeder nodes, the results show the power factor per phase and total feeder power factor. The following represents the power factor values and their deviation from the desired value of 0.95.

Table 5.11

The Power factor norms and deviation when a DG of two-third capacity is allocated at different nodes

DG location/ feeder node	Power Factor				Deviation			
	A	B	C	Total	A	B	C	Total
646	0.88	0.96	0.87	0.49	0.074	-0.014	0.077	0.461
633	0.95	0.93	0.93	0.94	0.003	0.021	0.018	0.014
611	0.88	0.85	0.98	0.80	0.071	0.100	-0.027	0.15
671	-0.99	0.96	-0.99	0.998	0.052	-0.007	0.0505	-0.005
692	0.88	0.85	0.96	0.82	0.07	0.10	-0.006	0.131
632	0.95	0.93	0.93	0.94	0.003	0.021	0.018	0.014

Above results show that power factor values obtained is satisfactory (compared to the test feeder power factor values as shown in Table 5.9) when a DG of two-third capacity is placed at 632. However, an improvement in the power factor for the efficient operation of distribution feeder is anticipated.

5.6.3.3 Allocation of two DGs with a total capacity of one-third of total load

The simulation continues with a DG of different size to determine its optimal location in a radial distribution feeder. In this case, the simulation for distribution power flow was run by taking two DGs each of one-sixth capacity. Two DGs are placed at different feeder nodes such as (671-633), (646-692), (646-671), (633-611), (632-611) and (632-671). The following results show the power factor values and the norm and deviation in each feeder node combination with an assumption of 0.95 power factor per phase and total power factor.

Table 5.12

The Power factor norms and deviation when two DGs of total one-third capacity are allocated at two different nodes

DG location/ feeder node	Power Factor				Deviation			
	A	B	C	Total	A	B	C	Total
671-633	0.99	0.96	0.96	0.97	-0.036	-0.007	-0.014	-0.021
632-611	0.92	0.89	-0.99	0.93	0.033	0.057	0.064	0.017
646-692	0.90	0.99	0.98	0.94	0.052	-0.044	-0.036	0.013
646-671	0.96	0.80	0.94	0.98	-0.009	0.146	0.015	-0.025
633-611	0.92	0.90	-0.98	0.93	0.033	0.057	0.064	0.017
632-671	-0.56	0.96	0.95	-0.95	0.490	-0.013	-0.005	0.098

From the results it can be concluded that (671-633) is the feeder combination at which the distribution power flow resulted in a power factor much greater than the assumed value of 0.95 per phase, as well as total feeder power factor. The allocation of DGs at these nodes can provide the reactive power requirements of most of the downstream loads and some of upstream loads. Though the results are better than the original system values, power factor can be improved to near unity for an efficient system's operation.

5.6.3.4 Allocation of two DGs with a total capacity of two-third of total load

In this case, the simulation for distribution power flow is performed with two DGs of two-third total capacity to determine the optimal location for them in the test feeder. Two DGs are placed at different feeder nodes, the same as mentioned in the one-third case. The following results show the power factor values, and its norm and deviation from the assumed value of 0.95 per phase and total power factor.

Table 5.13

The Power factor norms and deviation when two DGs of total two-third capacity are allocated at two different nodes

DG location/ feeder node	Power Factor				Deviation			
	A	B	C	Total	A	B	C	Total
671-633	-0.99	0.96	0.99	0.99	0.050	-0.015	-0.05	-0.05
632-611	0.91	0.88	0.85	0.91	0.041	0.07	0.10	0.04
646-692	0.89	0.89	0.45	0.97	0.06	0.06	0.5	-0.007
646-671	0.97	0.91	0.95	0.91	-0.021	0.034	0	0.04
633-611	0.91	0.88	0.85	0.91	0.041	0.069	0.1	0.04
632-671	-0.99	0.96	0.99	0.997	0.050	-0.014	-0.05	-0.05

The above tabulated results shows that the values of power factor per phase are nearly unity except in a phase with a total feeder power factor near to unity when two DGs are placed at nodes (671-633) and (671-632) individually. The power factor in this case can be obtained near to unity value in A-phase by following a procedure explained further in the next section.

5.7 Impact of change of DG reactive power capability on radial feeder

The following sections highlight the results obtained when the reactive power of the DG units is changed slightly in the test system and simulated for distribution power flow. In this simulation, the values of active power were kept constant, while the reactive power was changed in order to obtain better losses, a good voltage profile and an improved power factor. Since DG is modeled as a negative load in the test system that injects real and reactive power into the system, it is reasonable to tweak the value of reactive power capability of the DG system that brings the targeted results as said above. The values of Q were tweaked only for the test system with two DGs for two different capacities (one-third and two-third).

To analyze the results obtained in this section, original values obtained in the test systems are compared to the values obtained with two DGs (tweaked Q for any of DG) for two different capacities (one-third and two-third). In this test scenario, value of reactive power is tweaked only for the test systems with two DGs placed at combinational nodes (671-632 and 671-633) for two different capacities (one-third and two-third). The values of power factor, losses and voltage profile are compared in both cases.

5.7.1 Comparison of Values for tests system with two DGs of one-third total capacity

Nodes: *671-632*

A. *Power Factor*

DG location/ feeder node	Power Factor				Deviation			
	A	B	C	Total	A	B	C	Total
671-632 Original	-0.56	0.96	0.95	-0.95	0.4901	-0.014	-0.005	0.0979
671-632 Tweaked	0.98	0.96	0.99	0.98	-0.034	-0.041	-0.041	-0.033

B. *Losses*

Feeder Nodes/ 2-DG locations	Total Losses in System with DG		
	kW	KVAr	KVA
671-632(Original)	52.385	122.16	132.918
671-632(Tweaked)	35.473	75.93	83.8

C. *Voltage profile*

Voltage profile after tweaking reactive power of DG						
Node	A		B		C	
	Original	Tweaked	Original	Tweaked	Original	Tweaked
650	1.05	1.05	1.05	1.05	1.05	1.05
632	1.0436	1.0235	1.021	1.0243	1.0011	1.0186
645			1.0066	1.0099	1.0047	1.0221
646			1.0018	1.0051	1.0059	1.0233
633	1.0406	1.0204	1.019	1.0233	0.9985	1.016
634	1.0172	0.9966	1.0003	1.0037	0.9794	0.9972
671	1.0433	1.0216	1.0442	1.0456	0.9715	0.9948
692	1.0433	1.0216	1.0442	1.0456	0.9715	0.9948
675	1.0372	1.0154	1.0466	1.048	0.9694	0.9929
684	1.0412	1.0196			0.9695	0.9928
611					0.9675	0.9908
652	1.0345	1.031				
680	1.0433	1.0216	1.0442	1.0456	0.9715	0.9948

Nodes: *671-633*

A. *Power factor*

DG location/ feeder node	Power Factor				Deviation			
	A	B	C	Total	A	B	C	Total
671-633 Original	0.99	0.96	0.96	0.97	-0.036	-0.007	-0.014	-0.021
671-633 Tweaked	0.98	0.96	0.99	0.98	-0.034	-0.014	-0.041	-0.033

B. Losses

Feeder Nodes/ 2-DG locations	Total Losses in System with DG		
	kW	KVAr	KVA
671-633(Original)	36.0	78.57	86.4
671-633(Tweaked)	34.733	75.031	82.68

C. *Voltage profile*

Voltage profile after tweaking reactive power of DG						
Node	A		B		C	
	Original	Tweaked	Original	Tweaked	Original	Tweaked
650	1.05	1.05	1.05	1.05	1.05	1.05
632	1.0243	1.0235	1.0251	1.0243	1.0203	1.0186
645			1.0107	1.0099	1.0238	1.0221
646			1.0059	1.0051	1.025	1.0233
633	1.0238	1.0229	1.0256	1.0249	1.0219	1.0202
634	1.000	0.9991	1.007	1.0063	1.0033	1.0015
671	1.0232	1.0216	1.0478	1.0456	0.9916	0.9948
692	1.0232	1.0216	1.0478	1.0456	0.9916	0.9948
675	1.017	1.0154	1.0502	1.048	0.9897	0.9929
684	1.0212	1.0196			0.9896	0.9928
611					0.9876	0.9908
652	1.0146	1.0131				
680	1.0232	1.0216	1.0478	1.0456	0.9916	0.9948

Summary

The above results lead to the conclusion that the values of power factor, losses (active, reactive) and voltage profile are excellent when the reactive power was tweaked at the nodes 671-632, rather than the values obtained when DGs were placed at 671-633 with tweaked reactive power. The results in section 5.7.1 show that the optimal placement for two DGs of total capacity one-third is at nodes 671-632 as these DGs were able to supply active and reactive power requirements for most of the upstream and downstream loads in the test feeder.

5.7.2 Comparison of Values for tests system with two DGs of two-third total capacity

Nodes : *671-632*

A. Power factor

DG location/ feeder node	Power Factor				Deviation			
	A	B	C	Total	A	B	C	Total
671-632 Original	-0.99	0.96	0.99	0.997	0.052	-0.014	-0.05	-0.05
671-632 Tweaked	0.999	0.964	0.999	0.996	-0.05	-0.01	-0.05	-0.046

B. Losses

Feeder Nodes/ 2-DG locations	Total Losses in System with DG		
	kW	KVAr	KVA
671-632(Original)	27.462	50.32	57.326
671-632(Tweaked)	27.451	50.303	57.306

C. Voltage profile

Voltage profile after tweaking reactive power of DG						
Node	A		B		C	
	Original	Tweaked	Original	Tweaked	Original	Tweaked
650	1.05	1.05	1.05	1.05	1.05	1.05
632	1.0222	1.0216	1.0195	1.0196	1.019	1.0192
645			1.0051	1.0052	1.0225	1.0227
646			1.0004	1.004	1.0237	1.0239
633	1.0192	1.0215	1.0176	1.0205	1.0164	1.0228
634	0.9953	0.9976	0.9988	1.0018	0.9977	1.0041
671	1.0243	1.0238	1.0434	1.0434	0.9976	0.9978
692	1.0243	1.0238	1.0434	1.0434	0.9976	0.9978
675	1.0182	1.0176	1.0457	1.0457	0.9957	0.9959
684	1.0223	1.0217			0.9956	0.9958
611					0.9936	0.9938
652	1.0158	1.0152				
680	1.0243	1.0434	1.0434	0.9978	0.9976	0.9978

Nodes: *671-633*

A. *Power factor*

DG location/ feeder node	Power Factor				Deviation			
	A	B	C	Total	A	B	C	Total
671-633 Original	-0.99	0.96	0.99	0.99	0.052	-0.015	-0.05	-0.05
671-633 Tweaked	0.99	0.96	0.99	0.99	-0.050	-0.014	-0.050	-0.046

B. *Losses*

Feeder Nodes/ 2-DG locations	Total Losses in System with DG		
	kW	KVAr	KVA
671-633(Original)	27.2	50.061	57.0
671-633(Tweaked)	27.216	50.064	56.983

C. *Voltage profile*

Voltage profile after tweaking reactive power of DG						
Node	A		B		C	
	Original	Tweaked	Original	Tweaked	Original	Tweaked
650	1.05	1.05	1.05	1.05	1.05	1.05
632	1.0222	1.0216	1.0195	1.0196	1.019	1.0192
645			1.0051	1.0052	1.0225	1.024
646			1.0004	1.0004	1.0237	1.024
633	1.0222	1.0186	1.0204	1.0176	1.0225	1.0167
634	0.9984	0.9947	1.0017	0.9989	1.0039	0.9979
671	1.0244	1.0237	1.0434	1.0434	0.9976	0.9978
692	1.0244	1.0237	1.0434	1.0434	0.9976	0.9978
675	1.0182	1.0176	1.0457	1.0434	0.9957	0.9959
684	1.0233	1.0217			0.9956	0.9958
611					0.9936	0.9939
652	1.0158	1.0152				
680	1.0244	1.0237	1.0434	1.0434	0.9976	0.9978

Summary

The above results lead to the conclusion that the values of power factor, losses (active, reactive) and voltage profile are better when the reactive power was tweaked at the nodes 671-632, when compared to the values when DGs were placed at 671-633 with tweaked reactive power. The results in section 5.7.2 show that the losses were increased when compared to original values in the test system, 671-633.The results also show that the optimal placement for two DGs of total capacity two-third is at nodes 671-632 as these DGs were able to supply active and reactive power requirements for most of the upstream and downstream loads in the test feeder.

5.8 Summary

This chapter throws light on the technical evaluation comparing DG size and location impact on the operation of the IEEE 13-node test distribution systems. It highlights the impact of DG on test distribution system with distribution power flow performed. The simulation for distribution power flow was carried out using Radial Distribution Analysis Package (RDAP). In this distribution analysis tool, distributed generation was modeled as a negative load that injects real and reactive power into the system independent of system voltage. This simulation considered the DG capacities of one-third and two-third of total load present in the test distribution system. Distribution power flow was run for each DG capacity with single and two DGs at different feeder nodes of test feeder. The results of the distribution flow, such as line flows, losses and power factor, were taken individually as a variable for optimization of determining the DG location in distribution system. The results in each case were analyzed as a single variable optimization to identify the optimal placement of DG sources in a radial distribution feeder. However, the same type of technical evaluation can be performed on the real time distribution system but considering some of the real time local load conditions, fuel statistics, type of DG source, protection and intertie connection.

The placement of DG that results in the minimum losses, good voltage profile and improved power factor was determined as the optimal location for that DG in a radial distribution feeder. The different test case scenarios considered and their results are summarized in the following table.

Table 5.14

The summary of results of all test cases

S. No.	Test Case Scenarios	DG location / feeder nodes	Optimal locations of DG
1	Case 1 Single DG Capacity: one-third	646,633,611,671,682,632	671
2	Case 2 Single DG Capacity: two-third	646,633,611,671,682,632	671
3	Case 1 Two DG Total Capacity: one-third	632-611,671-633, 646-692,646-671, 633-611,632-671	671-633
4	Case 2 Two DG Total Capacity: two-third	632-611,671-633, 646-692,646-671, 633-611,632-671	671-633
5	Case 1 Two DG Change of Q Total Capacity: one-third	671-633, 632-671	671-632
6	Case 2 Two DG Change of Q Total Capacity: two-third	671-633, 632-671	671-632

CHAPTER VI

ECONOMIC ANALYSIS AND RESULTS

6.1 Introduction

The second part of this thesis's work resulted in an informative and useful economic analysis tool, DG-ECON with which the user can document the study results and analyze them for economic feasibility with minimum effort. The economic feasibility of a biomass-based renewable energy installation is shown by developing a user interface spreadsheet in Microsoft Excel.

The spreadsheet calculates project-economic information in a 20-year life cycle cost analysis. This cost analysis enables users to define projects that are most energy efficient and offer the greatest financial benefit. The emphasis on the user interface features of the application makes the application as user friendly as possible. The application has both numerical and graphical data representation using some of the features of Microsoft Visual Basic. The developed application is adaptive to specific analysis needs, such as the economic analysis of biomass renewable energy installations. A first order economic feasibility is demonstrated using the developed economic analysis tool.

The Mississippi Band of Choctaw Indians' (MBCI) proposal to locate a renewable energy installation that utilizes poultry litter as a fuel on the tribal lands under the Tribal

Energy Program and Department of Energy (DOE) was taken as a case study. The purpose of this project was to determine whether such an installation could be economically viable as well as technically sustainable. All the data required for economic feasibility was provided by MBCI and Community Power Corporation, Littleton, Colorado, manufacturer of biomass DG equipment.

6.2 Economic Calculations

The economic calculations used in DG-ECON are based on widely accepted financial equations. The following section explains the economical and financial calculations that were used in developing the analysis tool. DG-ECON uses the Net Present Value (NPV) method or Present Worth Analysis (PWA) as a financial measure to evaluate the present worth of money a year from now in today's term [32].

Net Present Value.

Net present value is a decision making financial measure that allows comparing future expenses to present ones. The value of money at any time in the future can be converted to its equivalent present worth using the following equation:

$$\text{NPV} = \sum_{j=0}^{n} X_j^{'} /(1+d-i)^{j}$$

where $X_j^{'}$ represents net cash flow in year j, n is the number of years of cash flow, j is the year in which the cash flow $X_j^{'}$ occurs, d is the discount rate, and *i* is the inflation rate. The algebraic sum of the NPVs of life cycle gives the net present value of economic parameter in that life cycle period.

Life Cycle Cost Analysis

One of the popular cost analysis methods for distributed generation systems is Life Cycle Cost (LCC) analysis that estimates the total expenses in the life cycle of the DG system. In other words, LCC gives the total cost of the DG system. The total cost is important, because it gives an idea of the cost involved with various DG options and also leads to a cost-effective DG system design. This analysis is based on work done previously [33].

The life cycle of a DG system is usually 20 years. LCC analysis introduces a method through which we can evaluate different technologies and put a dollar value on the various benefits that accrue from them. The formula for finding out the life cycle cost of DG system is:

$$LCC = C+F_{pv}+L_{pv}+M_{pv}-G_{pv}-A_{pv}$$

where “pv” represents net present worth.

C = Capital Cost
F = Fuel Cost
L = Labor Cost
M = Maintenance Cost
G = Power Generation Value
A = Ash Revenue (By product revenue)

6.3 Development of Economic Analysis tool

In the above section, discussion of the economical and financial equations required for developing the economic analysis tool was given. In this section, the step-by-step development of the economic analysis tool and a discussion on user-friendly features is given. The analysis tool is a Visual Basic Application (VBA) using Microsoft Excel (spreadsheet) as a development platform.

The Microsoft Visual Basic (VB) programming language was used to develop user interface features of this analysis tool. A proper design using the VB tools like Forms, Controls and Macros will result in a user-friendly and easy to use application. The emphasis was on the user interface features of the application, to make the application as user friendly as possible. The discussion on how to enter economic parameters, data verification and running the analysis is given in the next sections. The screenshot provided in Figure 6.1 gives a clear picture of the economic analysis tool developed.

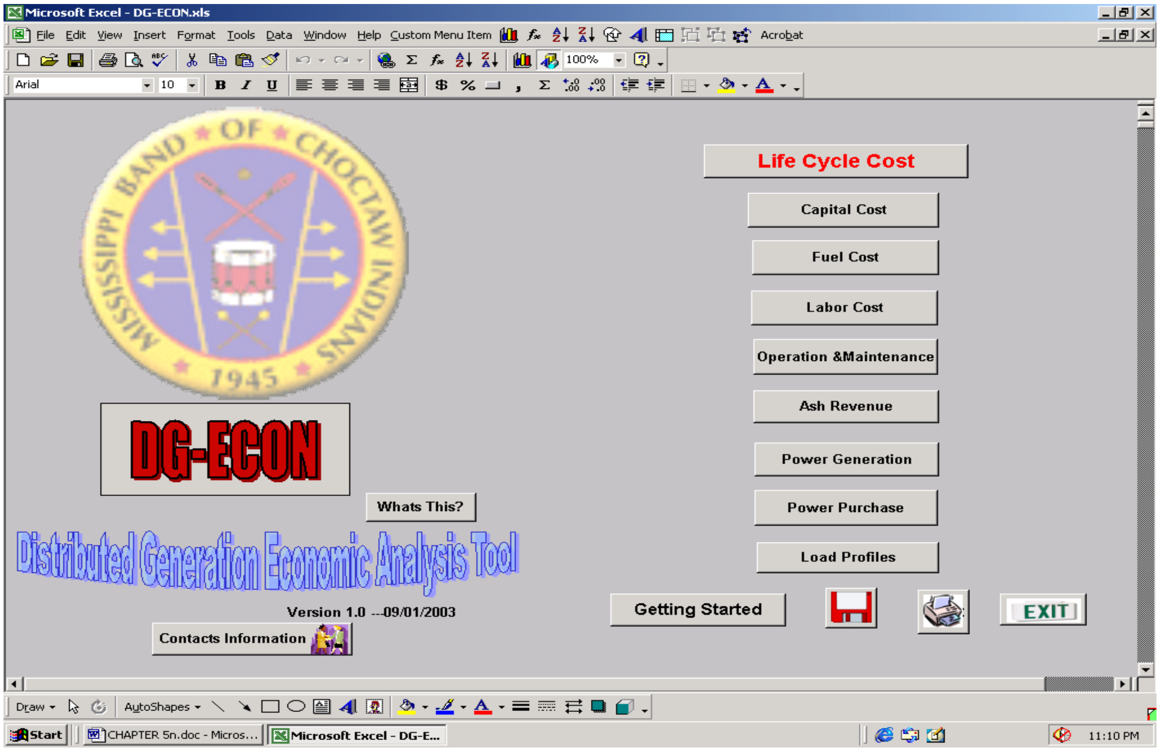


Figure 6.1 Screenshot of distributed generation economic analysis tool

In the bottom-right of the screenshot in Figure 6.1 there are buttons for different purposes. If the user uses the analysis tool for the first time, the basic steps to follow in running the economic analysis tool can be viewed by pressing the help button as shown in Figure 6.2. Apart from the start help, the user can also save the changes made in the application using save button, shown in Figure 6.3. To print the worksheets (consisting of life cycle costs and savings of economic parameters) in Microsoft Word, the user can press the print button, shown in Figure 6.4. The last button in the screenshot is the exit button in Figure 6.5; it is used to close the application whenever the user wants.

Figure 6.2. Help button for first time users

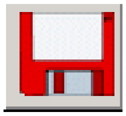


Figure 6.3. Button for saving the entire application

Figure 6.4. Print button for printing all economic analysis documents

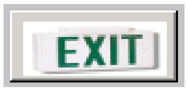


Figure 6.5. Button for closing the entire application

6.4 Features of economic analysis tool

6.4.1Entering economic parameters

DG-ECON calculates the basic project costs and investments criteria and reports them on the annual summary screen. These values are based on the economic parameters used for the analysis. The economic parameters are entered in each worksheet by pressing the buttons corresponding to each economic parameter placed on the main menu as show in figure 6.1. To make the analysis tool as user friendly as possible, a help button is provided in each worksheet that aids the user in entering the economic parameters.

The different economic factors that are considered in the analysis tool are:

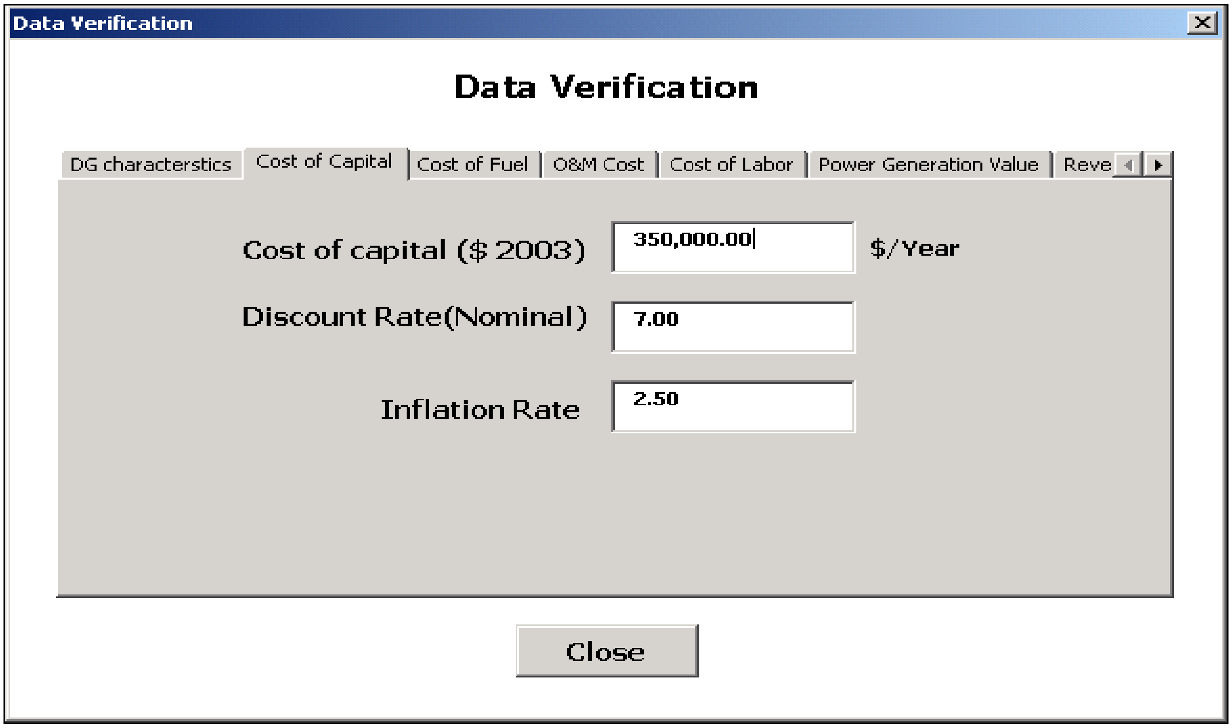
- The **Project Lifetime** is the period over which the economic analysis will be performed. The project lifetime is assumed to be equal to the system lifetime, or the expected life of the power system used. In this analysis tool the default project life is 20 years.
- The **Discount rate** is generally set equal to the rate of return of alternative investments of comparable risk. The user needs to enter a discount rate in each worksheet to run the analysis, but if no value is entered, a default of zero percent will be used.
- The **Inflation rate** is the annual increase of prices. It is used to adjust both the discount rate and the cost of each parameter over the project lifetime. The user needs to enter an inflation rate in each worksheet to run the analysis, but if no value is entered, a default of zero percent will be used.
- The **Capital Cost** is the sum of total cost of the power systems (Gen-set + Gas supply system) including building, installation, control, wiring and plumbing. The total cost also includes the equipment replacement costs. This is expressed as dollars per installed kW of electrical output. The user needs to enter the capital cost (single number) as a multiplication of dollars per installed kW of electrical output with the number of installed kW capacity of biomass energy installation.
- The **Fuel Cost** is the total cost of poultry litter fuel, which includes the cost of removal and transportation from the farm to the location of the proposed renewable energy plant.

To calculate the annual fuel cost, the user needs to enter the number of tons of poultry litter required and also dollars per ton of poultry litter.

- The **Labor Cost** is total cost of staff to run the facility, which includes the salary and any other allowances incurred to them per annum. To calculate the annual labor cost, the user needs to enter the number of full time staff and the annual cost of each full time labor.
- The **Operation and Maintenance (O&M) cost** is the sum of all operation and maintenance costs that are fixed by the installed capacity of the generating equipment expressed as dollars per installed kW per year. The user needs to enter the O&M cost (single number) as a multiplication of dollars per installed kW per year with the installed capacity in kW.
- The **Poultry Litter Ash Revenue** is the revenue from the poultry litter ash that can be sold for dollars per amount of ash resulting from one ton of combusted poultry litter. To calculate the poultry litter ash revenue, the user needs to enter the price of poultry litter ash per ton of poultry litter and also the number of poultry litter tons required for the installed capacity or electrical output. This economic parameter is termed as a negative cost element that can be a saving in renewable energy plant installation.
- The **Power Generation Value** is the value of power generated by the renewable energy installation per year for the given capacity of power generation. To calculate the power generation value per year, the user needs to enter the capacity of plant, number of operational hours per day and year and also the cost of electricity per MWh. This economic parameter is termed as a negative cost element that can be a saving in renewable energy plant installation.

6.4.2 Data Verification

This simulation tool has the feature of data verification that allows the user to verify the entered values of economic parameters in individual spreadsheets of the economic tool before running the analysis. The user can go back to a specific spreadsheet and change the data if he/she finds an error in data verification. This prevents errors in the entries entered by the user, thus making the analysis tool as accurate as possible for running economic analysis. Figure 6.6 shows the Dialog Box for the data verification.



Data Verification

Cost of capital ($ 2003) 350,000.00 $/Year

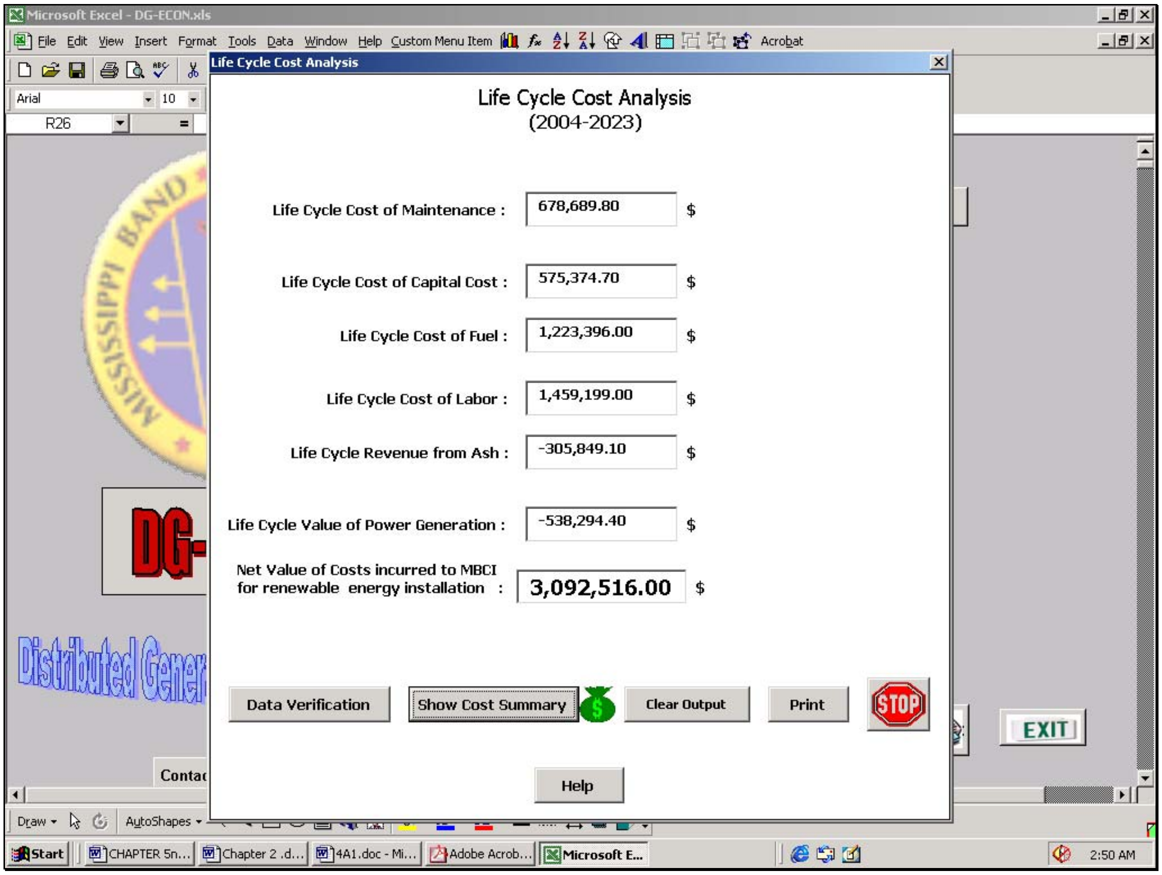
Discount Rate(Nominal) 7.00

Inflation Rate 2.50

Figure 6.6. Dialog Box for the data verification

6.5 Running economic analysis tool

After entering the required economic parameters in the worksheets as explained in section 6.4.1, the user needs to go back to the main menu and run the analysis to obtain the results of the life cycle cost analysis. The user can utilize the help button to know the steps to be followed in running the analysis. When a button named “ Life Cycle Cost” on the main menu is clicked, a window pops up with different options as shown in Figure 6.7.



Life Cycle Cost Analysis
(2004-2023)

Life Cycle Cost of Maintenance : 678,689.80 $

Life Cycle Cost of Capital Cost : 575,374.70 $

Life Cycle Cost of Fuel : 1,223,396.00 $

Life Cycle Cost of Labor : 1,459,199.00 $

Life Cycle Revenue from Ash : -305,849.10 $

Life Cycle Value of Power Generation : -538,294.40 $

Net Value of Costs incurred to MBCI for renewable energy installation : 3,092,516.00 $

Figure 6.7 Screenshot of life cycle cost analysis window

The user can verify all the data entered in the worksheets together by clicking the “Data Verification” button. The importance of this feature is already given in section 6.4.2. The user needs to click the “ Show Cost Summary” button to see the summary of life cycle costs involved in a project. The analysis tool also allows the user to print the summary of life cycle costs document if required. The document that shows the summary of life cycle costs for the MBCI case study is attached in Appendix B.1. The additional feature of this analysis tool is the graphical representation of different life cycle costs when the button named " Show Cost Summary" is clicked. The following figure shows the screenshot of graph showing the different costs in MBCI case study.

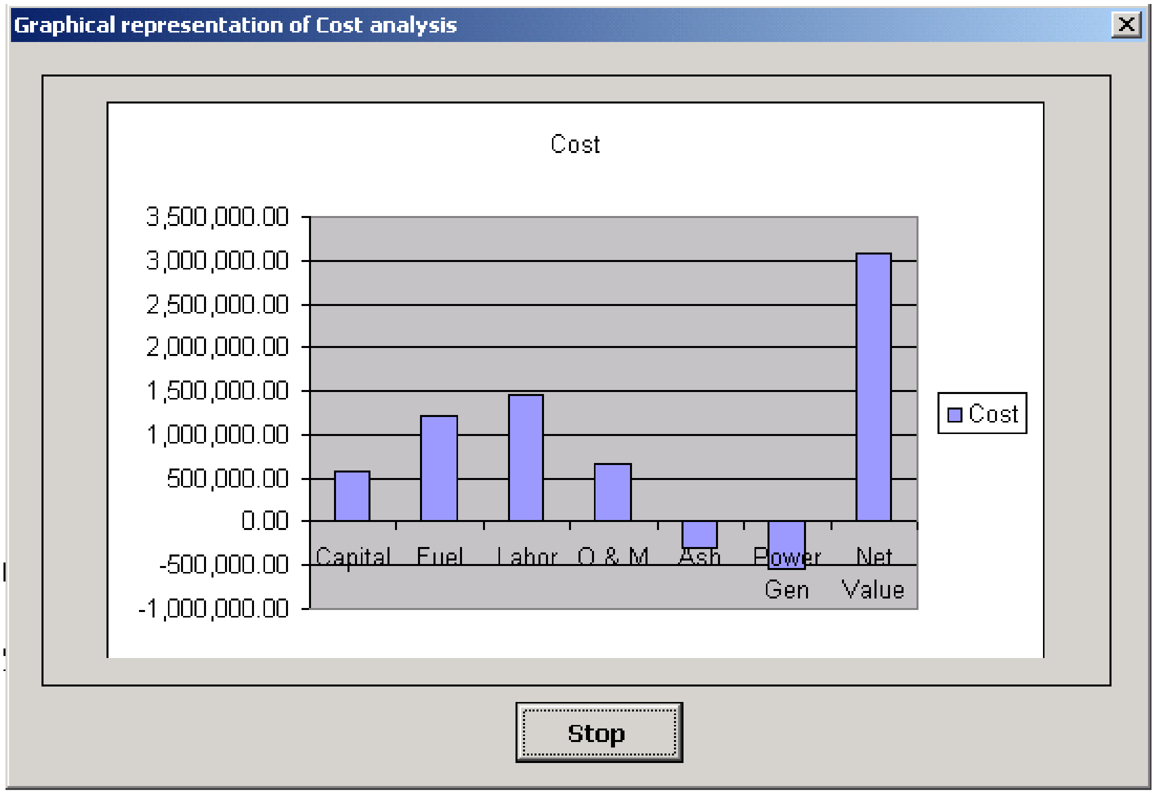


Figure 6.8 Screenshot of window showing the graphical representation of costs

6.6 Economic Analysis and results of case study

6.6.1 Introduction

This section represents the economic analysis of 20-year (2004 through 2023) life-cycle costs associated with the proposed establishment of renewable energy plant at MBCI. It also presents the economic and operational assumptions relied upon to develop the 20-year life-cycle costs. The discussion also provides details of each of the key economic and operational assumptions relied upon in the analysis, including fuel costs, MBCI electric loads, capital costs, recurring operations and maintenance costs, and other relevant factors.

The final section of this chapter presents the results of the life cycle cost analysis. This process was modeled after a similar analysis done in reference [33].

6.6.2 Analysis assumptions and parameters

To estimate the life cycle costs associated with the electric power generation at MBCI, numerous engineering, operational, and economic assumptions are required. The life cycle cost results are dependent upon these assumptions.

A. *MBCI Electrical Loads*

The assessment of the power utilization at Choctaw Laundromat, mentioned in Chapter 4, is taken as a basis to determine the electrical loads served by the poultry- litter-powered DG. The variation of load is from 100 kW to 380 kW on an average day, and the average monthly consumption is around 198 MWh.

B. Fuel costs, power costs, and financial/economic assumptions

This subsection addresses the current and future costs of fuels used for power generation, the cost of electric power purchased from Central Electric Power Association, and the financial and economic assumptions used in life cycle cost analysis.

FUEL PRICES - The price of poultry litter was assumed to be $ 20.0 per ton, which includes the cost of removal and transportation from the farm to the proposed location of the renewable energy plant at MBCI. The transportation costs associated with the total cost of poultry litter are $0.11 per ton per mile. However, there is substantial uncertainty regarding the removal cost of poultry litter at farms. The assumption of $20 per ton can be broken down to $15 commodity costs and transportation cost at $0.11 per mile per ton [34-35].

ELECTRIC POWER PRICES— Prices for power commercially purchased from Central Electric Power were computed from the applicable Central Electric Power tariff assuming an 85 percent load factor and converted to average annual per-kWh prices. The current electricity price per kWhr is 5.5 cents. For the analysis purpose, it is assumed that there is no inflation in electricity prices during the life cycle period (2004-2023).

OTHER FINANCIAL/ECONOMIC ASSUMPTIONS - In addition to the fuel and electric power prices, other economic and financial assumptions were required to complete the life cycle cost analysis. Each is discussed below.

Inflation Rate: An inflation rate of 2.5 percent per year was assumed throughout this analysis. The inflation rate is used to convert between real prices (and costs) and nominal prices (and costs). The 2.5 percent inflation rate is consistent with general short-term and long-term expectations. To the extent that any error exists in the assumed inflation rate, the life cycle cost results would not be affected since projections of prices and costs have been made in real terms (i.e., net of inflation)[33].

Discount Rate: A nominal discount rate of 7.0 percent is assumed to compute life-cycle costs.

6.6.3 Life cycle cost estimates

This section provides the factors or various costs that contributed towards the total life cycle costs. It also presents the results of the life cycle cost analysis developed for the scenario addressed. Because of the limited remaining life of the existing power generation facility, the existing facility is to be replaced with a similar, power system unit in 2014.

Life-cycle costs were calculated as the sum of:

- The cost of poultry litter for fueling the electric generating facility;
- The capital cost of the new electric generating facility, including ancillary construction requirements;

- Annual maintenance cost for the new generating facility;
- The capital cost of replacing the total power system in 2014;
- Labor costs to operate the new generating facility;
- Revenue to MBCI from the generation of electrical energy from poultry litter;
- Revenue to MBCI from the sale of poultry litter ash, a negative cost element.

6.6.4 Results and Analysis of case study

When the developed economic analysis tool was run for the MBCI case study with all economic parameters explained above, the results of detailed annual real and present values of different costs were obtained. Table 6.1 gives the summary of life cycle costs involved in the poultry litter powered DG installation at MBCI. The detailed documents (life cycle cost of all cost parameters) generated by the economic analysis tool are in the Appendix B to this report.

Table 6.1

Life-Cycle Cost Analysis summary for MBCI project

Life cycle costs (2004-2023; millions of 2003 dollars)	
Poultry Litter fuel cost	1.223
Capital Cost	0.575
Maintenance Cost	0.679
Labor Cost	1.460
Ash Revenue	-0.305
Value of Power generation using poultry	-0.538
Total Life-Cycle Cost	**$3.092**

Table 6.2

List of parameters and assumptions used in the economic analysis for the case study

Discount Rate (Nominal)	7.0 percent
Inflation Rate	2.5 percent
Poultry Litter Requirements (annual)	4,500 tons
Poultry Litter Price	$20/ton
Poultry Litter Ash Value (per ton of poultry litter)	$5
Choctaw Laundromat Power Demand (annual)	
2004-2023	198 MWh/year
Central Electric power Electricity Price	
2003	$55/MWh ($ 2003)
2004-2023 escalators	Assuming no inflation
Operation & Maintenance Cost (annual, real)	$50,000
Capital Cost (2004, real)	$350,000
Capital Cost (2014, real)	$225,375
Labor Additions (full-time employees)	3
Labor cost per full-time employer (2003, real)	$40,000
Capacity of the poultry litter powered renewable DG	100 kW
Number of operational hours per day	24
Number of operational hours per year	300

Analysis of results

This section focuses on the analysis of results obtained for the MBCI case study. The value of total costs incurred to MBCI for the poultry litter powered DG installation is \$3.092 million including the negative costs (savings) in the amount of 0.843 million dollars. The costs incurred to MBCI are more than the savings for the installation. The economic analysis tool also provides the detailed analysis of cash flow every year during the life cycle period. The document that shows the cash flow during 2004-2023 for the MBCI case study is attached in appendix B. A project is said to economically feasible if the savings are more in value than the costs incurred in establishing that project. The above results lead to the conclusion that the establishment of poultry litter powered DG at Choctaw Laundromat is not economically feasible at this time.

6.7 Summary

This chapter highlights the economic feasibility of a biomass-based renewable energy installation by developing a user interface spreadsheet in Microsoft Excel. The Mississippi Band of Choctaw Indian’s proposal to locate a renewable energy installation that utilizes poultry litter as a fuel on the tribal lands under the Tribal Energy Program and Department of Energy (DOE) was taken as a case study. The results were presented and analyzed for the economic feasibility. The next chapter discusses conclusions and future work.

CHAPTER VII

CONCLUSIONS AND FUTURE WORK

7.1 General Conclusions

The research work discussed in this thesis has related to DG optimal placement, loading and economic feasibility. The majority of the previous research in optimal placement of DG mainly dealt with the balanced distribution systems for simplicity. Optimal placement was determined based on the minimization of losses in distribution system. However, this thesis focused on the assessment of impact of DG placement on unbalanced radial distribution feeder by simulation in a distribution analysis tool, RDAP. The optimal location of DG was determined based on the results of a simulation that gives minimization of system losses, good power factor and voltage profile at every feeder node.

A Microsoft Excel-based application program that calculates the Life Cycle Cost of renewable distributed generation using poultry litter as a fuel was developed in this thesis work. The application was built to give a snapshot of total costs involved in a poultry litter powered renewable distributed generation.

The main feature of the application is the presentation of the data. The numerical data of different costs and the graphical representation of the load data help the user to have complete information about the economics involved in the project.

The application gives the user the means to document the results of an economic feasibility study with ease. The user can use the Windows print command for printing all the worksheets having life cycle costs data from the application into a Microsoft Word document. The user can also print the individual cost worksheet from the application in a Microsoft Word document by using the print button available at the top left corner of each worksheet.

Apart from the user-interface advantages discussed in the previous paragraph, the application also offers several other advantages. The application gives the user the ability to rectify the actual data entered by him/her by using the option “data verification” available in the tool. The ease of using the application is another advantage of the application. The user operates in the application environment without difficulty. The user is likely to find the application easy to use and to navigate through because of the simplicity of the user-interface feature of the application. Microsoft Excel software is necessary on the computer along with Windows environment for the application to open.

7.2 Benefits of this work

The work done for the optimal placement of distributed generation in distribution systems using the IEEE 13-node radial distribution feeder is useful for the researchers to assess the impact of DG placement on distribution systems and to determine optimal placement based on the simulation results of the Radial Distribution Analysis Package (RDAP).

The discussion on load utilization assessment is useful for the load profile analysis that gives an idea about the capacity of DG to build in order to meet the load demand of surrounding facilities attached with DG. Load profiling of various loads provide new data for the public.

The developed application can be used as an educational economic analysis tool for state energy agencies, other promoters of renewable energy, end users, and project financiers to decide which projects are most energy efficient and offer the greatest financial benefit. However, it should be noted the application's accuracy is limited by the assumption of economic parameters used in building the application.

7.3 Future Work

In this thesis, the placement of distributed generation in distribution system was implemented in the IEEE 13-node test feeder with two different capacities for single and two DGs. The optimal placement was determined by the single variable optimization and the future work can use multi-variable optimization. This work can be extended to the real-time distribution system model of MBCI, which gives an idea about determining the optimal location of DGs in the MBCI distribution system.

This thesis takes a myopic view towards DG by discussing the economic analysis of only poultry litter powered renewable distributed generation. Economic aspects of other types of renewable energy applications including Combined Heat and Power (CHP) applications, DG technologies like reciprocating engines, gas turbines, fuel cells and micro turbines should also be studied in future.

The application can also include the feature of environment impact assessment by taking emissions into account. Several other user interface features can be added to the application to make it even user-friendlier than this version. This application should also give the user an evaluation of the economic analysis using different financing options. The application can also include some technical issues to make it a complete analysis tool so that more advanced renewable energy systems can be studied from both economical and technical perspective.

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[35] The final report on "The Alternative energy on tribal lands" by Dept. of Electrical and Computer Engineering, Mississippi State University, submitted to Mississippi Band of Choctaw Indians (MBCI), September 1,2003.

APPENDIX A

DATA OF TECHNICAL FEASIBILITY

Configuration of IEEE 13- node Test Feeder

IEEE 13 radial distribution feeder is used as the test feeder to improve the performance of the existing feeder by using Radial Distribution Analysis Program (RDAP). This feeder is very small and yet displays some very interesting Characteristics.

1. Short and relatively highly loaded for a 4.16kV feeder.
2. One substation voltage regulator consisting of three single-phase units connected in wye, overhead and underground lines with variety of phasing.
3. Shunt capacitor banks,in-line transformer,Unbalanced spot and distributed loads.

In this project the base case of IEEE 13 node test feeder is run utilizing the complete data of the system given below.

TABLE A.1

OVERHEAD LINE CONFIGURATION DATA

CONFIG.	PHASING	PHASE	NEUTRAL	SPACING
		ACSR	ACSR	ID
601	B A C N	556,50026/7	4/0 6/1	500
602	C A B N	4/0 6/1	4/0 6/1	500
603	C B N	1/0	1/0	505
604	A C N	1/0	1/0	505
605	C N	1/0	1/0	510

TABLE A.2

UNDERGROUND LINE CONFIGURATION DATA

CONFIG.	PHASING	CABLE	NEUTRAL	SPACE ID
606	A B C N	250,000 AA, CN	NONE	515
607	A N	1/0 AA, TS	1/0 CU	520

Line segment: A radial feeder consists of *segments.* A segment is a three-phase or single-phase overhead or underground line that may have a *distributed load* associated with it. A segment is defined by its end nodes, length (distance between the nodes in feet) and the *Z-Model.* In the given test feeder the segments are considered those have loads along its length with the Z-model associated. The line segment data used for the test feeder are shown in Table III.

TABLE A.3

LINE SEGMENT DATA

Node A	Node B	Length(ft.)	Config.
632	645	500	603
632	633	500	602
633	634	0	XFM-1
645	646	300	603
650	632	2000	601
684	652	800	607
632	671	2000	601
671	684	300	604
671	680	1000	601
671	692	0	Switch
684	611	300	605
692	675	500	606

Transformers: Transformers can be located at either end node of any segment. Three-phase transformers can only be connected wye-wye in a wye system and delta-delta in a delta system. Single-phase transformers may be connected in a wye system only and are connected phase-to-neutral. The ratings, high-low values of voltage at both sides of the transformers are given along with their R, X settings in the following Table IV.

TABLE A.4

TRANSFORMER DATA

	kVA	kV-high	kV-low	R - %	X - %
Substation	5,000	115 - D	4.16 Gr. Y	1	8
XFM -1	500	4.16 – Gr.W	0.48 – Gr.W	1.1	2

Shunt capacitors: Capacitors are widely used in distribution systems to achieve power and energy loss reduction, system capacity release and maintain a voltage profile within permissible limits. Shunt Capacitor banks may be three-phase wye or delta connected and single phase connected line-to ground or line-to-line. The capacitors are modeled as constant susceptance and specified at nameplate rated kVAr and the capacitors used in the test feeder are shown in Table V.

TABLE A.5

CAPACITOR DATA

Node	Ph-A	Ph-B	Ph-C
	kVAr	KVAr	kVAr
675	200	200	200
611			100
Total	200	200	300

Voltage regulators: The regulation of voltages is an important function on a distribution feeder. As the loads on the feeder vary, there must be some means of regulating the voltage so that every customer's voltage remains within an acceptable level. A Common device used to maintain system voltages is the step-voltage regulator. Voltage regulators used in this test feeder are assumed to be "step-type" and can be connected in the substation and/or to a specified line segment. The regulators can be three-phase or single –phase. It should be noted that there is no significance in the order in which the data appears or whether node A or node B is closer to the source. Voltage regulator with its voltage level, bandwidth, compensator settings, PT ratio and CT rating are given below in Table VI.

TABLE A.6

REGULATOR DATA

Regulator ID:	1		
Line Segment:	650 – 632		
Location:	50		
Phases:	A - B -C		
Connection:	3-Ph,LG		
Monitoring Phase:	A-B-C		
Bandwidth:	2.0 volts		
PT Ratio:	20		
Primary CT Rating:	700		
Compensator Settings:	Ph-A	Ph-B	Ph-C
R - Setting:	3	3	3
X - Setting:	9	9	9
Volltage Level:	122	122	122

Spot load: A Spot load is connected to a node. The load may be three-phase, two-phase or single-phase. It can be connected in *wye* (phase to neutral) or *delta* (phase to phase). It can be modeled as constant real and reactive power, constant current, constant impedance or any combination of the three. All these combinations of loads models are taken in the test feeder with the varying loads at different nodes all along the radial feeder.

TABLE A.7

SPOT LOAD DATA

Node	Load	Ph-1	Ph-1	Ph-2	Ph-2	Ph-3	Ph-3
	Model	kW	kVAr	Kw	kVAr	kW	kVAr
634	Y-PQ	160	110	120	90	120	90
645	Y-PQ	0	0	170	125	0	0
646	D-Z	0	0	230	132	0	0
652	Y-Z	128	86	0	0	0	0
671	D-PQ	385	220	385	220	385	220
675	Y-PQ	485	190	68	60	290	212
692	D-I	0	0	0	0	170	151
611	Y-I	0	0	0	0	170	80
	TOTAL	1158	606	973	627	1135	753

Distributed load: A distributed load is served at the mid point of a *segment.* The load may be three-phase, two-phase or single-phase. It can be connected in *wye* (phase to neutral) or *delta* (phase to phase). It can be modeled as constant power and reactive power, constant current, constant impedance or any combination of the three. Distributed load is taken between the two nodes with a constant power load model.

TABLE A.8

DISTRIBUTED LOAD DATA

Node A	Node	Load	Ph-1	Ph-1	Ph-2	Ph-2	Ph-3	Ph-3
		Model	kW	kVA	kW	kVAr	kW	kVAr
632	671	Y-PQ	17	10	66	38	117	68

Test Cases for Optimal Placement of DG on test distribution feeder

1. One-third -Single DG case at 671 node

```
- V O L T A G E   P R O F I L E  ---- DATE: 11- 3-2003 AT 23:16:27 HOURS ----
SUBSTATION:  KORADI;   FEEDER:  650
-------------------------------------------------------------------------------
NODE  |  MAG      ANGLE  |  MAG      ANGLE      |  MAG      ANGLE    |mi.to SR
-------------------------------------------------------------------------------
______|_______ A-N _______ |_______ B-N _______ |_______ C-N _______ |
650    | 1.0500 at    .00    | 1.0500 at -120.00  | 1.0500 at  120.00   |   .000
RG1    | 1.0303 at    .00    | 1.0369 at -120.00  | 1.0369 at  120.00   |   .000
632    | 1.0221 at  -1.11    | 1.0297 at -120.63  | 1.0184 at  118.75   |   .379
645    |                     | 1.0153 at -120.81  | 1.0219 at  118.66   |  .474
646    |                     | 1.0104 at -120.89  | 1.0231 at  118.63   |  .530
633    | 1.0191 at  -1.17    | 1.0277 at -120.68  | 1.0158 at  118.75   |   .474
XFM1 |  .9952 at  -1.85    | 1.0092 at -121.15  |  .9970 at  118.27   |   .474
634    |  .9952 at  -1.85    | 1.0092 at -121.15  |  .9970 at  118.27   |  .474
671    | 1.0243 at  -2.85    | 1.0537 at -119.82  |  .9969 at  118.08   |  .758
692    | 1.0243 at  -2.85    | 1.0537 at -119.82  |  .9969 at  118.08   |  .758
675    | 1.0181 at  -3.09    | 1.0561 at -119.99  |  .9950 at  118.09   |   .852
684    | 1.0222 at  -2.87    |                    |  .9949 at  117.98   |  .815
611    |                     |                    |  .9929 at  117.83   |  .871
652    | 1.0157 at  -2.80    |                    |                     |  .966
680    | 1.0243 at  -2.85    | 1.0537 at -119.82  |  .9969 at  118.08   |  .947
1
```

Losses:

```
-  R A D I A L   F L O W   S U M M A R Y - DATE: 11- 3-2003 AT 23:14:50 HOURS ---
 SUBSTATION:  KORADI;   FEEDER:  650
 -------------------------------------------------------------------------------
 SYSTEM       PHASE          PHASE          PHASE           TOTAL
 LOSSES ------(A)-------|-------(B)-------|-------(C)-------|------------------
 kW   :       9.209         |       8.805      |      17.551     |       35.566
 kVAr :       29.537        |      22.410      |      24.089     |       76.035
 kVA  :       30.939        |      24.078      |      29.805     |       83.942
```

Power Factor:

```
-  R A D I A L   F L O W   S U M M A R Y - DATE: 11- 3-2003 AT 23:14:50 HOURS ---
 SUBSTATION:  KORADI;   FEEDER:  650
 -------------------------------------------------------------------------------
 SYSTEM        PHASE         PHASE        PHASE          TOTAL
             -------(A)-------|-------(B)-------|-------(C)-------|------------------
      PF   :      .9784        |       .9445      |       .9575      |       .9621
```

2. Two-third -Single DG case at 671 node

```
V O L T A G E   P R O F I L E  ---- DATE: 11- 3-2003 AT 23:44:27 HOURS ----
 SUBSTATION:  KORADI; FEEDER:  650
 ------------------------------------------------------------------------------
 NODE |  MAG      ANGLE |  MAG      ANGLE |  MAG       ANGLE |mi.to SR
 ------------------------------------------------------------------------------
 ________|________ A-N _______ |________ B-N ________ |________ C-N ________ |
 650     | 1.0500 at    .00     | 1.0500 at -120.00     | 1.0500 at  120.00     |  .000
 RG1     | 1.0238 at    .00     | 1.0238 at -120.00     | 1.0237 at  120.00     |  .000
 632     | 1.0227 at   -.51     | 1.0188 at -120.32     | 1.0197 at  119.32     |  .379
 645     |                      | 1.0044 at -120.50     | 1.0232 at  119.22     | .474
 646     |                      |  .9997 at -120.58     | 1.0244 at  119.19     | .530
 633     | 1.0197 at   -.57     | 1.0169 at -120.37     | 1.0171 at  119.31     |  .474
 XFM1 |  .9958 at  -1.25     |  .9981 at -120.84     |  .9983 at  118.84     |  .474
 634     |  .9958 at  -1.25     |  .9981 at -120.84     | .9983 at  118.84      | .474
 671     | 1.0314 at  -1.64     | 1.0453 at -119.18     | 1.0124 at  119.24     | .758
 692     | 1.0314 at  -1.64     | 1.0453 at -119.18     | 1.0124 at  119.24     | .758
 675     | 1.0254 at  -1.88     | 1.0476 at -119.35     | 1.0106 at  119.24     | .852
 684     | 1.0294 at  -1.66     |                       | 1.0104 at  119.14     | .815
 611     |                      |                       | 1.0084 at  119.00     | .871
 652     | 1.0228 at  -1.59     |                       |                       | .966
 680     | 1.0314 at  -1.64     | 1.0453 at -119.18     | 1.0124 at  119.24     | .947
```

Losses:

```
- R A D I A L  F L O W  S U M M A R Y - DATE: 11- 3-2003 AT 23:14:50 HOURS ---
 SUBSTATION:  KORADI;   FEEDER:  650
 ------------------------------------------------------------------------------
 SYSTEM       PHASE          PHASE          PHASE          TOTAL
 LOSSES ------(A)-------|-------(B)-------|-------(C)-------|-----------------
 kW   :        9.392      |      11.066    |       4.898    |      25.355
 kVAr :        12.693     |      25.857    |       5.798    |      44.348
 kVA  :        15.790     |      28.125    |       7.590    |      51.084
```

Power Factor:

```
- R A D I A L  F L O W  S U M M A R Y - DATE: 11- 3-2003 AT 23:14:50 HOURS ---
 SUBSTATION:  KORADI;   FEEDER:  650
 ------------------------------------------------------------------------------
 SYSTEM        PHASE         PHASE        PHASE          TOTAL
              -------(A)-------|-------(B)-------|-------(C)-------|-----------------
PF   :                -.9984   |      .9569     |      -.9995    |       .9983
```

3. One-third -Two DG case (671-632)

```
--- V O L T A G E   P R O F I L E ---- DATE: 11- 8-2003 AT 13:17:30 HOURS ----
 SUBSTATION:  KORADI;   FEEDER:  650
 ------------------------------------------------------------------------------
 NODE |  MAG      ANGLE |  MAG      ANGLE |  MAG      ANGLE |mi.to SR
 ------------------------------------------------------------------------------
 ______|_______ A-N _______ |_______ B-N _______ |_______ C-N _______ |
 650  |  1.0500 at   .00     |  1.0500 at -120.00  |  1.0500 at  120.00   |   .000
 RG1  |  .9975 at   .00      |  1.0304 at -120.00  |  1.0368 at  120.00   |   .000
 632  |  1.0436 at  -2.10    |  1.0210 at -119.02  |  1.0011 at  118.07   |   .379
 645  |                      |  1.0066 at -119.20  |  1.0047 at  117.98   |  .474
 646  |                      |  1.0018 at -119.28  |  1.0059 at  117.95   |  .530
 633  |  1.0406 at  -2.16    |  1.0190 at -119.07  |   .9985 at  118.06   |   .474
 XFM1 |  1.0172 at  -2.80    |  1.0003 at -119.55  |   .9794 at  117.57   |   .474
 634  |  1.0172 at  -2.80    |  1.0003 at -119.55  |   .9794 at  117.57   |   .474
 671  |  1.0433 at  -4.11    |  1.0442 at -118.35  |   .9715 at  117.05   |   .758
 692  |  1.0433 at  -4.11    |  1.0442 at -118.35  |   .9715 at  117.05   |   .758
 675  |  1.0372 at  -4.36    |  1.0466 at -118.52  |   .9694 at  117.06   |   .852
 684  |  1.0412 at  -4.14    |                     |   .9695 at  116.95   |   .815
 611  |                      |                     |   .9675 at  116.80   |   .871
 652  |  1.0345 at  -4.06    |                     |                      |   .966
 680  |  1.0433 at  -4.11    |  1.0442 at -118.35  |   .9715 at  117.05   |   .947
```

Losses:

```
- R A D I A L  F L O W  S U M M A R Y - DATE: 11- 3-2003 AT 23:14:50 HOURS ---
 SUBSTATION:  KORADI;   FEEDER:  650
 ------------------------------------------------------------------------------
 SYSTEM      PHASE          PHASE          PHASE          TOTAL
 LOSSES ------(A)-------|-------(B)-------|-------(C)-------|------------------
 kW   :      11.333      |      11.245    |      29.807    |      52.385
 kVAr :       74.936     |       8.229    |       38.995   |     122.160
 kVA  :       75.788     |      13.934    |      49.082    |     132.918
```

Power Factor:

```
- R A D I A L  F L O W  S U M M A R Y - DATE: 11- 3-2003 AT 23:14:50 HOURS ---
 SUBSTATION:  KORADI;   FEEDER:  650
 ------------------------------------------------------------------------------
 SYSTEM       PHASE         PHASE        PHASE          TOTAL
              -------(A)-------|-------(B)-------|-------(C)-------|------------------
PF   :               -.5599   |       .9634     |       .9546     |      -.9521
```

4. Two-third -Two DG case (671-632)

```
--- V O L T A G E   P R O F I L E ---- DATE: 11- 4-2003 AT 22:48:24 HOURS ----
 SUBSTATION:  KORADI;   FEEDER:  650
 -------------------------------------------------------------------------------
 NODE |  MAG      ANGLE |  MAG      ANGLE |  MAG      ANGLE |mi.to SR
 -------------------------------------------------------------------------------
 ______|_______ A-N _______ |_______ B-N _______ |_______ C-N _______ |
 650    | 1.0500 at    .00      | 1.0500 at -120.00   | 1.0500 at  120.00    |   .000
 RG1    | 1.0238 at    .00      | 1.0238 at -120.00   | 1.0237 at  120.00    |   .000
 632    | 1.0222 at   -.52      | 1.0195 at -120.32   | 1.0190 at  119.34    |   .379
 645    |                       | 1.0051 at -120.50   | 1.0225 at  119.24    |  .474
 646    |                       | 1.0004 at -120.58   | 1.0237 at  119.21    |  .530
 633    | 1.0192 at   -.58      | 1.0176 at -120.37   | 1.0164 at  119.33    |   .474
 XFM1 |  .9953 at  -1.25      |  .9988 at -120.85   |  .9977 at  118.86    |   .474
 634  |  .9953 at  -1.25      |  .9988 at -120.85   |  .9977 at  118.86    |   .474
 671  | 1.0243 at  -2.25      | 1.0434 at -119.49   |  .9976 at  118.66    |   .758
 692  | 1.0243 at  -2.25      | 1.0434 at -119.49   |  .9976 at  118.66    |   .758
 675  | 1.0182 at  -2.49      | 1.0457 at -119.66   |  .9957 at  118.67    |   .852
 684  | 1.0223 at  -2.27      |                     |  .9956 at  118.56    |   .815
 611  |                       |                     |  .9936 at  118.41    |   .871
 652  | 1.0158 at  -2.20      |                     |                      |   .966
 680  | 1.0243 at  -2.25      | 1.0434 at -119.49   |  .9976 at  118.66    |   .947
```

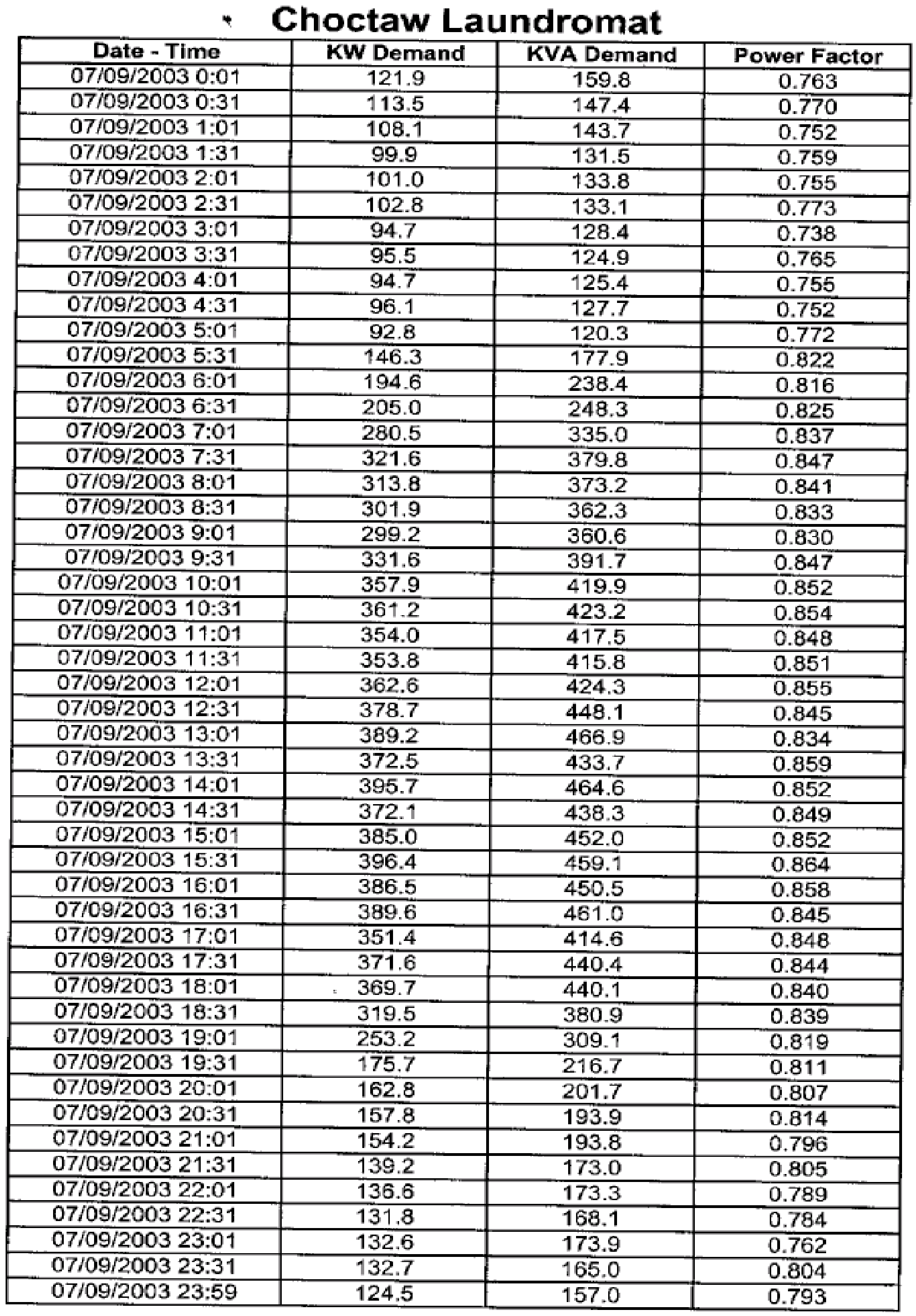
Losses:

```
- R A D I A L  F L O W  S U M M A R Y - DATE: 11- 3-2003 AT 23:14:50 HOURS ---
 SUBSTATION:  KORADI;   FEEDER:  650
 -------------------------------------------------------------------------------
 SYSTEM      PHASE         PHASE         PHASE         TOTAL
 LOSSES ------(A)-------|-------(B)-------|-------(C)-------|-----------------
 kW   :       7.488  |       7.938   |      12.035   |      27.462
 kVAr :       20.696  |       17.880  |       11.745  |       50.320
 kVA  :       22.009  |       19.563  |       16.817  |       57.326
```

Power Factor:

```
- R A D I A L  F L O W  S U M M A R Y - DATE: 11- 3-2003 AT 23:14:50 HOURS ---
 SUBSTATION:  KORADI;   FEEDER:  650
 -------------------------------------------------------------------------------
 SYSTEM       PHASE         PHASE        PHASE         TOTAL
           -------(A)-------|-------(B)-------|-------(C)-------|-----------------
PF   :             -.9998   |      .9643    |      .9999    |      .9969
```

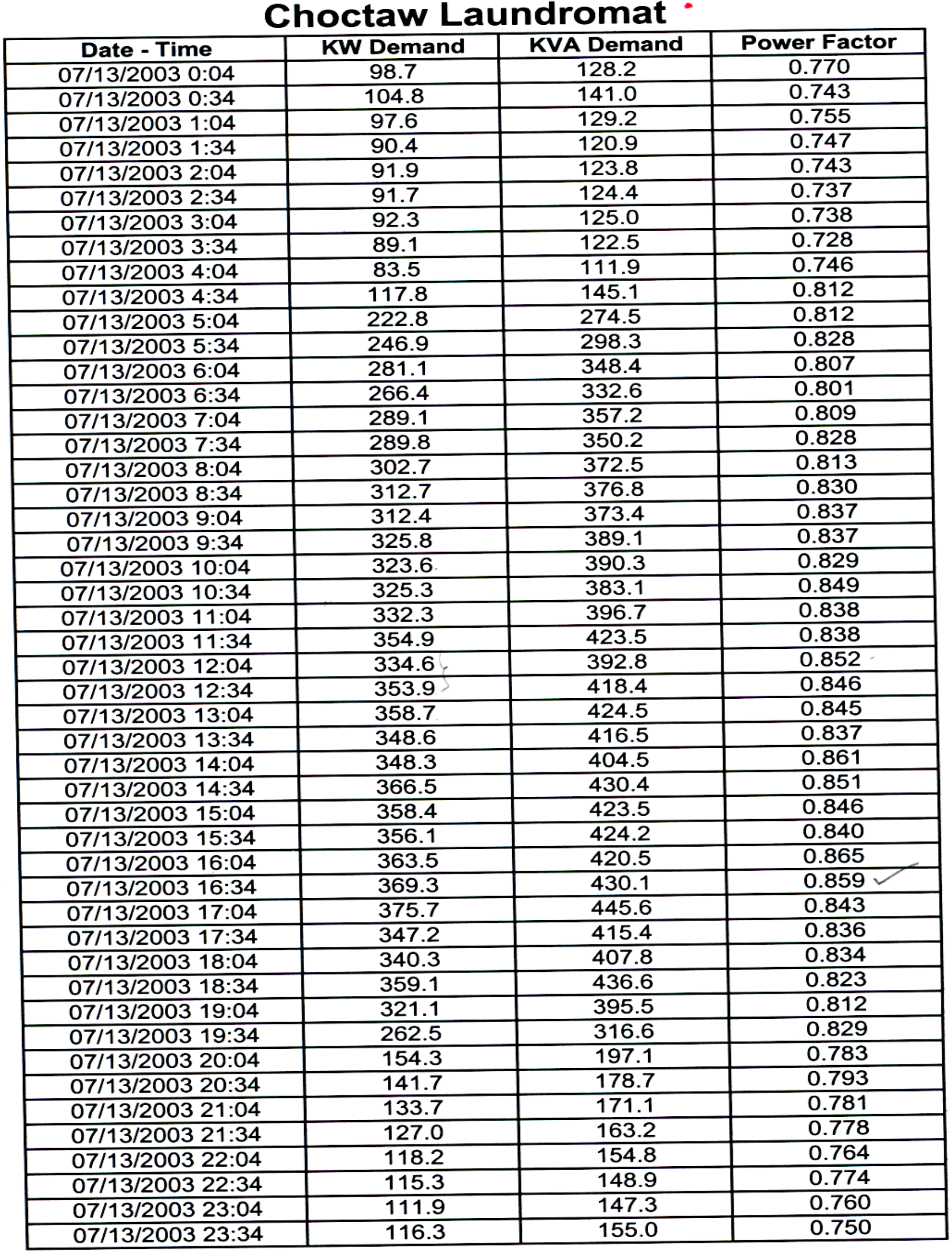
Load profile data of Laundromat: week day



Choctaw Laundromat

Date - Time	KW Demand	KVA Demand	Power Factor
07/09/2003 0:01	121.9	159.8	0.763
07/09/2003 0:31	113.5	147.4	0.770
07/09/2003 1:01	108.1	143.7	0.752
07/09/2003 1:31	99.9	131.5	0.759
07/09/2003 2:01	101.0	133.8	0.755
07/09/2003 2:31	102.8	133.1	0.773
07/09/2003 3:01	94.7	128.4	0.738
07/09/2003 3:31	95.5	124.9	0.765
07/09/2003 4:01	94.7	125.4	0.755
07/09/2003 4:31	96.1	127.7	0.752
07/09/2003 5:01	92.8	120.3	0.772
07/09/2003 5:31	146.3	177.9	0.822
07/09/2003 6:01	194.6	238.4	0.816
07/09/2003 6:31	205.0	248.3	0.825
07/09/2003 7:01	280.5	335.0	0.837
07/09/2003 7:31	321.6	379.8	0.847
07/09/2003 8:01	313.8	373.2	0.841
07/09/2003 8:31	301.9	362.3	0.833
07/09/2003 9:01	299.2	360.6	0.830
07/09/2003 9:31	331.6	391.7	0.847
07/09/2003 10:01	357.9	419.9	0.852
07/09/2003 10:31	361.2	423.2	0.854
07/09/2003 11:01	354.0	417.5	0.848
07/09/2003 11:31	353.8	415.8	0.851
07/09/2003 12:01	362.6	424.3	0.855
07/09/2003 12:31	378.7	448.1	0.845
07/09/2003 13:01	389.2	466.9	0.834
07/09/2003 13:31	372.5	433.7	0.859
07/09/2003 14:01	395.7	464.6	0.852
07/09/2003 14:31	372.1	438.3	0.849
07/09/2003 15:01	385.0	452.0	0.852
07/09/2003 15:31	396.4	459.1	0.864
07/09/2003 16:01	386.5	450.5	0.858
07/09/2003 16:31	389.6	461.0	0.845
07/09/2003 17:01	351.4	414.6	0.848
07/09/2003 17:31	371.6	440.4	0.844
07/09/2003 18:01	369.7	440.1	0.840
07/09/2003 18:31	319.5	380.9	0.839
07/09/2003 19:01	253.2	309.1	0.819
07/09/2003 19:31	175.7	216.7	0.811
07/09/2003 20:01	162.8	201.7	0.807
07/09/2003 20:31	157.8	193.9	0.814
07/09/2003 21:01	154.2	193.8	0.796
07/09/2003 21:31	139.2	173.0	0.805
07/09/2003 22:01	136.6	173.3	0.789
07/09/2003 22:31	131.8	168.1	0.784
07/09/2003 23:01	132.6	173.9	0.762
07/09/2003 23:31	132.7	165.0	0.804
07/09/2003 23:59	124.5	157.0	0.793

Weekend day:



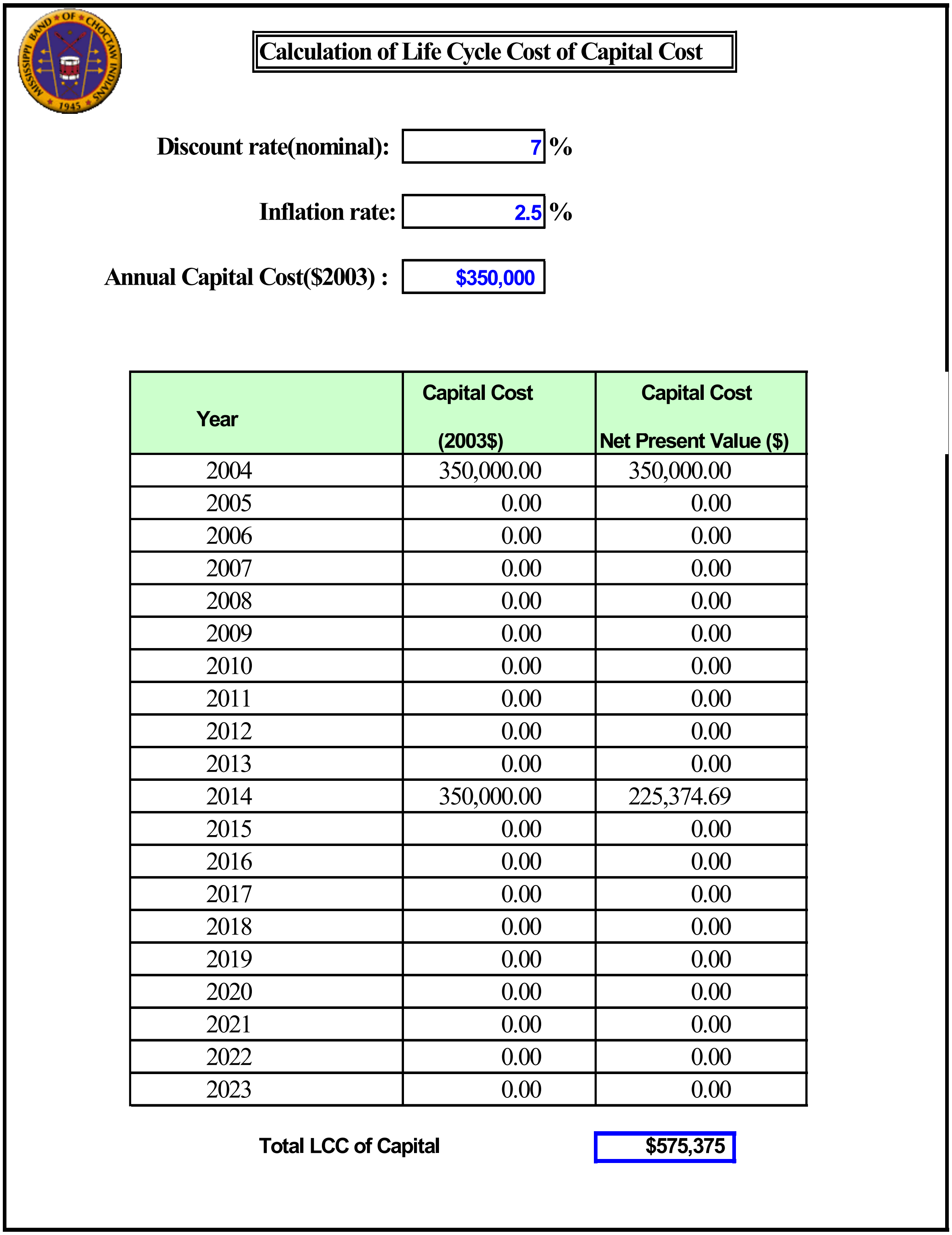
Choctaw Laundromat

Date - Time	KW Demand	KVA Demand	Power Factor
07/13/2003 0:04	98.7	128.2	0.770
07/13/2003 0:34	104.8	141.0	0.743
07/13/2003 1:04	97.6	129.2	0.755
07/13/2003 1:34	90.4	120.9	0.747
07/13/2003 2:04	91.9	123.8	0.743
07/13/2003 2:34	91.7	124.4	0.737
07/13/2003 3:04	92.3	125.0	0.738
07/13/2003 3:34	89.1	122.5	0.728
07/13/2003 4:04	83.5	111.9	0.746
07/13/2003 4:34	117.8	145.1	0.812
07/13/2003 5:04	222.8	274.5	0.812
07/13/2003 5:34	246.9	298.3	0.828
07/13/2003 6:04	281.1	348.4	0.807
07/13/2003 6:34	266.4	332.6	0.801
07/13/2003 7:04	289.1	357.2	0.809
07/13/2003 7:34	289.8	350.2	0.828
07/13/2003 8:04	302.7	372.5	0.813
07/13/2003 8:34	312.7	376.8	0.830
07/13/2003 9:04	312.4	373.4	0.837
07/13/2003 9:34	325.8	389.1	0.837
07/13/2003 10:04	323.6	390.3	0.829
07/13/2003 10:34	325.3	383.1	0.849
07/13/2003 11:04	332.3	396.7	0.838
07/13/2003 11:34	354.9	423.5	0.838
07/13/2003 12:04	334.6	392.8	0.852
07/13/2003 12:34	353.9	418.4	0.846
07/13/2003 13:04	358.7	424.5	0.845
07/13/2003 13:34	348.6	416.5	0.837
07/13/2003 14:04	348.3	404.5	0.861
07/13/2003 14:34	366.5	430.4	0.851
07/13/2003 15:04	358.4	423.5	0.846
07/13/2003 15:34	356.1	424.2	0.840
07/13/2003 16:04	363.5	420.5	0.865
07/13/2003 16:34	369.3	430.1	0.859 ✓
07/13/2003 17:04	375.7	445.6	0.843
07/13/2003 17:34	347.2	415.4	0.836
07/13/2003 18:04	340.3	407.8	0.834
07/13/2003 18:34	359.1	436.6	0.823
07/13/2003 19:04	321.1	395.5	0.812
07/13/2003 19:34	262.5	316.6	0.829
07/13/2003 20:04	154.3	197.1	0.783
07/13/2003 20:34	141.7	178.7	0.793
07/13/2003 21:04	133.7	171.1	0.781
07/13/2003 21:34	127.0	163.2	0.778
07/13/2003 22:04	118.2	154.8	0.764
07/13/2003 22:34	115.3	148.9	0.774
07/13/2003 23:04	111.9	147.3	0.760
07/13/2003 23:34	116.3	155.0	0.750

APPENDIX B

RESULTS OF ECONOMIC ANALYSIS TOOL

Results of economic analysis tool for MBCI case study



Calculation of Life Cycle Cost of Capital Cost

Discount rate(nominal): 7 %

Inflation rate: 2.5 %

Annual Capital Cost($2003) : $350,000

Year	Capital Cost (2003$)	Capital Cost Net Present Value ($)
2004	350,000.00	350,000.00
2005	0.00	0.00
2006	0.00	0.00
2007	0.00	0.00
2008	0.00	0.00
2009	0.00	0.00
2010	0.00	0.00
2011	0.00	0.00
2012	0.00	0.00
2013	0.00	0.00
2014	350,000.00	225,374.69
2015	0.00	0.00
2016	0.00	0.00
2017	0.00	0.00
2018	0.00	0.00
2019	0.00	0.00
2020	0.00	0.00
2021	0.00	0.00
2022	0.00	0.00
2023	0.00	0.00

Total LCC of Capital $575,375

Calculation of Life Cycle Cost of Poultry Litter

Discount rate(nominal): 7 %

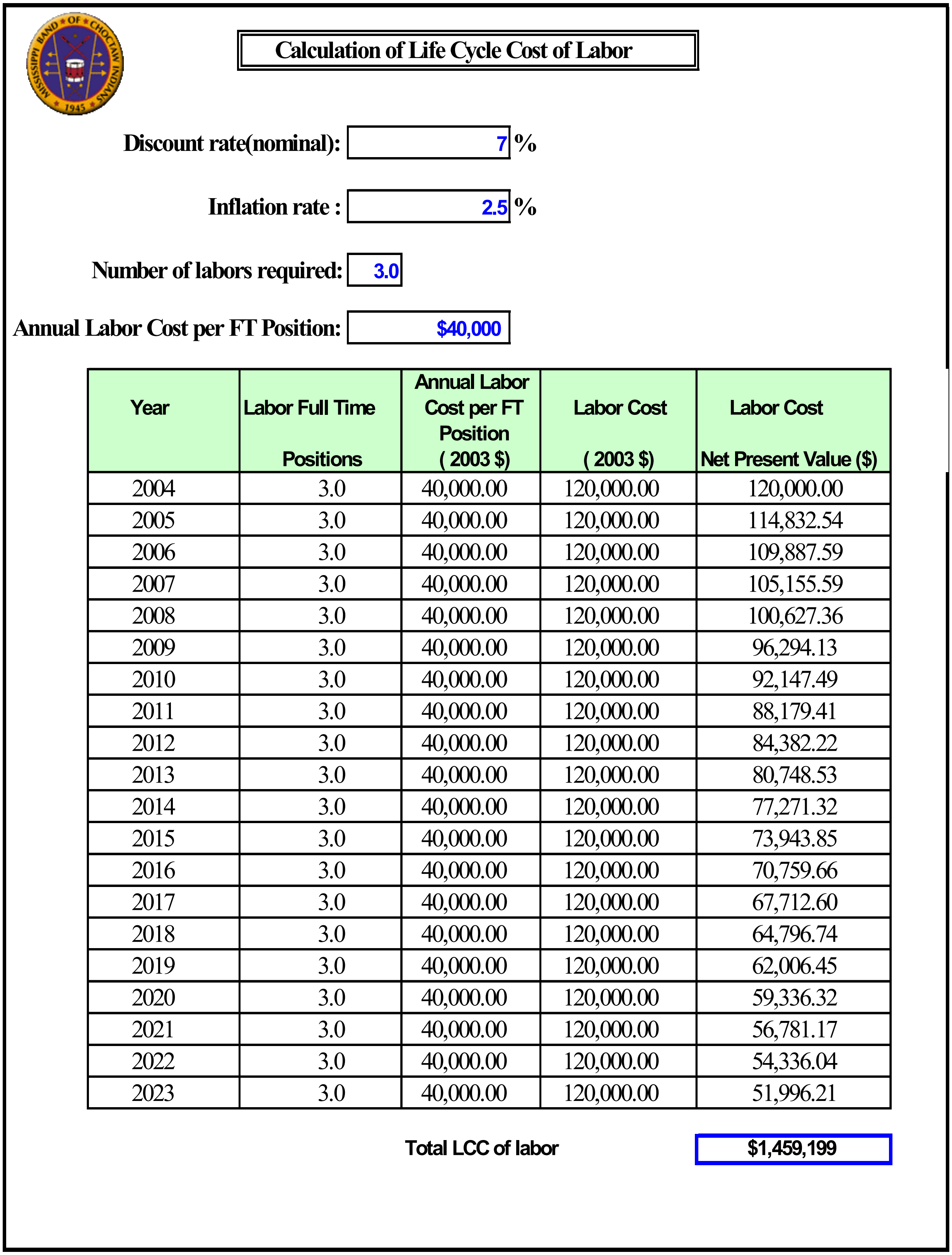
Inflation rate: 2.5 %

Poultry Litter required: 4500.00 tons

Poultry Litter price(2003 $): $20.00

Year	Poultry Litter (Tons)	Poultry Litter Price (2003 $)	Poultry Litter Cost (2003 $)	Poultry Litter Cost Net Present Value ($)
2004	4,500	20.00	90,000.00	90,000.00
2005	4,500	20.00	90,000	86,124
2006	4,500	20.00	90,000	82,416
2007	4,500	20.00	90,000	78,867
2008	4,500	20.00	90,000	75,471
2009	4,500	20.00	90,000	72,221
2010	4,500	20.00	90,000	69,111
2011	4,500	20.00	90,000	66,135
2012	4,500	20.00	90,000	63,287
2013	4,500	20.00	90,000	60,561
2014	4,500	20.00	90,000	57,953
2015	4,500	20.00	90,000	55,458
2016	4,500	20.00	90,000	53,070
2017	4,500	20.00	90,000	50,784
2018	4,500	20.00	90,000	48,598
2019	4,500	20.00	90,000	46,505
2020	4,500	20.00	90,000	44,502
2021	4,500	20.00	90,000	42,586
2022	4,500	20.00	90,000	40,752
2023	4,500	20.00	90,000	38,997

Total LCC of fuel **$1,223,396**



Calculation of Life Cycle Cost of Labor

Discount rate(nominal): 7 %

Inflation rate : 2.5 %

Number of labors required: 3.0

Annual Labor Cost per FT Position: $40,000

Year	Labor Full Time Positions	Annual Labor Cost per FT Position (2003 $)	Labor Cost (2003 $)	Labor Cost Net Present Value ($)
2004	3.0	40,000.00	120,000.00	120,000.00
2005	3.0	40,000.00	120,000.00	114,832.54
2006	3.0	40,000.00	120,000.00	109,887.59
2007	3.0	40,000.00	120,000.00	105,155.59
2008	3.0	40,000.00	120,000.00	100,627.36
2009	3.0	40,000.00	120,000.00	96,294.13
2010	3.0	40,000.00	120,000.00	92,147.49
2011	3.0	40,000.00	120,000.00	88,179.41
2012	3.0	40,000.00	120,000.00	84,382.22
2013	3.0	40,000.00	120,000.00	80,748.53
2014	3.0	40,000.00	120,000.00	77,271.32
2015	3.0	40,000.00	120,000.00	73,943.85
2016	3.0	40,000.00	120,000.00	70,759.66
2017	3.0	40,000.00	120,000.00	67,712.60
2018	3.0	40,000.00	120,000.00	64,796.74
2019	3.0	40,000.00	120,000.00	62,006.45
2020	3.0	40,000.00	120,000.00	59,336.32
2021	3.0	40,000.00	120,000.00	56,781.17
2022	3.0	40,000.00	120,000.00	54,336.04
2023	3.0	40,000.00	120,000.00	51,996.21

Total LCC of labor **$1,459,199**

Calculation of Life Cycle Revenue from Ash

Discount rate(nominal): 7 %

Inflation rate: 2.5 %

Price of poultry litter ash (per ton of poultry litter): $5

Poultry Litter required : 4500.00 tons

Year	Poultry Litter (Tons)	Price of poultry litter Ash/ton of poultry litter (2003 $)	Annual Revenue from Sale of Ash (2003 $)	Annual Revenue from Sale of Ash Net Present Value ($)
2004	4,500	5.00	22,500.00	22,500.00
2005	4,500	5.00	22,500.00	21,531.10
2006	4,500	5.00	22,500.00	20,603.92
2007	4,500	5.00	22,500.00	19,716.67
2008	4,500	5.00	22,500.00	18,867.63
2009	4,500	5.00	22,500.00	18,055.15
2010	4,500	5.00	22,500.00	17,277.65
2011	4,500	5.00	22,500.00	16,533.64
2012	4,500	5.00	22,500.00	15,821.67
2013	4,500	5.00	22,500.00	15,140.35
2014	4,500	5.00	22,500.00	14,488.37
2015	4,500	5.00	22,500.00	13,864.47
2016	4,500	5.00	22,500.00	13,267.44
2017	4,500	5.00	22,500.00	12,696.11
2018	4,500	5.00	22,500.00	12,149.39
2019	4,500	5.00	22,500.00	11,626.21
2020	4,500	5.00	22,500.00	11,125.56
2021	4,500	5.00	22,500.00	10,646.47
2022	4,500	5.00	22,500.00	10,188.01
2023	4,500	5.00	22,500.00	9,749.29

Total LCR of Ash $305,849

MISSISSIPPI BAND OF CHOCTAW INDIANS 1945

Calculation of Life Cycle Cost of Operation & Maintenance

Discount rate(nominal): 7 %

Inflation rate: 2.5 %

Annual O&M Cost($2003): $50,000

Year	Annual Maintenance Cost (2003 $)	Annual Maintenance Cost Net Present Value ($)
2004	50,000.00	50,000.00
2005	50,000.00	47,846.89
2006	50,000.00	45,786.50
2007	50,000.00	43,814.83
2008	50,000.00	41,928.07
2009	50,000.00	40,122.55
2010	50,000.00	38,394.79
2011	50,000.00	36,741.42
2012	50,000.00	35,159.26
2013	50,000.00	33,645.22
2014	50,000.00	32,196.38
2015	50,000.00	30,809.94
2016	50,000.00	29,483.19
2017	50,000.00	28,213.58
2018	50,000.00	26,998.64
2019	50,000.00	25,836.02
2020	50,000.00	24,723.47
2021	50,000.00	23,658.82
2022	50,000.00	21,665.09
2023	50,000.00	21,665.09

Total LCC of O&M $678,690

Calculation of Life Cycle Value of Power Generation at Facility

Discount rate(nominal): 7 %

Inflation rate: 2.5 %

Capacity of Plant: 100 kW

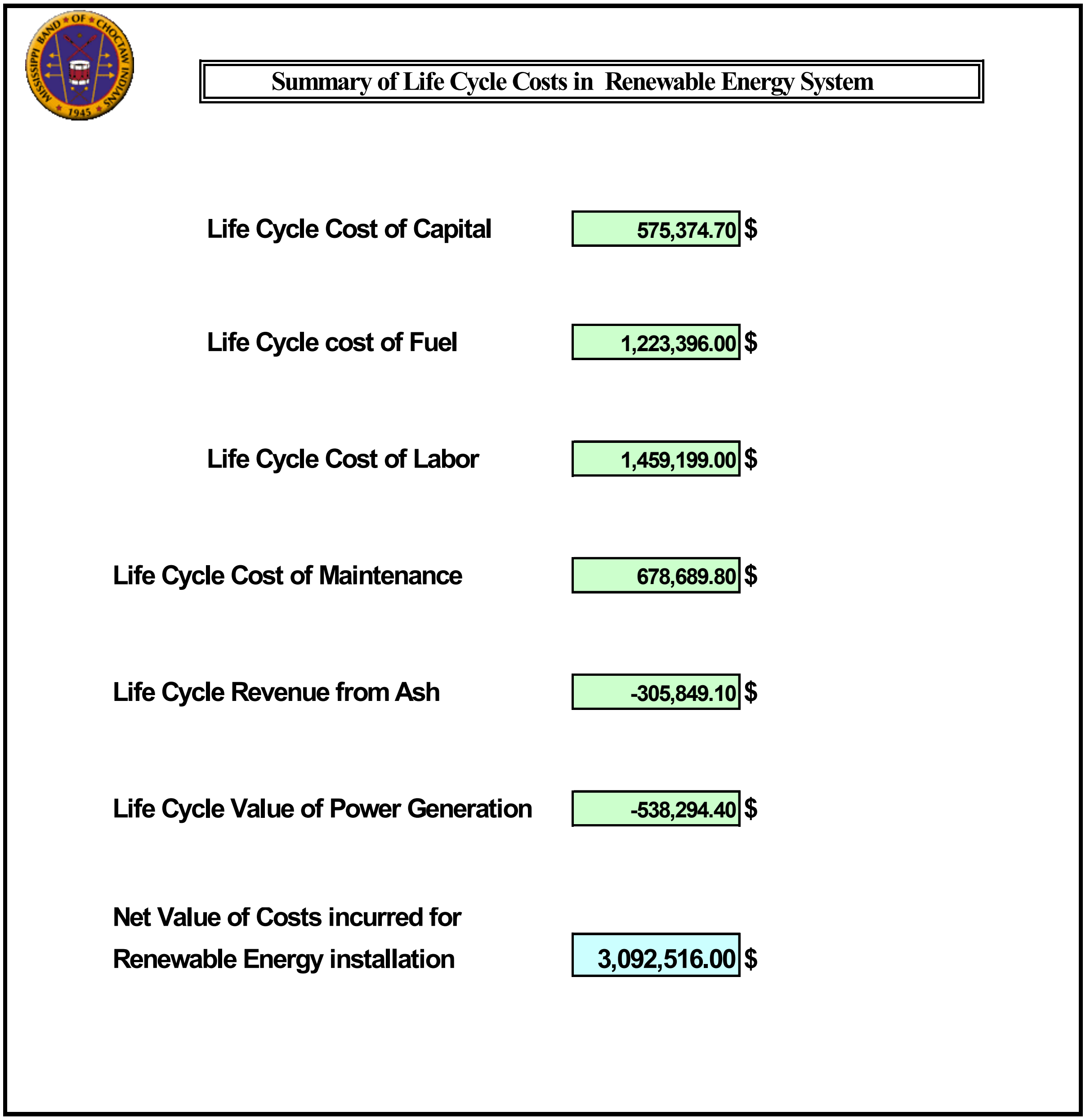
Number of Operational Hours per Day: 24

Number of Operational Days per Year: 300

Electricity price per MWh: $55.00

Year	Annual Power Generation (MWh)	Electricity Price Per MWh (2003 $)	Annual Value of Power Generation (2003 $)	Annual Value of Power Generation Net Present Value ($)
2004	720.0	55.00	39,600.00	39,600.00
2005	720.0	55.00	39,600.00	37,894.74
2006	720.0	55.00	39,600.00	36,262.91
2007	720.0	55.00	39,600.00	34,701.35
2008	720.0	55.00	39,600.00	33,207.03
2009	720.0	55.00	39,600.00	31,777.06
2010	720.0	55.00	39,600.00	30,408.67
2011	720.0	55.00	39,600.00	29,099.21
2012	720.0	55.00	39,600.00	27,846.13
2013	720.0	55.00	39,600.00	26,647.02
2014	720.0	55.00	39,600.00	25,499.54
2015	720.0	55.00	39,600.00	24,401.47
2016	720.0	55.00	39,600.00	23,350.69
2017	720.0	55.00	39,600.00	22,345.16
2018	720.0	55.00	39,600.00	21,382.93
2019	720.0	55.00	39,600.00	20,462.13
2020	720.0	55.00	39,600.00	19,580.99
2021	720.0	55.00	39,600.00	18,737.78
2022	720.0	55.00	39,600.00	17,930.89
2023	720.0	55.00	39,600.00	17,158.75

LCV of Power Generation **$538,294**



MISSISSIPPI BAND OF CHOCTAW INDIANS 1945

Summary of Life Cycle Costs in Renewable Energy System

Life Cycle Cost of Capital	575,374.70	$
Life Cycle cost of Fuel	1,223,396.00	$
Life Cycle Cost of Labor	1,459,199.00	$
Life Cycle Cost of Maintenance	678,689.80	$
Life Cycle Revenue from Ash	-305,849.10	$
Life Cycle Value of Power Generation	-538,294.40	$
Net Value of Costs incurred for Renewable Energy installation	3,092,516.00	$

MISSISSIPPI BAND OF CHOCTAW INDIANS 1945

CASH FLOW AND FINANCIAL ANALYSIS

Cost Parameter	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10
Capital Cost	350,000.00									225,374.70
Operation& Maintenance	50,000.00	47,846.89	45,786.50	43,814.83	41,928.07	40,122.55	38,394.79	36,741.42	35,159.26	33,645.22
Fuel Cost	90,000.00	86,124.40	82,415.70	78,866.70	75,470.52	72,220.59	69,110.62	66,134.56	63,286.66	60,561.40
Labor Cost	120,000.00	114,832.50	109,887.60	105,155.60	100,627.40	96,294.13	92,147.49	88,179.41	84,382.22	80,748.53
Revenue from Ash	-22,500.00	-21,531.10	-20,603.92	-19,716.67	-18,867.63	-18,055.15	-17,277.65	-16,533.64	-15,821.67	-15,140.35
Value of Power Generation	-39,600.00	-37,894.74	-36,262.91	-34,701.34	-33,207.03	-31,777.06	-30,408.67	-29,099.21	-27,846.13	-26,647.02

Cost Parameter	year 11	year 12	year 13	year 14	year 15	year 16	year 17	year 18	year 19	year 20
Capital Cost										
Operation& Maintenance	32,196.38	30,809.94	29,483.19	28,213.58	26,998.64	25,836.02	24,723.47	23,658.82	21,665.09	21,665.09
Fuel Cost	57,953.49	55,457.89	53,069.75	50,784.45	48,597.56	46,504.84	44,502.24	42,585.88	40,752.03	38,997.16
Labor Cost	77,271.32	73,943.85	70,759.66	67,712.59	64,796.74	62,006.45	59,336.32	56,781.17	54,336.04	51,996.21
Revenue from Ash	-14,488.37	-13,864.47	-13,267.44	-12,696.11	-12,149.39	-11,626.21	-11,125.56	-10,646.47	-10,188.01	-9,749.29
Value of Power Generation	-25,499.54	-24,401.47	-23,350.69	-22,345.16	-21,382.93	-20,462.13	-19,580.98	-18,737.79	-17,930.89	-17,158.75