IMPROVING POWER GRID ECONOMY USING
WINDPOWER GENERATION

by

Premkumar Packiriswamy

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Dr. Jalal Jalali, Thesis Advisor Date

Dr. Philip Munro, Committee Member Date

Dr. Frank X. Li, Committee Member Date

Peter J. Kasvinsky, Dean of School of Graduate Studies and Research Date

ABSTRACT

In this research the effects of wind generators (DG) interfaced with an electric power station network are studied. The addition of DG to the power system network is determined to enhance the power production during the peak demand and improve the efficiency of electric power usage. Additionally, the fossil fuel consumption is reduced and results in carbon-dioxide reduction. By adding four distributed generators each of 50 kVA capacities, the power production at the power station is reduced from 29 MW to 28 MW to compensate 12 MVA load density during the peak hours. The amount of coal that would be required to produce 29 MW of power at the power station is calculated to be 69,765 tons/year and the amount of CO_2 released is 204,400 tons/year. On the other hand the amount of coal that is required for producing 28 MW of power is determined to be 68,630 tons/year and the amount of CO_2 released is 201,115 tons/year. The total cost that could be saved because of this reduction in the power production is calculated to be $528,000/year and the overall power usage can be improved from 89% to 91%.

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CHAPTER 1: INTRODUCTION

Power is usually generated using hydro, coal, gas, petroleum and nuclear power generating stations. These power stations are not necessarily located near the customers, hence long transmission lines are designed to transport electrical energy. Initially distribution networks are designed to transfer electrical energy from power generation stations (source) to the customers (load) through very high voltage (greater than 1000 V_{AC} and less than 275 kV_{AC}) transmission lines [1]. Power losses along the transmission lines in developing and developed countries are about 23 percent and 10 percent respectively [2]. Due to these power losses, the voltage profile of the network is not stable. Voltage stability can be improved by embedding small power generators on the distribution network [3]. These small power generators are called distributed generators (DG).

The world's total consumption of marketed energy was projected to increase by 49% from 2007 to 2035 but growth rate and energy consumption rate of the world has decreased because of the 2008 recession. The energy consumption rate decreased by 1.2 percent in 2008, and then by 2.2 percent in 2009 [4]. Although there was a decrease in consumption rate in 2008 and 2009 the total energy consumption is expected to reach the projected value in 2035 as most of the countries are out of recession [4]. The net electricity generation worldwide would have to be increased to supply for this additional energy demand, following the increase in energy consumption. Increasing power production at the generating station, results in overloading of the transmission line, more active losses and hence a decrease in overall distribution efficiency [5].

1.1 MOTIVATION

One of the main motivations for this work is the need for alternative energy resources. At the present rate of consumption, all proven resources of fossil fuels would deplete within 210 years. This indicates that with an increase in the energy consumption rate of 1.4% per year, the fossil fuels would not last more than 150 years [6]. This made us lookout for other possible energy resources. The most widely referred alternative energies are hydro, nuclear, wind, solar and biomass.

Until a couple of decades ago utility companies used to do a load growth demand forecasting in advance with a predetermined load value and come up with different possible ways to meet this demand. The usual ways of meeting the demand were to upgrade an existing substation capacity or install a new capacity at an appropriate location [7]. With the implementation of distributed generator at a proper location, power produced from the distributed generator can be used to fulfill customer demands locally and this defers the upgrade or the need for new capacity [2].This also reduces the burden on the utility company's production as distributed generator takes care of part of the growing demand by decreasing the peak load.

With the implementation of distributed generator, active power loss can be reduced. It also improves the overall voltage stability, reliability, and quality of the supplied power [2]. The amount of greenhouse gases, especially CO_2 emitted from the utility companies using the fossil fuels [8], led to a number of environmental issues like acid rain, global warming, and adverse effects on ecosystem making the fossil fuel potentially danger. In case of coal powered plants for every ton of coal being burnt 2.93 tons of CO_2 is being emitted [9]. When using renewable energy resources like wind energy there are no harmful emissions that are being sent into the atmosphere and the system is emission free making a greener pollution free environment.

After the 2008 recession the federal and the state governments of the United States have provided special funding for the promotion of green energy techniques. Federal government of US provides 30% tax credits for a wind energy setup in Ohio. The US treasury gives cash grants up to 30% on the applicable cost of qualified property for the setup of a wind mill [10]. This reduces the huge initial setup cost of the distributed generator.

1.2 HISTORY OF WIND POWER

The concept of using wind power is not new to the human race. It has been in use for more than 5500 years. Wind power finds its application in sailing boats, sailing ships, water pumping windmill and even in buildings for natural ventilation. It's been the main means by which irrigation is made possible in Asian countries including India, Pakistan, Bangladesh and Afghanistan with the help of wind mills since 7th century [11]. Electricity produced from wind turbines with the help of a generator can be stored in battery banks and provide electricity to isolated farms.

Professor James Blyth, a Scottish academic in July 1887 conducted many wind power experiments which concluded in a UK patent in 1891[12]. Poul la Cour, a Danish scientist in the 1890's constructed a wind turbine to generate electricity which was later used to produce hydrogen [12]. The modern wind power industry began in the European countries in 1979 when the Danish manufactures produced a series of wind turbines with 20-30 kW capacities each. Gradually they were able to increase the capacity up to 7 MW [13]. Meanwhile the wind turbine production started expanding to many countries around the world. By 1900 in Denmark alone there were about 2500 wind mills which produced a peak power of about 30 MW including mechanical wind pump and wind mills [13]. The first known wind mill capable of generating electricity was a battery charging machine installed in 1887 by James Blyth of Scotland [13]. In the United States the first wind mill that produce electricity was built in 1888 by Charles F. Brush in Cleveland Ohio [12]. In 1908 in the United States alone there were about 72 wind driven electric generators producing power which ranged from 5 to 25 kW [13].

1.3 OUTLINE

In this work outline of wind power is discussed in chapter 2. Different terms involved with the wind turbine, the importance of distributed functions are discussed. Main focus of this chapter is to find out the total output power generated for a given wind system. Chapter 3 gives a brief idea on power distribution system and various subsystems involved with it. In addition it gives us basic knowledge of various demands and the importance of peak demand in load allocation. In chapter 4 the actual calculations for a model circuit in the existing distribution system for a triangular voltage drop model is calculated and is compared against a system with distributed generators to show the increase in efficiency of the system discussed. Various factors like CO_2 emission, coal burned, cost involved and energy saved are all discussed showing the benefits including a distributed generator in the distribution system. Chapter 5 deals with the economic analysis and feasibility of having any distributed generators in the existing circuit. Cash flow statements are used for this analysis. Matlab program and Simulink are used to obtain the necessary results and graphs which are displayed in chapter 6.

CHAPTER 2: ELECTRIC POWER GENERATION USING WIND

Wind power is clean, plentiful, renewable and widely distributed. Unlike fossil fuels wind power does not emit any harmful greenhouse gases during its operation, hence is favored by the environmentalist [14]. Wind power is the conversion of wind energy into electrical energy with the help of wind turbines. Typical parts of the wind turbine include blade, nacelle, rotating shaft, gear box and the generator [15]. The turbine is connected to the blade or the rotating fan. When wind blows against the rotating fan, wind energy is converted to low speed rotational energy. The rotating fan is in turn connected to a rotating shaft. The shaft is connected to a gear box which increases the rotational speed of the generator depending on the speed at which the blade rotates. This generator converts the rotational energy into electrical energy.

2.1 WIND POWER

Power is the rate at which energy is available or the rate at which energy passes through an area per unit of time [14]. The amount of energy associated with the wind is a function of its speed and mass density. The higher the speed of the wind, the more the power associated with it. Wind power is dependent on the density of air (ρ), wind speed (V), the area swept (A) or intercepting the wind [14].

$$\textit{Wind Power} = \tfrac{1}{2}(\rho A V^3) \tag{2.1}$$

where ‘ρ’ is the air density in (kg/m^3), ‘A’ is the area swept by the wind (m^2) and ‘V’ is the wind speed in (m/s).

2.1.1 DENSITY OF AIR (ρ)

The density of air is defined as its mass per unit volume. It is measured as the number of kilograms of air in a cubic meter (kg/m^3). The density of dry air can also be calculated from the ideal gas equation.

$$\rho = \frac{P}{R*T} \tag{2.2}$$

where 'ρ' is the air density in kg/m^3, 'P' is absolute pressure in Pascal (Pa), 'R' =287.058 J/(kg*K) is the specific gas constant in for dry air, and T is absolute temperature in kelvin (K).

2.1.2 AREA SWEPT (A)

The space or region covered by the rotor blades of wind turbine when in motion constitute the area swept by the turbine. Amplitude of power output of a wind turbine is directly related to the area swept by its blades. A larger blade will thus have larger output power. Larger blades need to be made stronger as they need to withstand higher levels of centrifugal and cyclic varying gravitational loads. Usually the size and weight of the blades are not proportional to the power rating of the machine [15]. The area swept by the blade would be that of an area of a circle formed by the rotation of the rotor blades of the wind turbine which is expressed as

$$A = \frac{\pi D^2}{4} \tag{2.3}$$

where'D' is the diameter of the rotating blade in meters.

2.1.3 WIND SPEED HEIGHT CORRECTION

The amount of wind received by a turbine depends on its height. Hence the speed of the wind should always be measured at the turbine height. If it is not measured at the height of the turbine then we will have to make some necessary height corrections [16]. This can be done with the help of one seventh power law.

$$\frac{V2}{V1} = \left(\frac{H2}{H1}\right)^{a} \tag{2.4}$$

where 'V2' and 'V1' are the velocities of wind at a desired height of 'H2' and 'H1' respectively and 'a' is known as ground surface friction coefficient or the shear component. The value of 'a' varies with the location, temperature and pressure of the wind turbine [17]. The most commonly selected value is 1/7 [16].

2.1.4 SPEED OF WIND

The speed at which wind blows in a particular location is the most important factor which determines total output electrical power produced. We do not have much control on the speed of wind unlike other factors associated in determining wind power. Any minor change in wind speed has a significant effect on the total output power as output power depends on the cube of wind speed. For example if the wind speed is doubled then output is increased by a factor of 8 [15].

2.2 DISTRIBUTION OF WIND SPEED

The strength of the wind at any given location varies drastically. So an average value of wind speed is usually taken for calculating the output power. The total output power from a wind turbine is a function of the cube of the wind speed as shown in equation 2.1. There are two ways of expressing average wind speed [17]. They are average value of the cube of wind speed $\left(\frac{1}{N}\sum_{n=1}^{N} V_n{}^3\right)$ and cubic average value of wind speed $\left(\frac{1}{N}\sum_{n=1}^{N} V_n\right)^3$ where V is velocity of wind in m/s.

From equation 2.5 it is observed that for values of N (total number of distinctive wind speed) >1 cube of the average wind speed will always be less than the average of cube ofwind speed.

$$\left(\frac{1}{N}\sum_{n=1}^{N} V_n\right)^3 < \left(\frac{1}{N}\sum_{n=1}^{N} V_n{}^3\right) \qquad (2.5)$$

Measured value of total output power produced from a wind turbine vary between 10-20% from the calculated value for both the average values [17]. Wind speed variations are well explained by the probability distribution function (PDF), and provide a better way of calculating the total output power of a wind system [15].

2.3 PROBABILITY DISTRIBUTION FUNCTION

Probability distribution functions give us the probability of an event taking a value of ‘x’ under certain test conditions. Wind speed is the input ‘x’, scale and shape parameters ‘a’ and ‘b’ are the test conditions and are unique for a given location [15]. Using these values we can find out the actual power associated with a turbine. There are two different types of probability distribution functions which are used in practice for this purpose. They are namely Weibull and Rayleigh distribution functions [17]. The formula to calculate Weibull distribution $f(x|a,b)$ for different speed of wind 'x' under a given test condition is obtained from equation 2.6.

$$f(x|a,b) = ba^{-b}x^{b-1}e^{-\left(\frac{x}{a}\right)^{b}} \tag{2.6}$$

where 'a' is the scale factor , 'b' is the shape factor.

The scale factor 'a' defines the bulk of distribution while shape factor 'b' indicates the distribution of wind speeds for a given average wind speed [17]. A smaller shape factor indicates a relatively wide distribution of wind speed and vice versa. Rayleigh Distribution is a special case of Weibull distribution when the shape parameter has a value of two [17]. In many locations around the world especially in the Northern Europe, the shape parameter is chosen to be approximately two. The higher the value of the shape factor 'b' which ranges between (1 and 3), the higher the median wind speed, which means the locations with consistently high wind speed will have a larger shape factor. [18]

Matlab software is used to calculate the Weibull distribution curve by using the formula y =WBLPDF(X,A,B) [19]. This returns the PDF of the Weibull distribution with scale parameter 'A' and shape parameter 'B', evaluated at wind speed 'X'. A typical graph showing us the variation of Weibull distribution for a constant shape factor and varying scale factor is shown in figure 2.1. Here the distribution curves corresponding to shape parameter 'b'=2 for different values of scale parameter 'a' ranging from 2 to 5 m/s is plotted and f (x) is the probability that a wind speed will reach a value of 'x' m/s on a given day. If the probability is multiplied by 24, it gives the expected number of hours during a day when the wind speed will be of 'x' m/s.

From the figure 2.1 it is observed that, for higher values of the scale parameter the curve is skewed to its right and is more widely spread. This means the wind speed will be higher than average speed for more number of hours in a day.

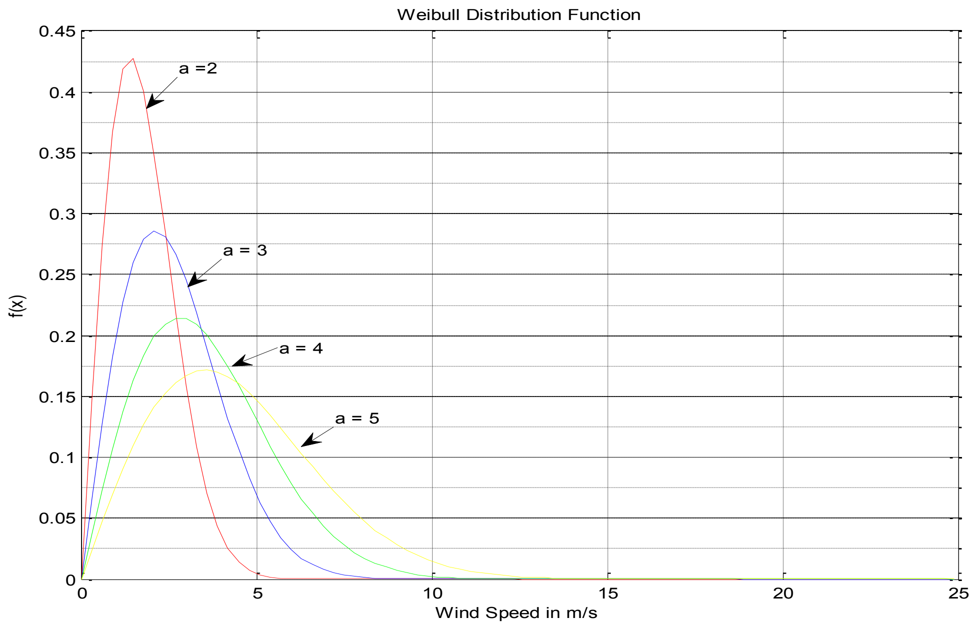

Figure 2.1. Weibull Probability Distribution Function with Shape Parameter b = 2 and Scale Parameter a = 2, 3, 4 and 5.

Figure 2.2 shows the variation of shape parameter b from 1 to 3 for a constant scale parameter value of ‘10’. F(x) in figure 2.2 indicates the probability of wind speed taking a value of ‘x’ m/s. The graph corresponding to b=1 shows that the probability of wind speed taking a higher value keeps decreasing, which tells us that there is not a strong wind flow in these regions. Graphs corresponding to b=2 and 3 shows, probability of wind reaching an intermediate value between the highest and lowest speeds is more likely and is true in most locations [17]. Therefore, on a number of occasions the value of shape parameter is chosen to be two.

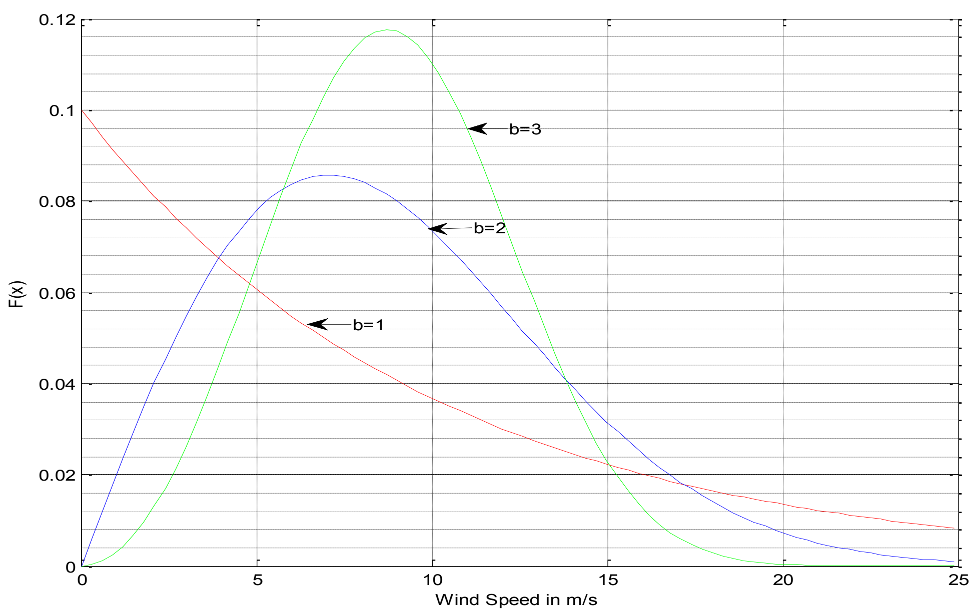

Figure 2.2. Weibull Probability Distribution Function with Scale Parameter a = 10 and Shape Parameter b = 1, 2, and 3.

2.4 POWER CURVE

A power curve is a graph which represents the output power of a wind turbine at different wind speeds [15]. It is unique for each wind turbine and is usually provided by the manufacturer of the turbine. One of the major advantages of having a power curve is that they include the efficiencies of the turbine [20]. This means the total output power mentioned in power curve is the rated power and not the peak power that can be produced by the wind turbine. An example of power variation of a wind turbine with respect to wind speed is shown is table 2.1. These power measurements are made at a hub height of 37 meters and a rotor diameter of 21 meters [20].

Table 2.1 Northwind100's Output Power Variation with Wind Speed

Wind speed 'm/s'	Power	Wind speed 'm/s'	Power 'kW'
1	0	14	97.3
2	0	15	100.0
3	0	16	100.8
4	3.7	17	100.6
5	10.5	18	99.8
6	19.0	19	99.4
7	29.4	20	98.6
8	41.0	21	97.8
9	54.3	22	97.3
10	66.8	23	97.3
11	77.7	24	98.0
12	86.4	25	99.7
13	92.8		

The graph shown in figure 2.3 is obtained from table 2.1, by plotting the wind speed on x axis, and output power in 'kW', on the y axis. It can be observed from figure 2.3, that the turbine starts producing electricity only after the wind speed crosses a particular threshold value, cut-in wind speed. The output is zero below the cut-in wind speed, and is 3.5 m/s in this case. This is simply because there is not enough kinetic energy obtained from the wind to make the rotors rotate and hence no power is generated [20]. Similarly this turbine stops producing electricity when the wind speed crosses 25 m/s and this is the cut-out wind speed [20].There is a protective device fitted to the wind turbine which ceases electrical power generation to avoid mechanical damage to the turbine.

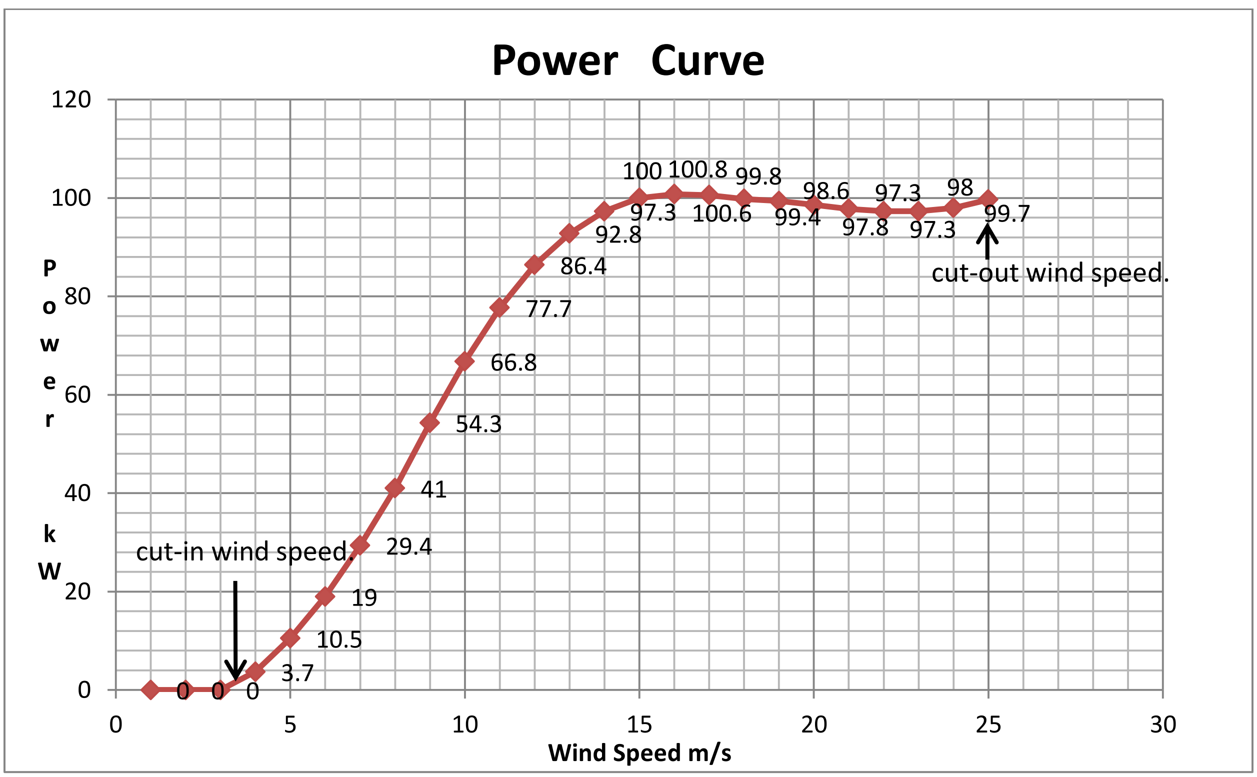

Figure 2.3. Power Curve of Northwind100 Wind Turbine

2.5 CALCULATION OF OUTPUT POWER FROM WIND TURBINE

Power generated from a wind turbine can now be determined using the power curve and probability distribution function. Using the probability distribution function ('Weibull' in our case) the number of hours in a day/year, during which wind speed will take a given value of 'x' can be obtained by multiplying the probability value with the number of hours in a day/year. A Weibull distribution curve with shape factor of 6 and scale factor of 2 is obtained using matlab.

A bar diagram is drawn using the obtained values as shown in figure 2.4. From the figure 2.4 the probability of wind speed being 5 m/s is 0.139. The number of hours in a day for which the wind speed will be 5m/s is 3.34 hours and is 1218 hours in a year.

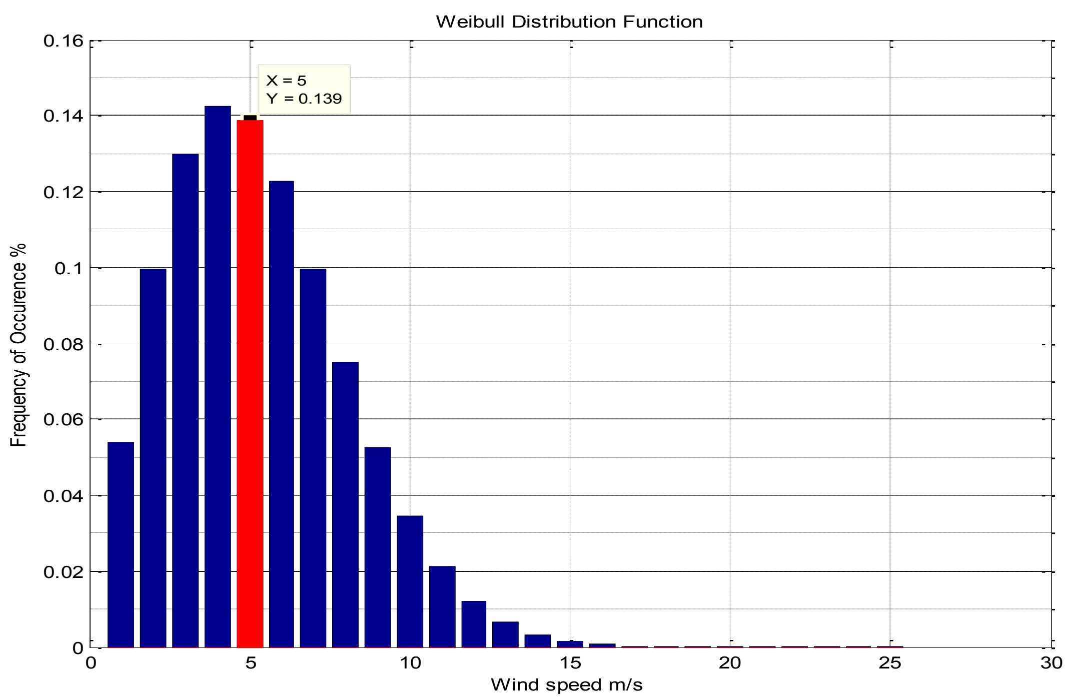

Figure 2.4. Bar diagram of Weibull Distribution with a = 6 and b = 2

A bar diagram for the Northwind100 turbine's power curve is shown in figure 2.5. The total output power that can be obtained from this wind turbine at a location with wind speed distribution as shown in figure 2.4 is calculated. From the figure 2.4 we see that the total output power is 10.5 kW when the wind speed is 5 m/s. The total number of hours in a year when the wind will have a speed of 5 m/s is 1218 hours. So the total annual output power that can be obtained at a speed of 5 m/s will be 12785 kW or 12.78MW.

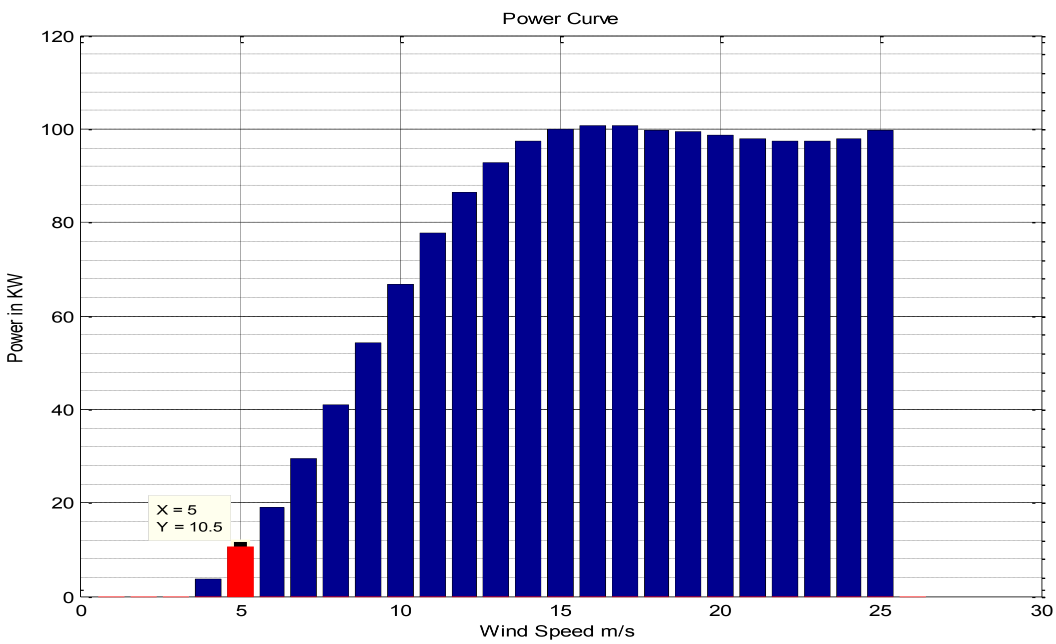

Figure 2.5. Bar Diagram of Nothwind100 Turbine's Power Curve

In order to obtain the total output power that can be produced at all wind speed, the probability distribution function is integrated over the power curve. A bar diagram as shown in figure 2.6 is then obtained using the integrated results and the total calculated output power is found to be 170 MW.

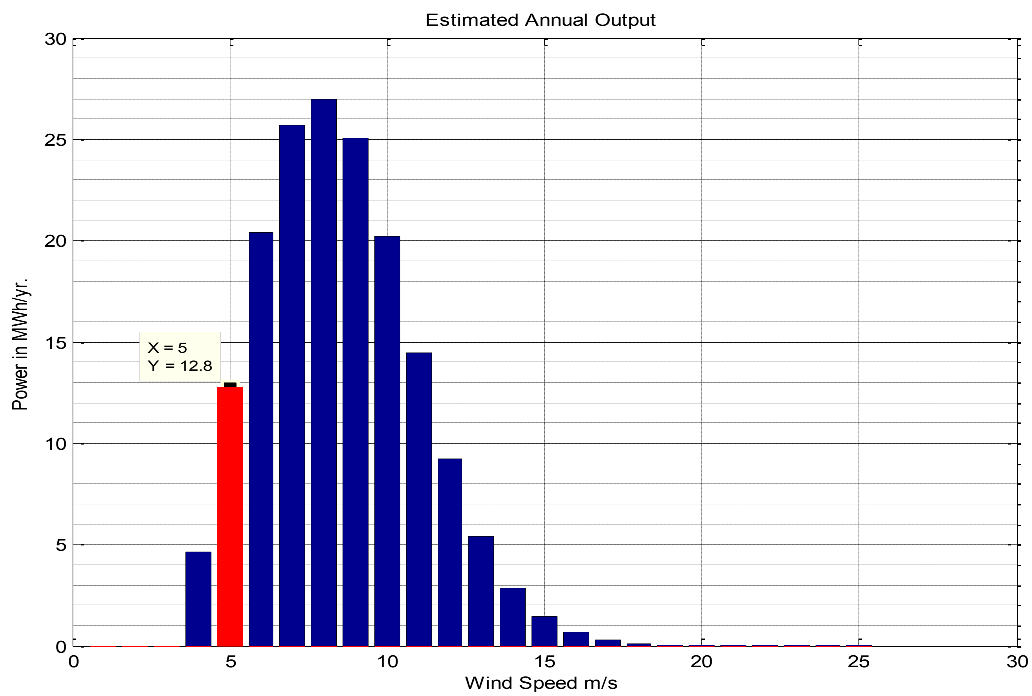

Figure 2.6. Estimated Annual Output Power

2.6 DRAWBACKS OF WIND POWER

There are certain drawbacks which makes wind turbine unpopular among small green energy generators.

- The construction of wind farms are not favored by most of the people because of their visual impact and other effects on the environment. The amount of electricity generated from a wind turbine varies highly with the climatic conditions, time scales ranging from hour to hour and seasonally.
- The output of a particular wind plant is highly unpredictable. There are a number of wind forecasting methods used in the recent time but the predictability of the output is still less accurate with a deviation of about 5% [15].
- They have a very low capacity factor. Typical capacity factors are usually in 20-40% of the name plate for a highly favorable site. Wind turbines have a very long payback period of greater than 10 years which makes it less favorable among the power generators [15].
- The extracted power from a wind farm is always fluctuating because of the continuous variation of the speed of the wind. Therefore, frequency adaptive techniques are required to make them produce a constant output power [21].
- Very often in most of the geographical locations, peak wind speed will not coincide with the peak electrical demand. For instance in the United States , southern states like Florida and Texas, which have hot days in summer will have high electricity demand because of the use of air conditioners and other cooling devices. If the speed of the wind during this time is low then the turbine will not produce enough electricity to meet the demand.

CHAPTER 3: ELECTRIC POWER SYSTEM AND ITS COMPONENTS

3.1 POWER SYSTEM

Electrical power system comprises of electrical power generating station, transmission network and the distribution network. These components are connected together by transformers and conductors. Power produced at the generating stations is stepped up to a very high voltage, of the order of 138kV, and are then sent through the transmission lines [22]. Transmission lines are the conductors that carry power from the generating stations to the receiving station. Transmission line systems are generally constructed along with two other parallel lines, called 'duplicate lines'. The major roles of these lines are to ensure continuity in case of faults and to meet the future growing demands [22]. From the receiving station power is stepped down to 12.47 kV and is transformed to the nearby substation for distribution [23].

3.2 DISTRIBUTION SYSTEM

Electric power received from the receiving stations is distributed to substation with the help of conductors, called 'feeders'. This process is called secondary distribution [22]. Distribution of power from substation to the local distribution centers is done by 'distributors'. For factories and industries using heavy loads, this power is sent directly. For lighter loads, the distribution center consists of distribution transformers, where the voltage is stepped down to 110V before sending. The cables carrying lighter loads are called as primary distributors [22]. In cities the overhead cables are covered with insulators for safety and are used as underground cables to serve the customers. These are called as 'secondary distributors' [22].

3.3 COMPONENTS OF A DISTRIBUTION SUBSTATION

The distribution substation is the most important component of the distribution system. Substations are usually fed by one or more sub-transmission lines or may be fed directly from a high-voltage transmission line [23]. A diagram of a very simple distribution substation is shown in Figure 3.1 which includes all the major components.

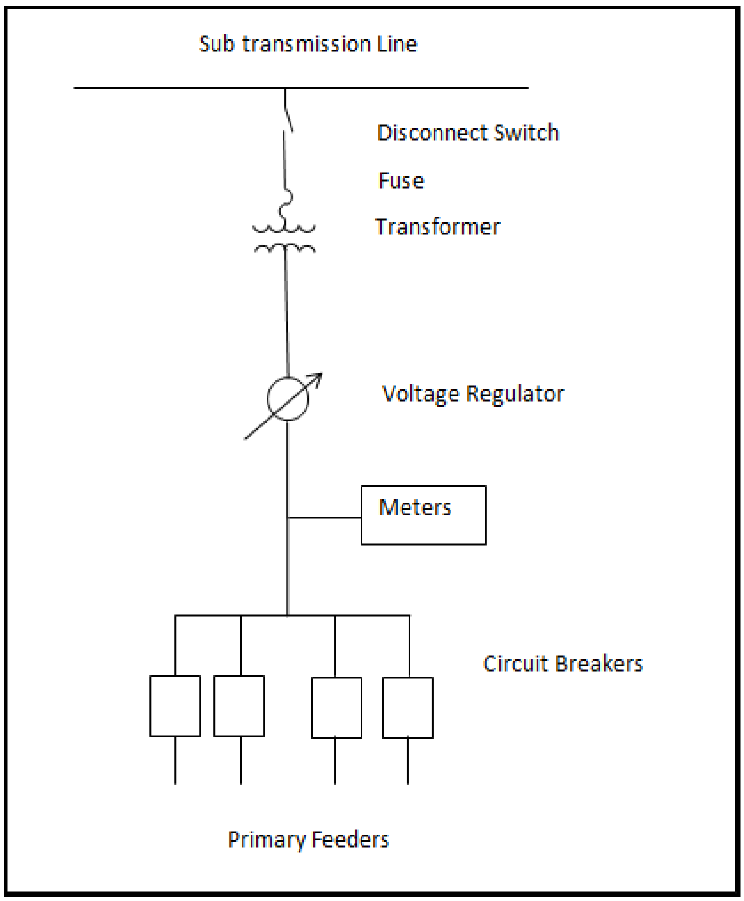

Figure 3.1. A Simple Distribution Substation.

- High side and low side switching

  High voltage switching can be done with the help of a simple switch or by using high-voltage circuit breakers. The number of breakers used and their arrangement is very vital.

- Low voltage switching

  This can be accomplished with the help of a relay controlled circuit breakers.

- Voltage Transformers

  Any transformer has a primary and a secondary side. A voltage transformer is used to increase or decrease the incoming voltage and they are called as step up or step down transformers respectively. The primary function of a substation is to reduce the substation voltage level. This is accomplished by the use of transformers. Transformers are used for this purpose and they can be single or three phases. The standard distribution voltage levels are 34.5 kV, 23.9 kV, 14.4 kV, 13.2 kV, 12.47 kV, and, in older systems it is 4.16 kV [23].

- Voltage Regulators

  The voltage drop between any given substations varies depending on the load associated with the feeders. To maintain the proper acceptable voltage level we use regulators. They can be either step up or step down regulators. Sometimes a "load tap changing" transformer (LTC) is provided for this purpose [23].

- Protection

  We do not want any kind of short circuits within the substation. In the example shown in figure 3.1, the only protection device that we have is the fuse, but more extensive protective schemes are employed in protecting the transformer and the substation for a more complex circuit. Usually circuit breakers and re-closers serve this purpose.

- Metering of sub-stations

  Every substation is provided with some kind of meter. They may be simple analog ammeter showing the present value of current. They may also record the maximum and minimum currents that have occurred over a period of time. Recently digital meters capable of recording voltage, power, power factor etc. are also being used.

A more comprehensive substation layout is shown in figure 3.2 which has two load-tap changing transformers, serves four distribution feeders (FD1, FD2, FD3 and FD4) and is fed from two sub transmission lines (Line 1 and Line 2).

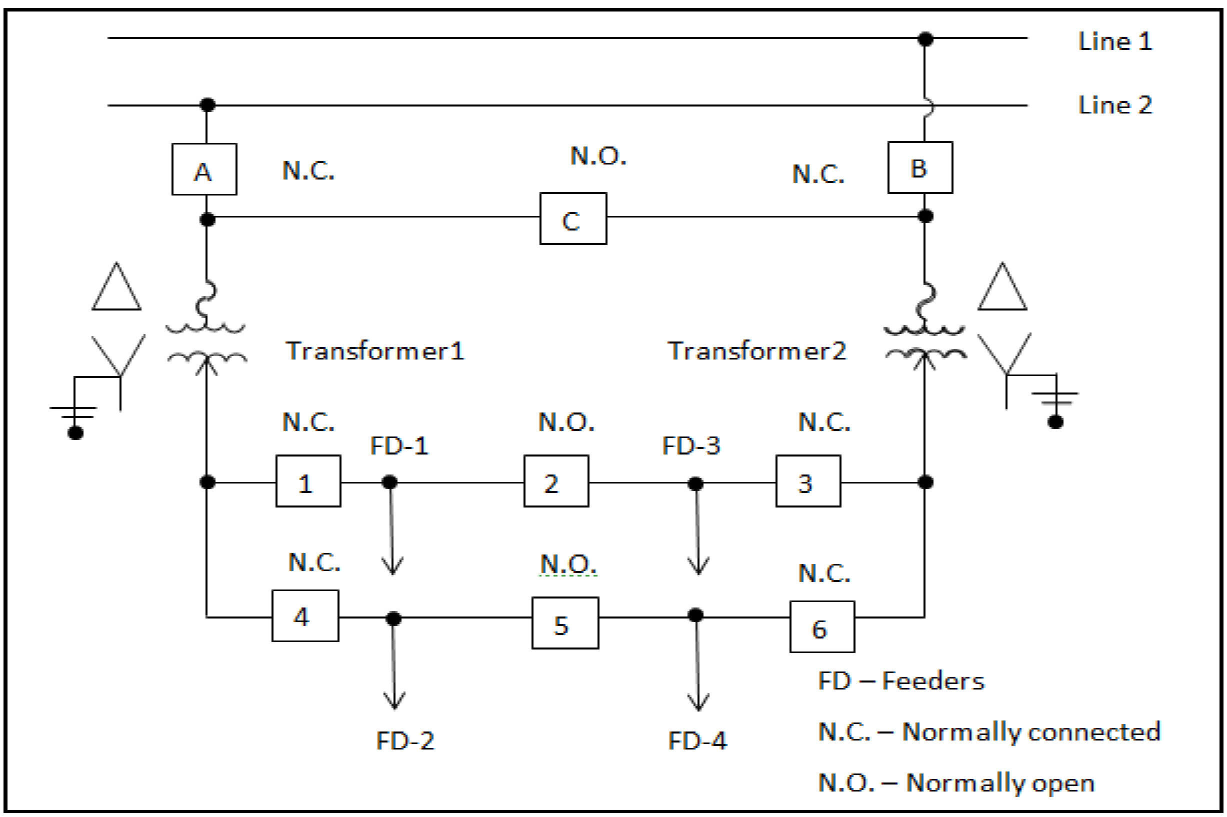

Figure 3.2. Complex Two Transformer Substation

There are six circuit breakers of which 2 and 5 are normally open while 1, 3, 4 and 6 are in closed positions. If one of the substations has to be serviced then breaker C (which is normally open) is closed while breakers A or B (which are normally closed) corresponding to the transformer requiring service will be opened. The transformers are sized such that each one can supply all the four feeders in case of an emergency operating condition. For example if transformer T-2 is out of service then breaker B, 3 and 6 are opened the breakers 2 and 5 are closed. Here we have used “breaker and a half scheme” since we need only three breakers for two feeders.

The amount of load to be allocated on a power distribution system depends on the demand. Modeling and analysis of a power system depends upon the load. The load on the power system is constantly changing and hence for different analyses we require different definition of load. Therefore it becomes vital to study these loads [23].

3.4 DEMAND AND ITS TYPES

Demand is the load averaged over a specific period of time. In order to determine the load we need a demand curve. The average value of demand in an interval of 15 minutes is defined as the “15-minute kW demand” [23].

- Maximum Demand

  It is the maximum value of the demand of a particular customer. It is usually expressed in kW. In figure 3.3 during the 24-hour period of a demand curve there is a great variation in demand from 2 kW to 7 kW. This particular customer has 4 periods in which the demand exceeds 6 KW and the greatest of these is called the “15-minute maximum kW demand”.

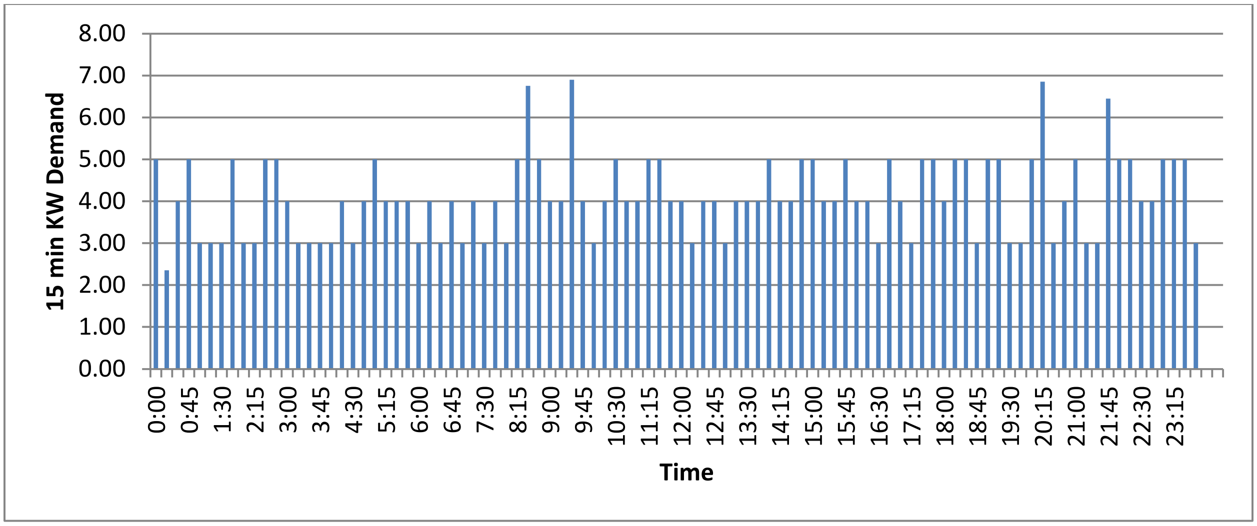

Figure 3.3. 15-min Demand of a Customer

- Average Demand

  It is the ratio of the total energy consumed by a customer for a specific period of time in hours to the number of hours included in that specific period.

- Load Factor

  It is the ratio of the average demand to the maximum demand. It gives us an indication of how well the utility's facilities are being utilized. It is advisable not to have a low load factor .It has an ideal value of 1.

- Diversified Demand and Maximum Diversified Demand

  A distribution transformer will provide service to one or more customers. Each customer will have his own demand curve and hence the maximum demand, average demand will be different for each of them. The sum of all the customer demands for each time interval is the diversified demand for that group of customers served by the distribution transformer. The maximum value of the demand in the diversified demand curve is called as the maximum diversified demand.

- Power Consumption

A typical residential customer’s demand depends on his/her usage of one or more of the electrical appliances. Energy consumed by different appliances in a small house is shown in table 3.1.

Table 3.1 Home Energy Consumption in ‘kwh’ for Different Appliances

Appliances	**Average monthly Home Energy used in kWh**
Refrigerator	180
Freezer	190
Dishwasher	65
Oven	100
Microwave	15
Coffee Maker	20
T.V 25”	28
Stereo	6
Computer	18
Ceiling Fan	85
Hot Tub	600
Window Air Conditioner	125
Water Heater	110
Room Lighting	10
Outdoor Lighting 200W	75
Washer	8
Dryer	4

CHAPTER 4: DISTRIBUTION SYSTEM ANALYSIS

Efficiency of the distribution system decreases with increase in losses along the line [2]. If the losses along the lines are decreased, then the efficiency of the system can be improved. In this chapter the line losses along the transmission and distribution system are calculated and compared under 2 different conditions namely with no distributed generator and with the implementation of distributed generator with battery banks.

Electrical energy produced at the generating station must be transferred to the customers for utilization. To transfer Electrical energy to the customers, the voltages produced at the generating station are stepped to very high voltage level of the order of 138kV. There are losses along the line due to voltage drop across active components in the circuit [2]. There are 3 main components which constitute line loss namely, copper loss, dielectric loss, radiation and induction losses. Copper loss is the major component of the power loss and is calculated as I^2R where 'I' is the current in the conductor and R is the resistance of the conductor [24].

In this chapter line loss for a small circuit is calculated. For the purpose of this work the following assumptions are made. There are three conductors A, B and C which forms the overhead transmission lines. The area served by the distribution system is triangular in shape (length = 18,000 ft. and width = 5280 ft.), load density of the area is 3000 kVA/mile^2 and the spacing between conductors are D_{ab} = 3 ft., D_{bc} = 5 ft., and D_{ca} = 8 ft., where $D_{ab,}$ $D_{ab,}$ D_{ab} are the distance between the conductors AB, BC and CA. In order to calculate the copper loss it is necessary to calculate the impedance of the line. All the calculations in this work were made using W.H.Kersting's "Distribution System and Modeling Analysis" as reference [24].

4.1 ANALYSIS OF AN EXISTING SYSTEM

Let us assume that the line segment is transposed and is three phase. The impedance for a three phase line as in the figure 4.1 will then be

$$Z = r + j\ 0.12134 * ln\left(\frac{Deq}{GMR}\right)\ \Omega/mile \tag{4.1}$$

$$D_{eq} = \sqrt[3]{D_{ab} * D_{ab} * D_{ca}}\ (ft) \tag{4.2}$$

where 'r' is the conductor resistance from table I in $\Omega/mile$ and GMR is the conductor geometric mean radius from table (ft.)

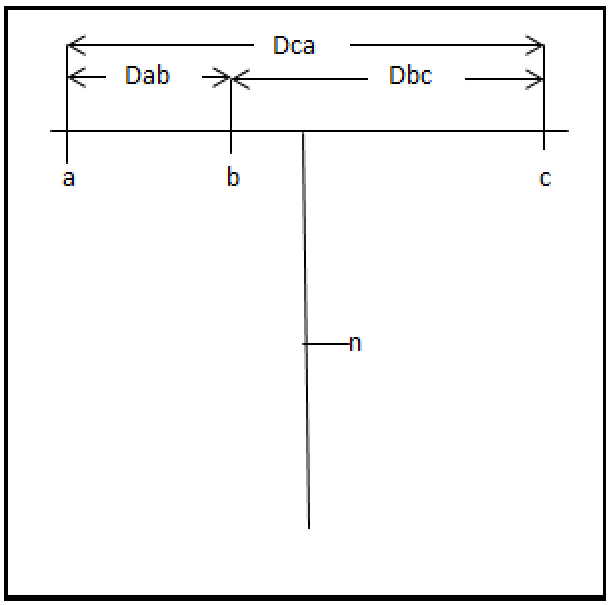

Figure 4.1. Three Phase Line Configuration

The spacing between three conductors are chosen to be

D_{ab} = 3 ft., D_{bc} = 5 ft., and D_{ca} = 8 ft.

The conductor that will be used for the line is 336,400 26/7 ACSR.

Now line impedance is calculated to be

$$Z = 0.306 + j\ 0.6442\ \Omega/mile \tag{4.3}$$

To calculate the voltage drop across the lines we need to know about 'K' factors. They are of two types K_{rise} and K_{drop}. The K factor is defined as the percent voltage drop or rise down a line that is one mile long serving a balanced three-phase load of 1 kVA. In K_{rise} the load is a shunt capacitor where the current leads the voltage and hence there is a voltage increase [24]. In order to calculate this power factor of the load is to be assumed and for this work we assume it to be 0.9 (lagging). K factors K_{rise} and K_{drop} can be calculated using the equations 4.4 and 4.5 respectively. The value of K factor is a property of the conductor, spacing and the voltages carried by the conductor. The approximate value of voltage drop down a line can be quickly calculated using the K_{drop} factor [24].

$$K_{drop} = \frac{Percent\ voltage\ drop}{load * distance} \tag{4.4}$$

$$K_{rise} = \frac{Percent\ voltage\ rise}{load * distance} \tag{4.5}$$

$$V\,drop = Re\,[Z * I] \tag{4.6}$$

$$I = \frac{load}{\sqrt{3} *\ KV_{LL}} \angle(-\cos^{-1} PF) \tag{4.7}$$

From the equation 4.7 the value of current taken by a load of 1 kVA and a power factor of 0.9 is calculated to be I = 0.046299 $\underline{/ -25.84}$°A and the value of V_{drop} from equations 4.3 and 4.6 is calculated to be V drop = 0.0256 V. In this work the nominal line to line voltage is assumed to be 12.47 kV and therefore the line to neutral voltage is VLN = $\frac{12.47\ KV}{\sqrt{3}} = 7199.6\ V$. The value of K_{drop} calculated from equation 4.4, is K_{drop} = 0.00035767 % drop/kVA mile. Similarly the value of K rise is calculated to be K_{rise} = 0.000403338 % rise/kVA mile.

In order to calculate the voltage drop and the power loss across the entire area served by the feeders, the areas are represented by geometric configurations such as rectangular, triangular or trapezoidal [24]. In this work the area served by the feeder is considered to be triangular in shape. The length and width of the triangular area can be calculated by knowing the length and width through which the line runs in order to serve a particular location. In this work we assumed length ‘l’ to be 3.4091 miles and width ‘w’ to be 1 mile (1 mile = 5280 ft.) and a load density of 3000 kVA. The area of the triangular region is calculated to be 1.71 mile^2 and total load density of the area to be served will therefore be 5113.65kVA.

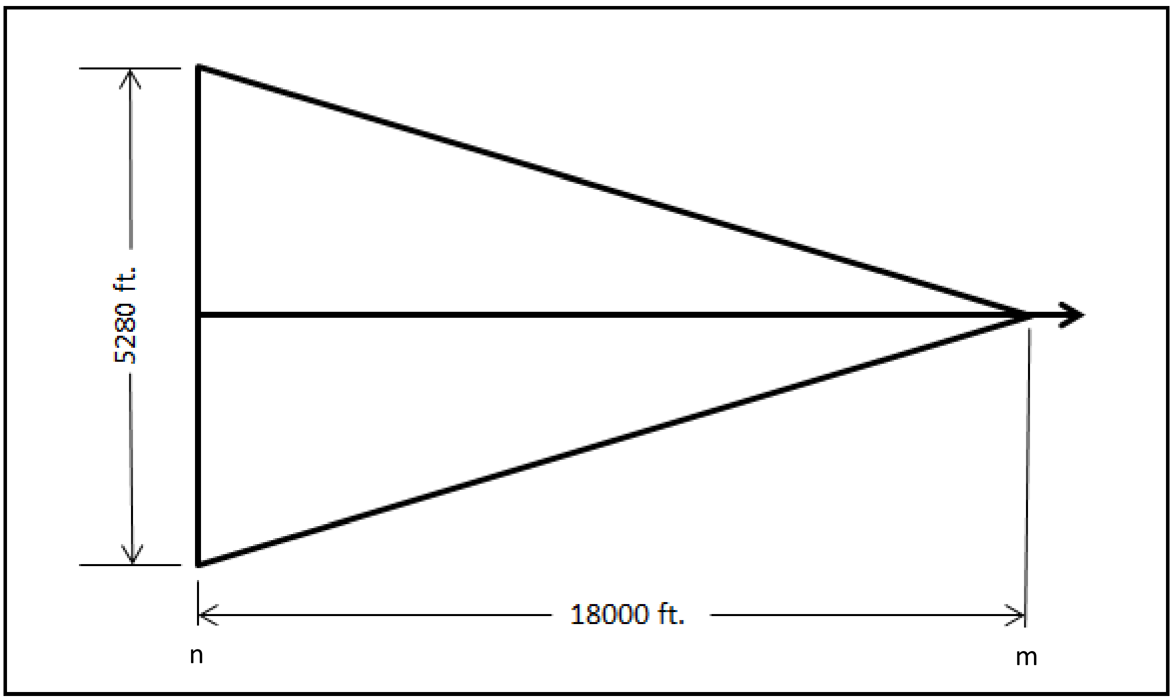

Figure 4.2. Triangular Voltage Drop Model

Total complex power ‘S’ of the triangular region and the voltage drop in this region are given by equations 4.8 and 4.9, respectively.

$$\text{‘}S\text{’} = load \angle(-\cos^{-1} PF) \quad (4.8)$$

$$\%V_{drop} = \frac{2}{3} * K\,drop * load * distance \quad (4.9)$$

Using equation 4.8 complex power of the system is calculated as S = 5113.65 $\underline{/-25.84°}$ kVA which is 4602.36 – j2228.83 kVA and the voltage drop is calculated to be V_{drop} = 4.15 %. Voltage at a terminal needs to be maintained close to its rated value for proper functioning of the load like motor or lighting circuit. According to the National Electrical Code for a low voltage public power distribution system the maximum allowable voltage drop is only 3%. So voltage drop of 4.15% is not acceptable. In a distribution system capacitor banks are usually placed to boost up the voltage to an acceptable level [24]. The total reactive power of the area from 'S' is found to be 2229 kvar. This emphasizes the need of a capacitor bank of 2229 kvar somewhere along the line without causing the feeder to go into a leading power factor condition. This rating of the capacitor is assumed for the peak value of the load.

If we use a capacitor bank of 1900 kvar (three phase) then the required voltage rise is given by

$$\%V_{rise} = \%V_{drop} - 3\% = 1.15\% \tag{4.10}$$

The distance along the line where we need to place the capacitor, to maintain the voltage drop to a maximum of 3% is

$$\text{Distance in mile} = \frac{V_{rise}}{K_{rise} * Kvar} = 1.5 \text{ miles from node 'n'}. \tag{4.11}$$

For a single phase lateral, a capacitor placed at a distance of 1.5 miles away from node 'n' is required to maintain the voltage drop to 3%. For a three phase lateral or feeder, the load needs to be lumped to find the exact power and voltage loss when transformers of different ratings are used for different lines [24]. Therefore the shunt capacitor location for a triangular lumped load and the load current is given by

$$L_{load} = \frac{8}{15} * l = 1.8181 \text{ miles from node 'n'}. \tag{4.12}$$

$$I_T = \frac{load}{\sqrt{3}.kv_{ll}} * l = 236.7575\underline{/-25.84°}\ A \tag{4.13}$$

Total resistance of the main can be found using

$$R = r.\ l\ \ \Omega \tag{4.14}$$

where ‘r’ is the resistance per mile calculated from equation 4.3 and ‘l’ is the length of the triangular area. The value of R is found to be 1.0432 Ω

Three phase power loss down the primary is then calculated as

$$P_{loss} = \frac{3}{1000}\left[\frac{8}{15}R.\,|I_T|^2\right] = 93.56W \tag{4.15}$$

This is the power lost along the line of transmission. Before distributing power to the customers, a step down transformer is employed to step down the voltage to 240V. There is power lost at the transformer side. The transformers used for this purpose comes in different sizes. For the purpose of this work we will consider a 50 kVA transformer. In order to find the transformer loss we need to find its impedance, load loss and no load loss.

Distribution Transformer loss

In the name plate details of a transformer its impedance value in % is usually specified.

$$\%\,Z = \sqrt{\%R^2 + \%X^2} \tag{4.16}$$

$$\%\,R = \frac{Load\ losses\ (W)}{Transformer\ capacity\ KVA} \tag{4.17}$$

From the table II in Appendix B we can get the load losses and ‘% Z’ for a specific transformer. For a 50 kVA transformer the value of load losses and ‘% Z’ are found to be 564 W and 1.97%

respectively. Using these values, '% R' is calculated using equation 4.17 and is found to be *1.128* and the relative reactance value '% X' can be found using equation 4.18

$$\% X = \sqrt{\%Z^2 - \%R^2} = 1.6151 \tag{4.18}$$

In a distribution Transformer the value of voltage drop can be calculated using the following steps. In our case we have assumed a base voltage of 240V and transformer base capacity to be 50 kVA. Using this information actual value of impedance can be calculated as follows.

$$Base\ current = \frac{Base\ KVA}{Base\ Voltage} = \frac{50{,}000}{240} = 208.33\ A \tag{4.19}$$

$$Base\ Z = \frac{Base\ Voltage}{Base\ Current} = \frac{240}{208.33} = 1.152\ \Omega \tag{4.20}$$

$$Actual\ R\ ohms = \%\ R * Base\ Z = 0.0130\ \Omega \tag{4.21}$$

$$Actual\ X\ ohms = \%\ X * Base\ Z = 0.0187\ \Omega \tag{4.22}$$

$$Actual\ Z\ ohms = \%\ Z * Base\ Z = 0.0227\ \Omega \tag{4.23}$$

In order to find the voltage drop across the transformer we need to find the peak current and peak voltage of the transformer. Peak current are usually 140-200% of the rated current and the peak voltage between 105-140% of the rated voltage. I_{peak} can be calculated from equation 4.24 and then voltage drop for a power factor of 0.9 is calculated using equation 4.25

$$I\ peak = \frac{208.34}{1.05} * 1.4 = 277.8\ A \tag{4.24}$$

$$Voltage\ drop = I\ peak\ (R\cos\theta + X\sin\theta) = 5.51V \tag{4.25}$$

Now distribution transformer losses can be calculated as follows.

$$Load\ losses = \left[\frac{I_{load}}{I_{rated}}\right]^2 \tag{4.26}$$

$$=\left[\frac{208.33}{277.8}\right]^2 = 1003\ W$$

$$\%\ load\ losses = \frac{Load\ loss\ (W)}{1.4 * VA_{rated} * \cos\theta} \tag{4.27}$$

$$= \frac{564}{1.4 * 50k * 0.9} * 100 = 1.59\%$$

For the actual no-load losses, the rated no-load losses obtained from table II in appendix B is then corrected for a peak voltage and the value normally used is 1.15.

$$No\text{-}load\ losses = Rated\ no\ load\ losses * voltage\ correction\ factor \tag{4.28}$$

$$=103(1.15) \quad = 118.5\ W$$

$$Total\ percent\ losses = \frac{Load\ losses + No\ load\ losses}{1.4 * VA_{rated} * \cos\theta} \quad = 1.78\% \tag{4.29}$$

The results found above are tabularized in table 4.1.

Table 4.1 Small Triangular Voltage Drop Model Results

ATTRIBUTES	**RESULT**
Geometric coordinates of the served area	Triangular
Length and width	3.41miles and 1 mile
Load density	3000 kVA
Power loss	93.56W
Voltage drop	4.15%
Conductor wire used	336,400 26/7 ACSR
Distribution transformer capacity	50 kVA
Distribution transformer losses	1121.5 W

These results are used for the analysis of a circuit which divides into four different feeders serving four different areas each of which are considered to have triangular geometrics and need a load density of 3000 kVA to serve its customer's needs. The total distance through which the transmission line runs is assumed to be 2.5 miles. The distances between clusters are shown in figure 4.3. There are 5 nodes and we will analyze the voltage drop values at each node.

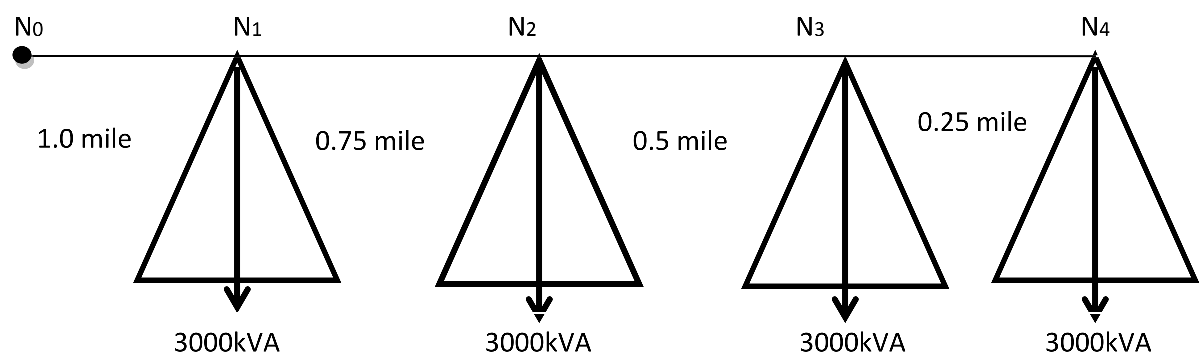

Figure 4.3. Voltage Drop from Node to Node

Total load flow from node N_0 to N_4 $= 3000+3000+3000+3000 = 12{,}000\ kVA$

$$Vdrop_{0\text{-}1} = K\ drop\%\ x\ kVA\ x\ Distance = 4.292\% \tag{4.30}$$

Similarly,

$$V_{drop1\text{-}2} = 2.414\% \tag{4.31}$$

$$V_{drop\ 2\text{-}3} = 1.073\% \tag{4.32}$$

$$V_{drop\ 3\text{-}4} = 0.268\% \tag{4.33}$$

$$Total\ V_{drop\ 0\text{-}4} = 9.047\% \tag{4.31}$$

To maintain voltage drop to less than 3%, we need to add a capacitor bank of:

$$kvar = \frac{V_{rise}}{K_{rise}\ .Distance} = 6000\ kvar\ at\ node\ N_0 \tag{4.34}$$

To supply power to these four clusters, with a loss of 9.047%, the power required at the substation is 4* 4.6 MW = 18.4 MW. But a 9% loss of 18.4 MW = 1.656 MW. So total power required is 18.4 + 1.66 = 20.06 MW.

To supply the substation with 20.06 MW of power, we need to have a generating station of capacity 28.65 MWh of energy considering 30% loss during transformation. Three different factors such as cost involved, amount of coal burned and the amount of CO_2 emitted are calculated.

- *COST INVOLVED*

  To produce 1MWhr of power using coal we need $129.3 [25]. So to produce 28.65MWhr of power we need (129.3 x 28.65) $3,704.5. Therefore to produce 28.65 MW of power for one year the incurred cost is 3,704.5 * 24 * 365 = $ 32,451,420 in one year. This includes the cost of carbon capture and sequestration (CCS) [25].

- *COAL BURNT*

  To produce 1MW of power, we need a power plant with an electrical power output of 1MW. But the actual power from coal combustion also needs to be determined by considering the efficiency of the plant. Most of the coal fired plants on an average are only 35% efficient. This means to produce 1 MW of power we need to produce, 1/0.35 MW = 2.857 MW of power. So if we want 28.65MW of power at the output then we need to consider producing 28.65MW * 2.857 which is 81.85 MW of power. One watt of power is equivalent to one joule/s. To produce 81.85 MW of power the plant need to produce 81.85MW * 10^6 joules per second. Now we need to determine the amount of coal required to produce this 81.85 * 10^6 joules per second of energy. For this we need to take the energy per mass of coal. There are different types of coal and each type has different calorific values. For the purpose of this work, the most commonly used coal which has a calorific value of 37 MJ/kg is considered. The amount of coal which needs to be burnt to get energy of 81.85 * 10^6 joules per second can now be calculated as:

$$\text{Amount of coal required} = \frac{81.853 \text{ x } 10^6}{37 \text{ x } 10^6} \text{ kg/s} = 2.21224 \text{ kg/s} \qquad (4.35)$$

Therefore the amount of coal required per day is (86400 x 2.21224 Kg/s) 192 tons and that per year is (192 x 365) 69,765.35 tons.

- CO_2 *EMITTED*

The energy density of black coal (heating value) is 24 MJ/kg. One kilowatt-hour is 3.6 MJ. So heating value of black coal is 24/3.6 =6.67 kWh/kg. Black coal has 80% of carbon content and the atomic value of carbon is 12. So in molar concept, one kg of black coal when burned has $\frac{0.8 \text{ kg}}{12 \text{ kg/kmol}} = \frac{1}{15}$kmol of carbon. Atomic weight of CO_2 is 44 kg/mol. So one kg of coal when burnt emits 44/15 kg = 2.93 kg of CO_2. So if we are using 192 tons of coal per day then the amount of $C0_2$ emitted will be (192 x 2.93) 560tons and for one year is 204,400 tons [9].

4.2 DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATORS

There are a lot of private sectors who have taken steps to provide us with green energy. They constitute only to a very small extent in making the environment green. Carbon dioxide is emitted into the atmosphere by the burning of coal. The amount of coal being burned to get the adequate electrical energy to meet the demand has not decreased by the increase in the private green energy producers. This is mainly because of the regulation of the PUCO (Public Utility

Commission of Ohio). According to the PUCO the utility companies should consider the peak demand in an area and then allocate load which is large enough to meet this peak demand in that particular area rather than considering the average demand of that area. Due to this regulation of the PUCO though the peak demand is only for few hours a day the utility companies are forced to allocate load that would meet the peak demand at all times. As a result most of the power supplied by the utility companies remains unused except during those peak hours.

4.3 DISTRIBUTED GENERATOR WITH BATTERY BANKS

In this research the distributed generator considered is built by a small farm owner who wants to produce his own electricity and supply the excess electricity produced by him on to the utility grid. There will be battery banks sufficient enough to hold power and supply them continuously for about 6 hours at its maximum amplitude without any or minimal losses. The wind turbine producing electricity is our distributed generator. Electricity produced by distributed generator is partially used to charge battery banks and the remaining gets converted into alternating current before being injected on to the grid. Once the battery banks are charged then all electricity produced goes onto the grid. There will be a current transformer (C.T.) and a meter placed at the distribution transformer where power from Distributed Generator is connected onto the grid. The C.T. uses a smart relay which will in turn is connected to a relay controlling the switch at Distributed Generator. Whenever current reaches a particular value which is considered as the starting of peak, current transformer will sense this increase and will trigger the relay attached to it. This relay in turn triggers another relay located at D.G. to start injecting power from battery banks onto the grid. This action can be accomplished by a switch at the production side.

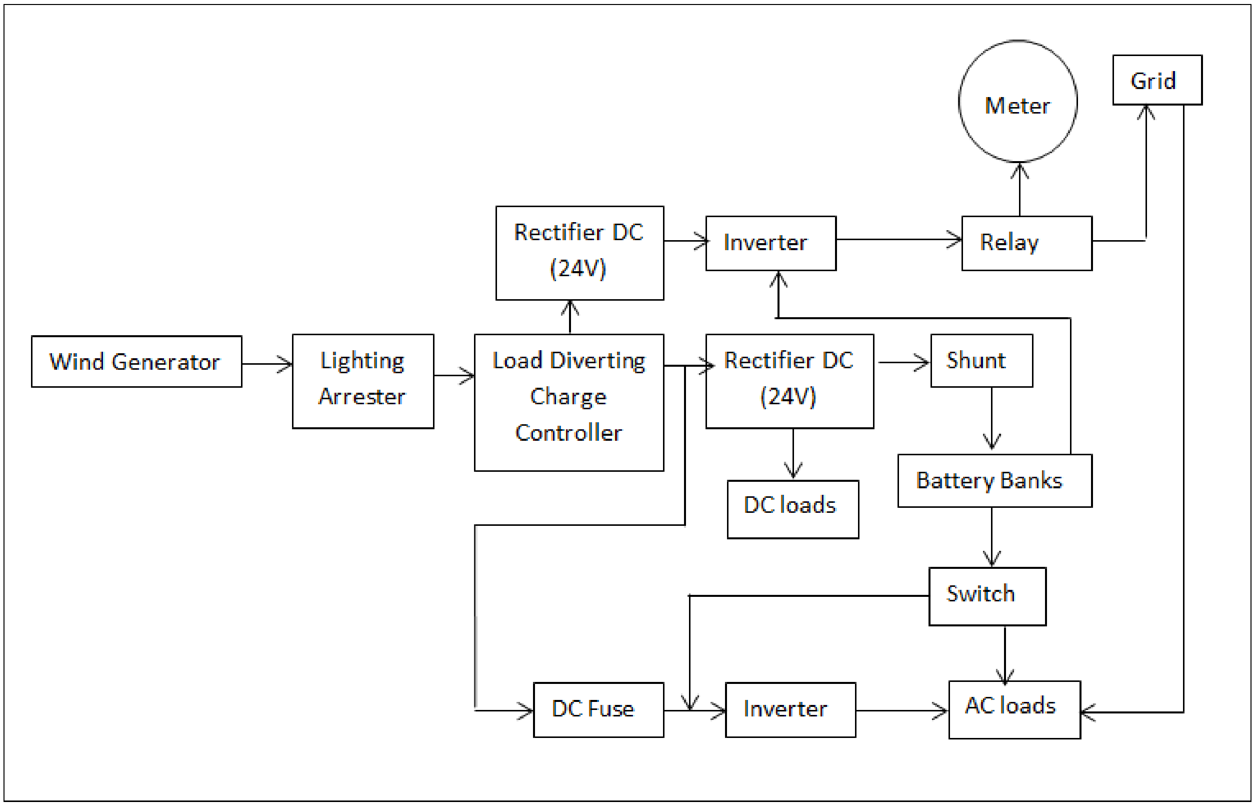

Figure 4.4. Wind Generator Interconnection with Grid

A model of Wind distributed generator's interconnection with the grid is shown in figure 4.4. Here the electricity produced by the D.G. is used by the customer to serve his DC and AC loads and the excess power generated is stored in battery banks for later use, when the D.G. does not generate enough electricity for the customer needs. When we design a wind turbine we need to make sure that excess charge produced the wind turbine is taken care of else it will destroy the turbine generator. The load diverting charge controller is used for this purpose. It also prevents the batteries from over charging. The electricity produced by the wind turbine is not DC. It is AC and the frequency of it varies according the speed of rotation of the wind turbine. Modern wind turbine has inbuilt rectifiers to convert the output to a $240V_{DC}$. We then convert it to an AC with the help of inverters before injecting it onto the grid. During the peak hours the electricity is supplied onto the grid from the battery source which is also converted to AC before injecting onto the grid in addition to the power being injected at all times. This action can be performed with the help of a relay which tells the system when to start injecting electricity from the battery storage. There is an electrical shunt which is a precision resistor creating a tiny voltage drop relative to the current flowing through it to monitor proper charging of battery banks.

4.4 ANALYSIS OF MODIFIED SYSTEM

When power is injected onto the grid from a distributed generator (D.G.) during the peak hours, it reduces the peak by an equal amount of power provided by the D.G. Thus the utility companies need to allocate load for this reduced peak demand. This reduces part of the burden on the utility companies. Figure 4.5 shows the same circuit considered in figure 4.3 expect that we have a D.G in all the four clusters which is capable of providing 50 kVA during peak hours.

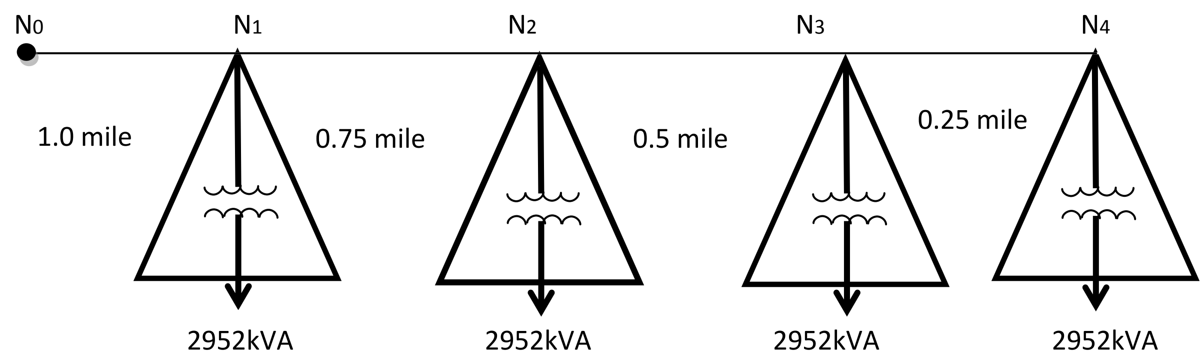

Figure 4.5. Voltage Drop from Node to Node with the Inclusion of D.G

The D.G. injects power onto the grid using a 50kVA transformer and from the previous results the transformer loss is calculated to be 1.78% for a 50 kVA transformer hence the net power injected will then be 49.11kVA.

So we need to consider a load of (3000 - 49.11) = 2951.89 kVA

The total load flow from node N_0 to N_4 = 2951.89+2951.89+2951.89+2951.89 = 11807.56 kVA

$$V_{\mathbf{drop0\text{-}1}} = K_{drop}\% \times kVA \times Distance = 4.223\% \quad (4.36)$$

Similarly,

$$V_{drop1\text{-}2} = 2.375\% \quad (4.37)$$

$$V_{drop2\text{-}3} = 1.055\% \quad (4.38)$$

$$V_{drop3\text{-}4} = 0.264\% \quad (4.39)$$

$$\text{Total } V_{drop0\text{-}4} = 8.917\% \quad (4.40)$$

To supply power to these 4 clusters, with a loss 8.917%, the power required at the substation will be 4 * 4.53 MW which is 18.1 MW. Considering a loss of 9% (rounded) which is 1.6296 MW, the total power required at the source end will be 19.729 MW. In order to transfer 19.729 MW of power we need to have a generating station of capacity 28.184 MW considering 70% efficient power generating station.

The 3 factors discussed for the earlier case is analyzed again.

- *COST INVOLVED*

  To produce 1MWhr of power using coal we need \$129.3. So to produce 28.184MWhr of power, the amount required is (129.3 x 28.184) \$3,644.20. Therefore to produce 28.184 MW of power for one year it is 3,644.20* 24 * 365 = \$ 31,923,115. This includes the cost of carbon capture and sequestration (CCS).

- *COAL BURNT*

$$\text{Amount of coal required} = \frac{80.522 \text{ x } 10^6}{37 \text{ x } 10^6} \text{ Kg/s} = 2.1763 \text{ Kg/s} \quad (4.41)$$

Therefore the amount of coal required per day is (86400 x 2.1763 Kg/s) 188 tons and that per year is 68,630.6 tons.

- *CO_2 EMITTED*

Calculated $C0_2$ emission for this system is (188 x 2.93) 551 tons/day and that per year is 201,115 tons.

4.5 MATLAB SIMULATION

Distributed generators considered here are small farm owners, who want to produce electricity for their own needs and sell the excess electricity produced by them to the utility grid by injecting it on to the grid. At present these small farm owners inject the excess electricity directly onto the grid. In this work we proved that the use of battery banks which can store the excess electricity produced and inject them during peak hours will be more beneficial to both the small farm owners and the utility companies. In this design instead of the small farm owner directly injecting his excess power onto the grid sends the excess power produced to charge the battery and once when the battery is fully charged he sends the power onto the grid. During peak hours power from the battery bank which is converted to alternating three phase power is injected onto the grid.

A Matlab simulation has been developed in order to study the voltage and current values. In this work, the duration of the day during which the peak occurs is assumed to be known. During these hours maximum power is injected onto the grid which helps in meeting part of the peak demand and hence reducing burden on the utility company. Although the location of distributed generator has a major role in determining the efficiency of the distribution system, it does not apply in this case because the distributed generator is built by the small farm owner for his need and not the utility company.

Figure 4.6 shows Matlab simulation block diagram drawn in Simulink. There are sub systems under some of the blocks which are not shown in this figure. A power plant and two distributed generators are simulated. Distributed generator is injected onto the grid at two different locations and the net voltage after the injection at those nodes is studied. There is a battery system which injects maximum power during peak demand and at other times it injects only the excess power produced onto the grid.

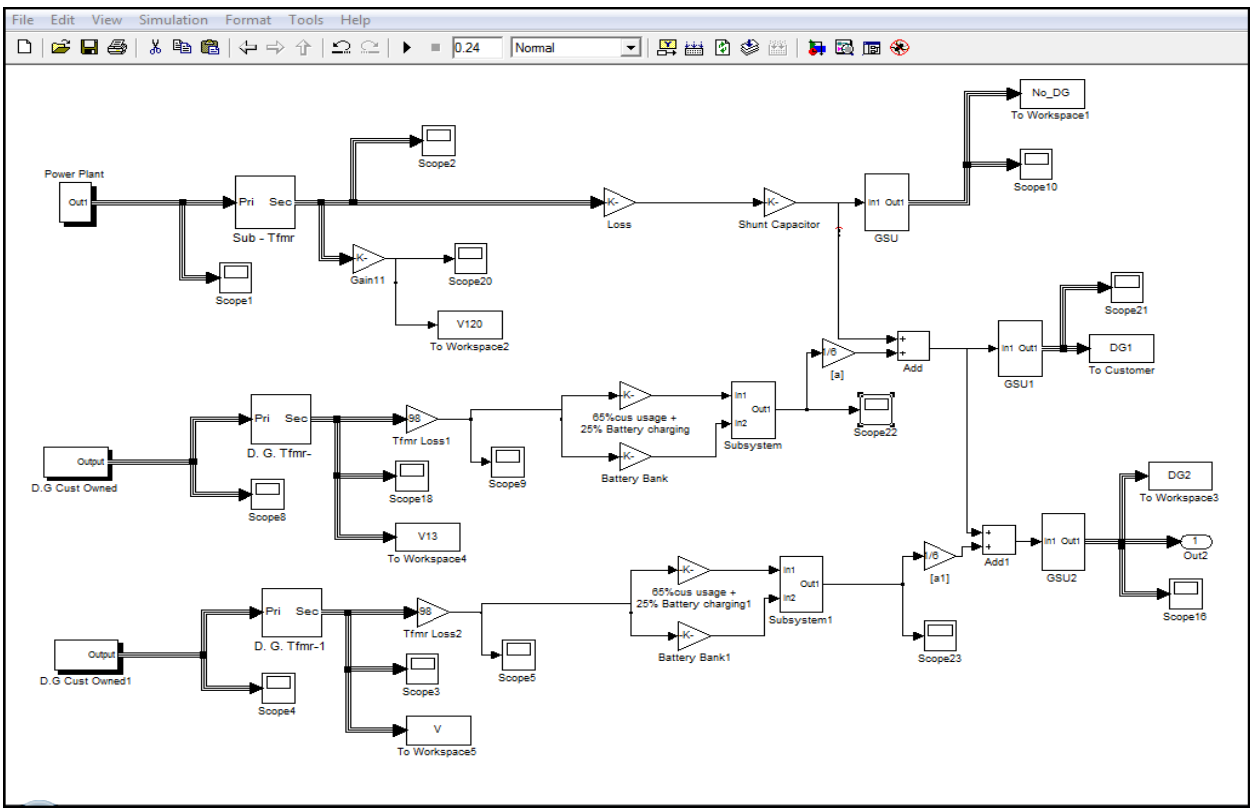

Figure 4.6 Matlab Simulation Using Simulink

Figure 4.7 shows the value of voltage at the customer end using Matlab Simulink. This is voltage obtained at the customer end without any addition of distributed generators. The voltage value is found to be 119.4V and the x-axis denotes time in milliseconds. The value of voltage at the customer end with the inclusion of a distributed generator is 119.8V and 120.2V for two distributed generators respectively showing an improved voltage profile. These values are obtained using Matlab Simulink and are shown in the figures 4.8 and 4.9, respectively. The total runtime of the simulation is 2400 ms which can be compared with the total number of hours in a day assuming 100 ms to represent an hour.

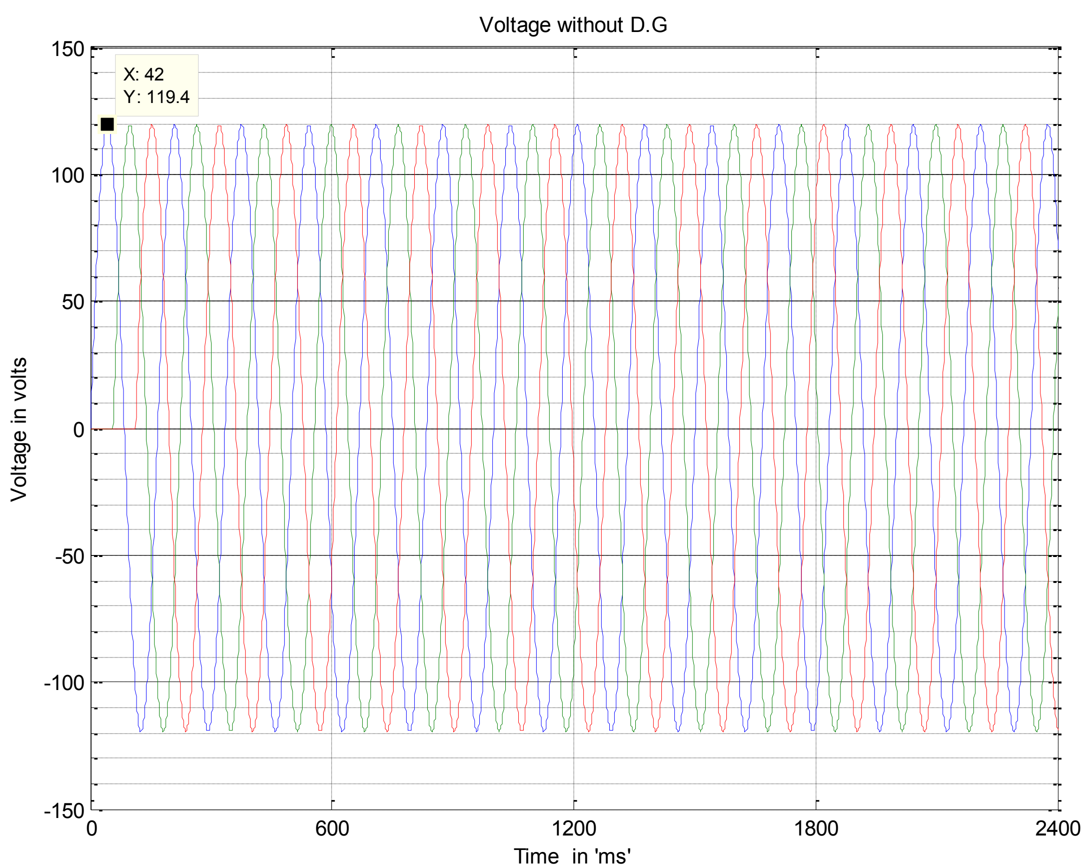

Figure 4.7. Voltage at the Distribution Transformer without D.G.

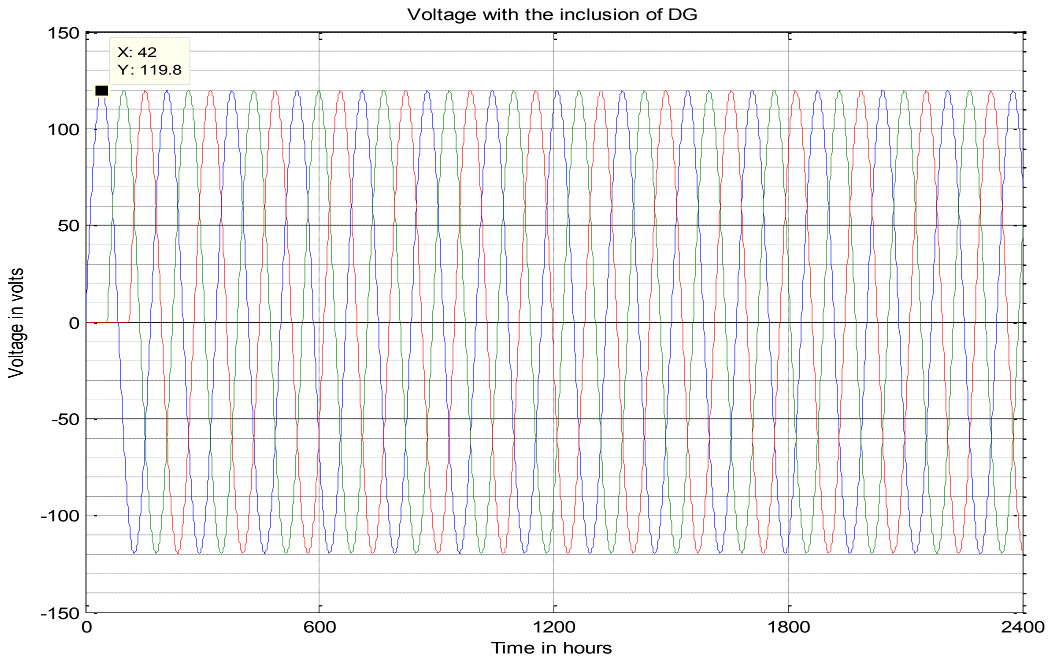

Figure 4.8. Voltage at the Distribution Transformer with One D.G.

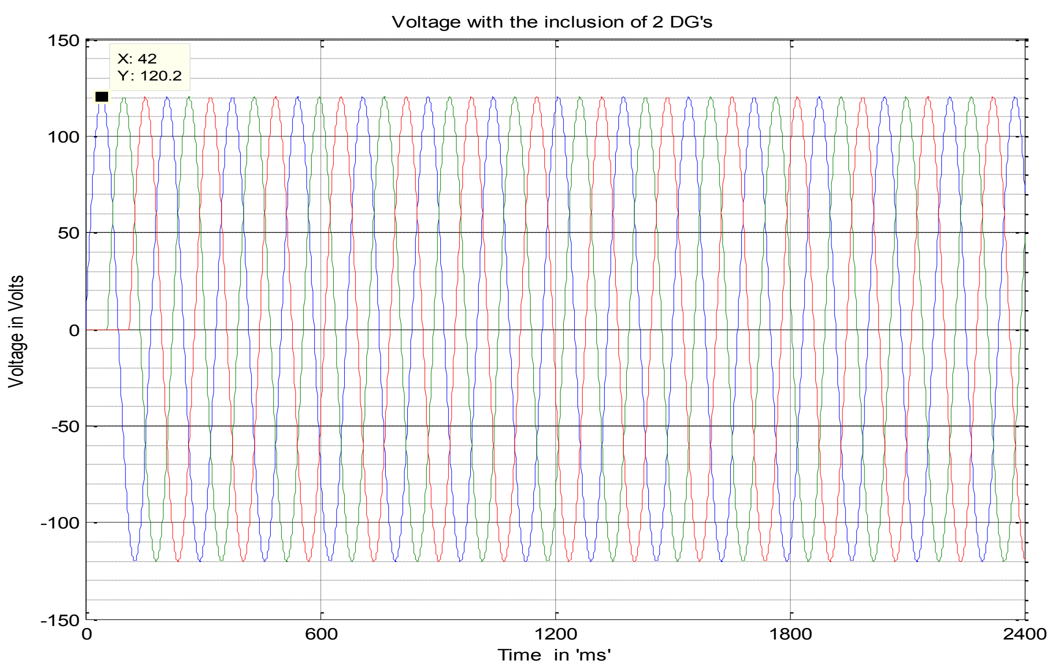

Figure 4.9. Voltage at the Distribution Transformer with Two D.G.s

Figure 4.10 shows the value of current injected on to the grid from the distributed generator. The peak loading is assumed to take place between 600 'ms' and 1000 'ms' and again between 1800 'ms' and 2100 'ms'. The value of the current during these peak hours is higher than during the normal hours. This is because power from the distributed generator is injected onto the system at its maximum of 50 kVA only during the peak hours and during other periods, only the excess power that is left out after meeting injector's requirements is injected onto the grid.

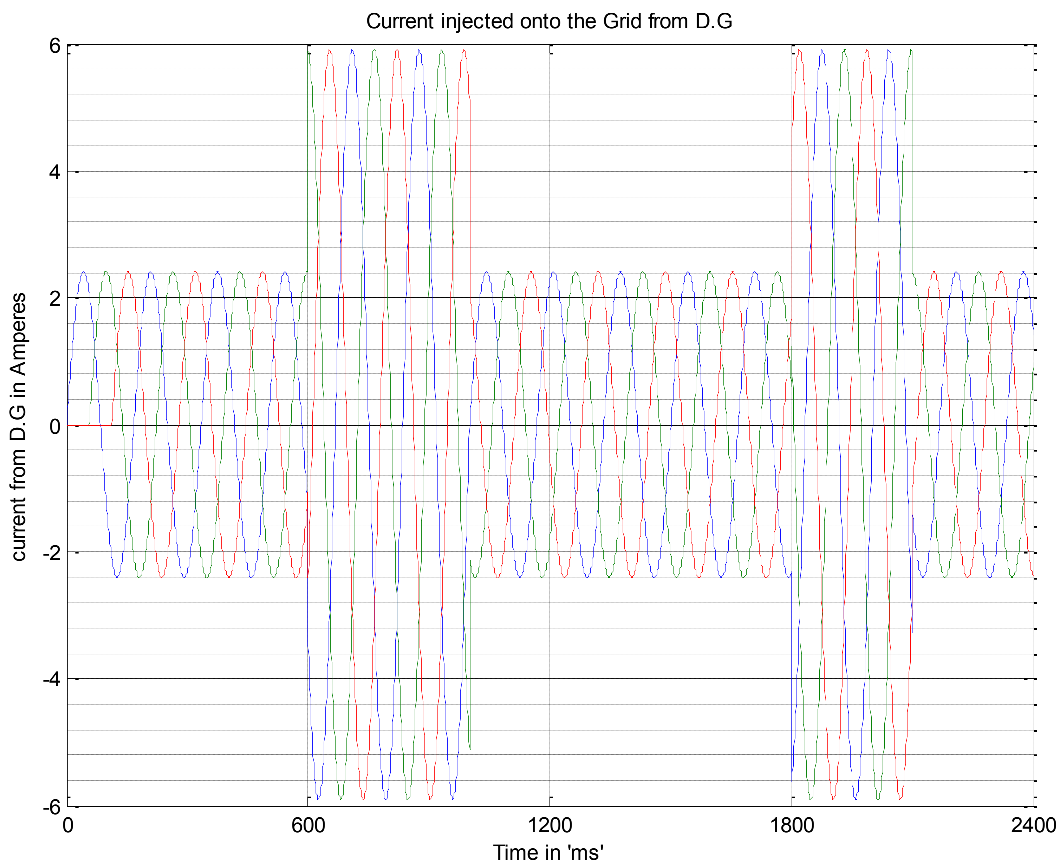

Figure 4.10. Current Injected onto the Grid from Battery Banks

Figure 4.11 shows the value of current without inclusion of the distributed generator and is found to have maximum amplitude of 555.5A at the distribution transformer during both the normal and peak hours of the day.

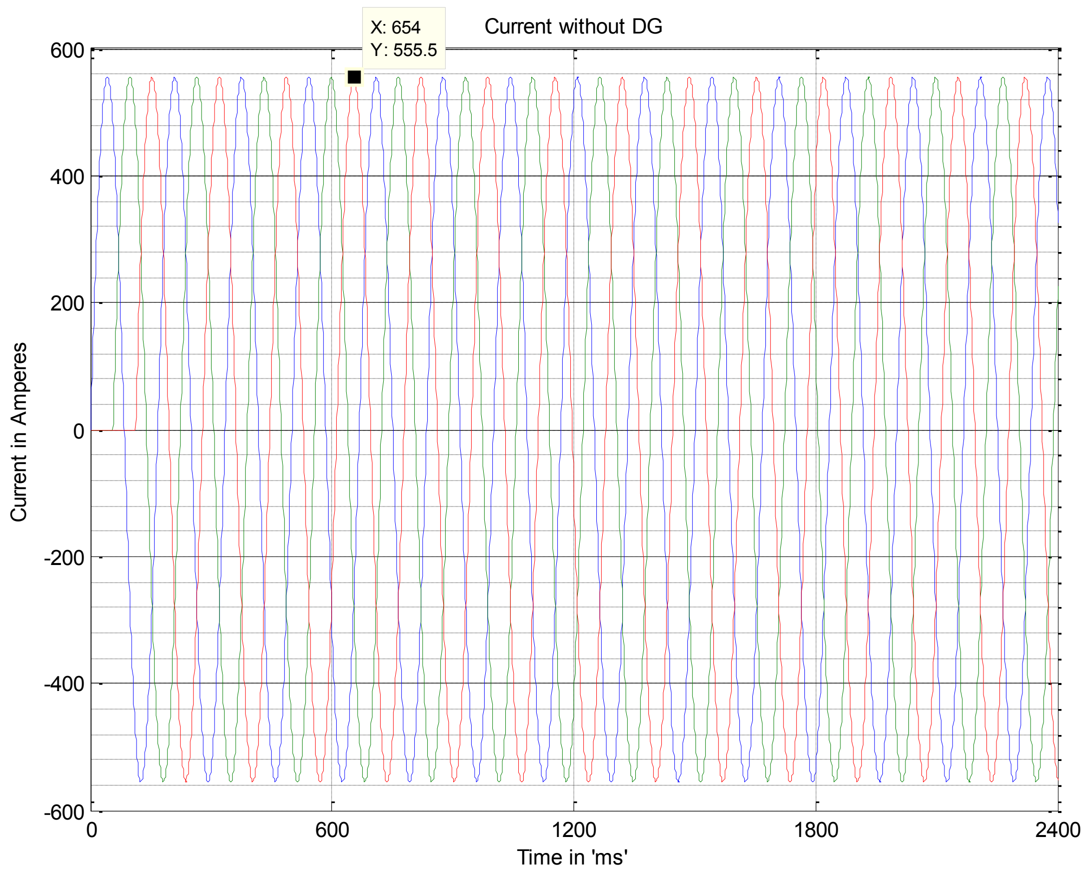

Figure 4.11. Current at the Distribution Transformer without D.G.

Figure 4.12 shows the value of current with inclusion of the distributed generator and the current during peak hour is found to be 561.4A and is 555.5A during normal hours.

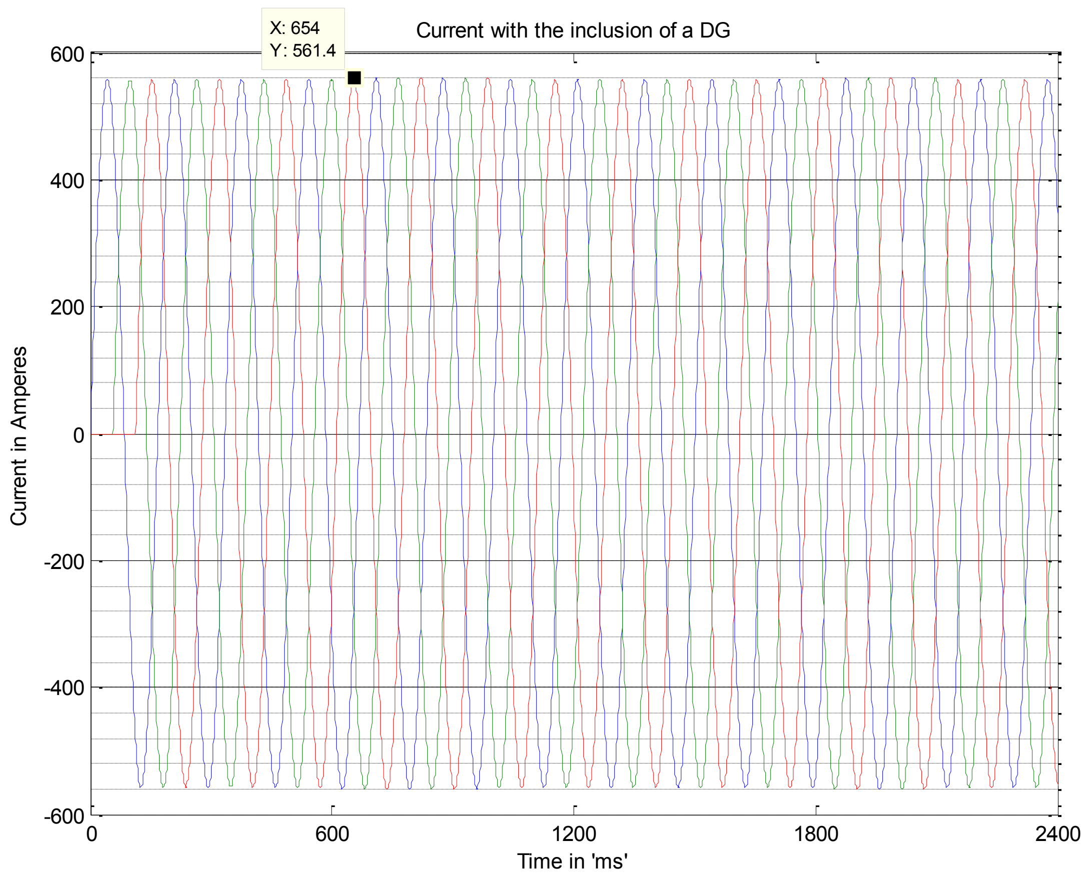

Figure 4.12. Current at the Distribution Transformer with a D.G.

Figure 4.13 shows the current variation at the distribution transformer with 4 distributed generators injecting their excess power onto the grid and from the battery banks during peak hours. The value of current at peak hour has maximum amplitude of 571A and 555.5A during normal hours.

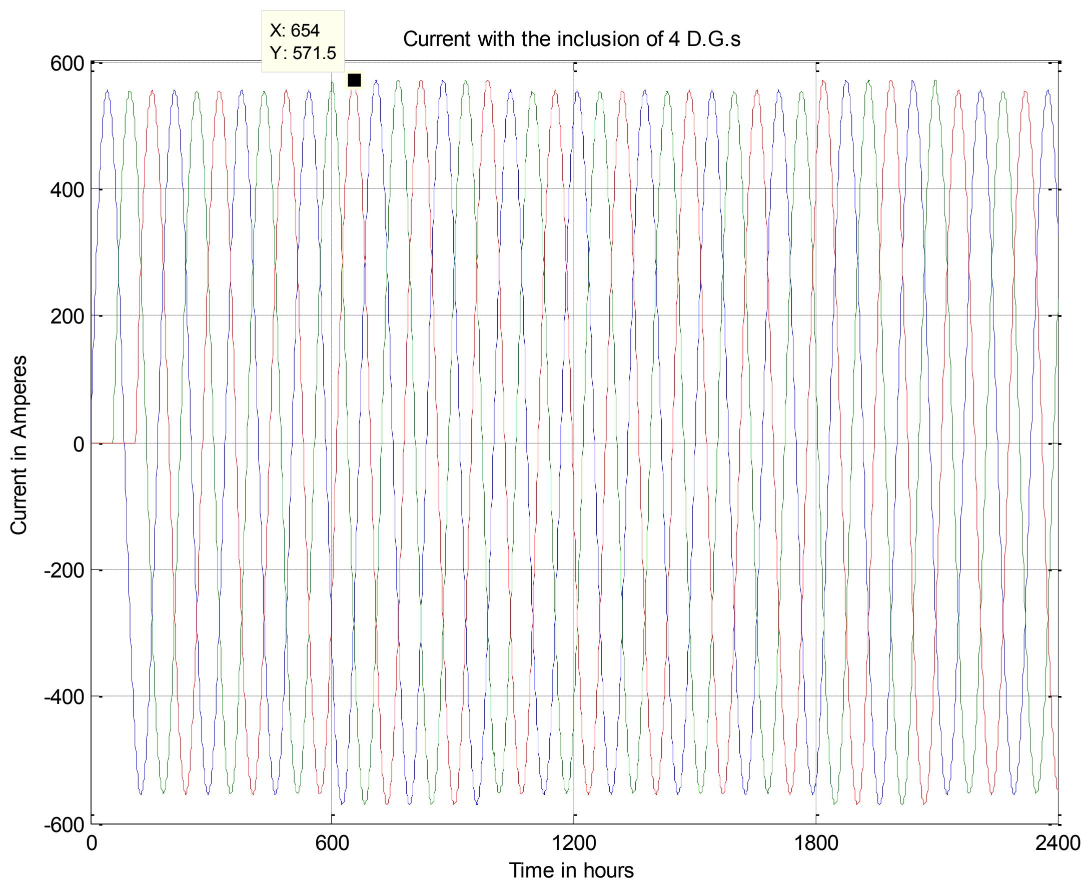

Figure 6.8. Current at the Distribution Transformer with 4 D.G.s

CHAPTER 5: ECONOMICS AND FEASIBILITY

Introduction of distributed generator on a distribution system improves the voltage profile by reducing the losses. As the electric power produced by a distributed generator is stored in battery banks and injected onto the distribution grid during peak hours it reduces the power produced at the generating station, amount of coal burned, cost involved and the amount of CO_2 emitted. In this chapter the cost effectiveness of distributed generator is analyzed with and without battery banks.

5.1 COST OF ENERGY

There are several ways to evaluate the economics and feasibility of injecting power onto the grid. In this work Cost of Energy (COE) approach is used to analyze the feasibility. This method takes initial cost, maintenance, interest rates and performance of the life of the wind system installed. In this method we will produce an estimate of cost of electricity in cents/kwh for the wind system's life time. Thus this method tells us about the cost of producing electricity using wind energy.

- *ADVANTAGES OF COE*

  This method tells us about the cash flow for every year or month of generating electric power by a wind system. It also tells us about the payback period for our investment.

- *DRAWBACKS*

  Using this method we cannot conclude whether or not the money invested in this system is a better investment compared to interest bearing account at any local banks. We will have to assume the maintenance cost as we will not have any clue about the maintenance even before we start our project.

5.2 COST OF ENERGY ANALYSIS AND TERMS USED

The following are the terms used as a major component in the COE analysis.

- Installation Cost

  It is simply the cost associated in building the turbine, tower, wiring, transportation and the labor involved in installing all these together.

- Operation and Maintenance

  These are the cost associated with the operation, servicing and repairing of the system. In most of the wind system operation and maintenance cost was about 1% of the installation cost [15]. This is in accordance with Paul Gipe's work (a pioneer in wind system)

- Retail Rate

  Rate at which the utility company sells electricity to the customers expressed in cents/kwh.

- Resale Rate

  It is the rate utility company pays the customer for injecting unused electricity on to the grid. It is expressed in cents/kwh.

- Peak Rate

  It is the rate the utility company pays the customer for injecting electricity on to the grid during the peak usage hours. It is expressed in cents/kwh.

- Tax Bracket

For tax payers in the United States based on their income there are a set of rates at which the taxes are calculated. This is called tax bracket and is usually expressed in percentage.

- Tax Credit Rate

Taxes play a very significant role in any investment. Tax credits are even more important as it would reduce the cost of maintenance and other such expenses. People who are in high tax brackets are benefitted more than those in the less tax bracket. For example if a person is in 35% tax bracket, he will have a tax credit rate of 1.538% [1/ (100%-35%)] while the one in30% tax bracket will have a tax credit rate of 1.428% [15].

- Utility Escalation Rate

The electricity that is produced by the utility company comes either from coal or petroleum products. An increase in the cost of these raw materials that are necessary for the power production will increase the cost of the supplied electricity. Hence the utility company will have to escalate the rate to make some profit. Utility escalation rate also increases with inflation rate.

- Cost of Financing

Since the initial setup cost is as high as $100,000 most of the time any individual who wants to build a wind system, may not have enough financial resources to meet the cost that would be incurred. He will have to seek loan from a bank or any other lending resources. In this case, while assessing the feasibility report we need to consider the down payment, interest rate, loan term into the account.

- Insurance

Since wind systems are not all that safe, they must be insured. There could be property damage if the turbine falls down from the tower, any mishandling of equipment within the system may result in an accident. The payback period of wind is usually greater than 10 years so most of the owners would want to run their machine or the wind system with insurance as they do not want to bear any cost that could occur when there is a fault with the machinery and its operation. In this work the cost of insurance is considered to be 1% of installation cost in accordance with Paul Gipe's work [15].

Figure 5.1 shows the annual revenue and the cumulative revenue of a wind system without battery banks. From the figure it can be observed that the generator takes 11 years to recover all costs before starting to earn income.

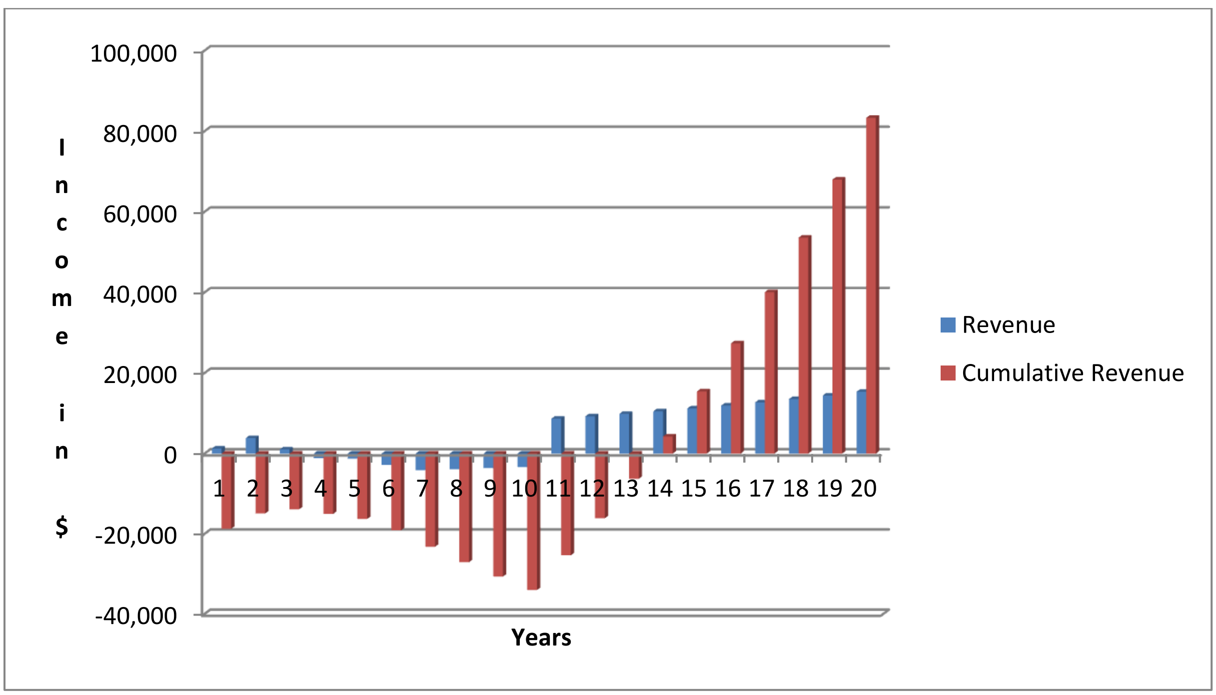

Figure 5.1. Revenue of Wind System Without Peak Injection for 20 Years

The cash flow for the wind system without battery banks is shown in table 5.1. Here the annual energy output per year is calculated assuming wind turbine capable of producing 50kW of power.

Table 5.1. Cash Flow for Wind System without Peak Injection [6].

Rotor Diameter		15	m	Retail rate		0.10	$/kwh	Utility rate escalation		6%	
Average wind speed		6	m/s	Resale rate		0.02	$/kwh	Inflation rate		3%	
Yield		500	kWh/m^2/y	% at retail rate		90%		Down payment		20%	
Installed cost		100,000		Tax credit rate		0.0143	$/kwh	Loan term		10	yrs
O&M		0.01	$/kwh	% Tax credit used		100.00%		Loan intrest		8%	
Insurance		1%		Tax bracket		30%		Discount rate		6%	
Swept area		177	m^2					Annual Energy Output		90,000	kWh/yr
Year	Gross Revenue	O&M	Insurance	Loan Interest	Loan Principal	Depreciatio Deduction	Income Tax	Tax Credit Value	Revenue	Cummulitive Revenue	
0	-20,000	0	0	0	0	0	0	0	-20,000	-20,000	
1	8,280	-900	-1,000	-6,400	-5,522	-22,000	6,606	129	1,192	-18,808	
2	8,777	-927	-1,030	-5,958	-5,964	-30,000	8,742	133	3,772	-15,036	
3	9,303	-955	-1,061	-5,481	-6,441	-20,000	5,458	137	960	-14,076	
4	9,862	-983	-1,093	-4,966	-6,957	-12,000	2,754	141	-1,242	-15,318	
5	10,453	-1,013	-1,126	-4,409	-7,513	-11,000	2,128	145	-1,334	-16,653	
6	11,081	-1,043	-1,159	-3,808	-8,114	-5,000	-21	149	-2,916	-19,569	
7	11,745	-1,075	-1,194	-3,159	-8,763		-1,895	154	-4,187	-23,756	
8	12,450	-1,107	-1,230	-2,458	-9,464		-2,297	158	-3,947	-27,704	
9	13,197	-1,140	-1,267	-1,701	-10,222		-2,727	163	-3,696	-31,400	
10	13,989	-1,174	-1,305	-883	-11,039		-3,188	168	-3,433	-34,832	
11	14,828	-1,210	-1,344	0	0		-3,682		8,592	-26,240	
12	15,718	-1,246	-1,384	0	0		-3,926		9,162	-17,078	
13	16,661	-1,283	-1,426	0	0		-4,186		9,766	-7,312	
14	17,661	-1,322	-1,469	0	0		-4,461		10,409	3,097	
15	18,720	-1,361	-1,513	0	0		-4,754		11,092	14,190	
16	19,844	-1,402	-1,558	0	0		-5,065		11,818	26,008	
17	21,034	-1,444	-1,605	0	0		-5,396		12,590	38,598	
18	22,296	-1,488	-1,653	0	0		-5,747		13,409	52,007	
19	23,634	-1,532	-1,702	0	0		-6,120		14,280	66,286	
20	25,052	-1,578	-1,754	0	0		-6,516		15,204	81,491	
							Total 20-year revenue		81,491		
							Net present Value		17,000		

Table 5.2 shows the cash flow of wind system distributed generator with battery banks. Here the cost of battery is not included. When included the net present value of the system went negative indicating the project was financially not feasible. The main difference between the two tables is the inclusion of peak rate. The customer gets higher resale rate which we refer as peak rate for injecting power during the peak hours.

Table 5.2. Cash Flow for Wind System with Peak Injection [6].

Rotor Diameter		15	m	Retail rate		0.10	$/kwh	Utility rate escalation		6%	
Average wind speed		6	m/s	Resale rate		0.02	$/kwh	Inflation rate		3%	
Yield		500	kWh/m^2/yr	% at retail rate		90%		Down payment		20%	
Installed cost		100,000		Tax credit rate		0.0143	$/kwh	Loan term		10	yrs
O&M		0.01	$/kwh	% Tax credit used		100.00%		Loan intrest		8%	
Insurance		1%		Tax bracket		30%		Discount rate		6%	
Swept area		177	m^2	Peak Rate		0.05	$/kwh	Annual Energy Output		90,000	kWh/yr
Year	Gross Revenue	O&M	Insurance	Loan Interest	Loan Principal	Depreciat Deduction	Income Tax	Tax Value credit	Revenue (Loss)	Cummulitive Revenue	
0	-20,000	0	0	0	0	0	0	0	-20,000	-20,000	
1	8,342	-900	-1,000	-6,400	-5,522	-22,000	6,587	129	1,236	-18,764	
2	8,842	-927	-1,030	-5,958	-5,964	-30,000	8,722	133	3,817	-14,947	
3	9,373	-955	-1,061	-5,481	-6,441	-20,000	5,437	137	1,009	-13,938	
4	9,935	-983	-1,093	-4,966	-6,957	-12,000	2,732	141	-1,191	-15,129	
5	10,531	-1,013	-1,126	-4,409	-7,513	-11,000	2,105	145	-1,280	-16,409	
6	11,163	-1,043	-1,159	-3,808	-8,114	-5,000	-46	149	-2,858	-19,267	
7	11,833	-1,075	-1,194	-3,159	-8,763		-1,922	154	-4,126	-23,393	
8	12,543	-1,107	-1,230	-2,458	-9,464		-2,324	158	-3,882	-27,275	
9	13,296	-1,140	-1,267	-1,701	-10,222		-2,756	163	-3,627	-30,902	
10	14,093	-1,174	-1,305	-883	-11,039		-3,219	168	-3,359	-34,261	
11	14,939	-1,210	-1,344	0	0		-3,716		8,670	-25,591	
12	15,835	-1,246	-1,384	0	0		-3,962		9,244	-16,348	
13	16,785	-1,283	-1,426	0	0		-4,223		9,854	-6,494	
14	17,793	-1,322	-1,469	0	0		-4,501		10,502	4,008	
15	18,860	-1,361	-1,513	0	0		-4,796		11,190	15,198	
16	19,992	-1,402	-1,558	0	0		-5,109		11,922	27,120	
17	21,191	-1,444	-1,605	0	0		-5,443		12,700	39,820	
18	22,463	-1,488	-1,653	0	0		-5,797		13,526	53,345	
19	23,811	-1,532	-1,702	0	0		-6,173		14,403	67,749	
20	25,239	-1,578	-1,754	0	0		-6,572		15,335	83,084	
							Total 20-year revenue		83,084		
							Net present value		18,000		

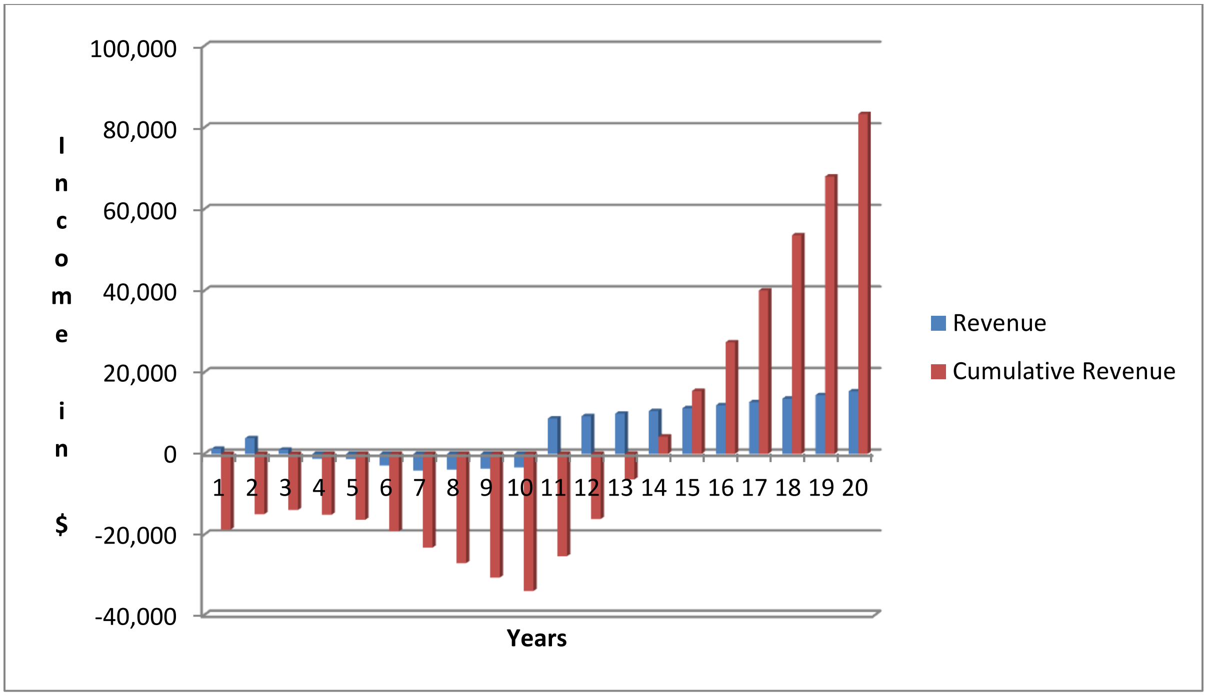

Figure 5.2. Revenue of Wind System With Peak Injection for 20 Years.

Figure 5.2 shows the revenue and the cumulative revenue of the modified system with battery banks. It can be observed that there is not much difference between the two systems in terms of profitability.

5.3 COMPARISON

From the two tables we see that the net present value of the table 1 is less than that of the table 2. This shows that the customer would be making extra money if the power produced is stored and then injected onto the system during the peak time. The cost involved with the battery banks are not taken into account. It is assumed that this cost will be taken by the utility company. From our previous chapter we know that the utility company would be making a profit of $527,823 per year. Assuming there are four distributed generators each one capable of injecting 50 kW of power onto the grid. The cost of battery for storing this power was calculated to be about \$15,000 to \$20,000 for every distributed generator per year. The utility company would therefore be spending about \$60,000 to \$80,000 on battery for all the four distributed generators. Even with the inclusion of this battery cost the utility company will still be making a profit of around \$400,000 per year and the environment would be free from 3,200 tons of CO_2 emitted into the atmosphere per year.

There is not a big difference in the net present value between the two systems so it might become difficult for the utility company in convincing the customer to implement the battery bank for injecting power during the peak hours. One solution to this would be providing the customer with an incentive. The utility company may provide the customer with an incentive which depends on the amount of power the customer is injecting onto the grid during the peak hours. Now assuming all four customers provided equal amount of power during the peak demand in a given year then the utility company gives away \$12,000 to each of these customers which accounts to \$48,000 per year and net profit of utility company will be about \$350,000 profit per year.

CHAPTER 6: RESULTS AND CONCLUSIONS

6.1 RESULTS:

Results obtained from the analysis of the two systems in chapter 4 with and without distributed generator are tabulated in table 6.1

Table 6.1 Comparison of Distribution System

Factors	System with no D.G.	Modified System with D.G.	Difference
Cost involved	$ 32,451,420 per annum.	31,923,115 per annum.	$ 528,305
Coal burned	69,765.35 tons per annum.	68,630.6 tons per annum	1134.75 tons
CO_2 emitted	204,400 tons per annum.	201,115 tons per annum	3,325tons
Voltage drop	9.047%	8.917%	0.13%
Line losses	1.66 MW	1.6 MW	600 kW

- With 4 distributed generators each one capable of providing 50 kVA during peak demands the total power that could be saved is 466 kW. This indicates that instead of producing 28.65 MW of power to serve the cluster, it is sufficient to produce only 28.18 MW.
- The amount of coal that can be saved is (69,765.35 - 68,630.6) tons = 1134.75 tons/year.
- Cost saved by reducing the production is calculated to be $530,000/year.
- The amount of CO_2 that can be reduced without emitting into the atmosphere is 3,325 tons/year.

- The effective power used with the existing system was (100-9.047) % = 90.953%and with the new system is (100-8.917) % = 91.083%
- The efficiency of the system considered in this example improved from 89% to 91% and the efficiency can be still be increased if more distributed generators can be included in the distribution system with more capacity.
- The inclusion of distributed generators have reduced the use of capacitors which otherwise needs to be used to boost the voltage.

6.2 CONCLUSIONS:

- Using Matlab Simulink and calculations it is proved that insertion of power from a distributed generator during peak demand can reduce the peak demand and hence power produced and sent over the transmission lines.
- The power distribution efficiency of the system can be improved.
- Wind distributed generators makes the environment greener by reducing the amount of coal being burned and hence the amount of CO_2 emissions onto the atmosphere.
- The feasibility report shows that this method is beneficial to both the utility company and the customer who is injecting power from the distributed generator.

APPENDICES

APPENDIX A: MATLAB CALCULATION FOR A THREE PHASE LOAD

```
disp('entering the inputs');
ri=.306;
GMRi=0.0244;
rn=.592;
GMRn=.00814;
Rdc=.03004;
Rds=.02346;
Dab = 3;%distance between conductor a and b%
Dbc = 5;%distance between conductor b and c%
Dca = Dab+Dbc;%distance between conductor a and c%
cn = 3.5;%distance between neutral and c%
ng = 26;%vertical distance between neutral and b%
nl = 4.5;%vertical distance between neutral and conductor%
disp('end of the input')
an=Dca-cn;
bn=Dbc-cn;
Dan =sqrt((an)^2+(nl)^2);
Dbn =sqrt((bn)^2+(nl)^2);
Dcn =sqrt((cn)^2+(nl)^2);
Zaa = (ri+.09530+1i*0.12134*(log(1/GMRi)+7.93402));
Znn = (rn+.09530+1i*0.12134*(log(1/GMRn)+7.93402));
Zab = 0.09530+1i*(0.12134*(log(1/Dab)+7.93402));
Zac = 0.09530+1i*(0.12134*(log(1/Dca)+7.93402));
Zbc = 0.09530+1i*(0.12134*(log(1/Dbc)+7.93402));
Zbb = Zaa ;
Zcc = Zbb;
Zan = 0.09530+1i*(0.12134*(log(1/Dan)+7.93402));
Zbn = 0.09530+1i*(0.12134*(log(1/Dbn)+7.93402));
Zcn = 0.09530+1i*(0.12134*(log(1/Dcn)+7.93402));
disp (' impedance matrix');
Z = [ZaaZabZacZan;ZabZbbZbcZbn;ZacZbcZccZcn;ZanZbnZcnZnn]
Zij = [ZaaZabZac;ZabZbbZbc;ZacZbcZcc];
Zin=[Zan;Zbn;Zcn];
Znj=[ZanZbnZcn];
disp('kron reduction');
disp('calculation of phase impedance matrix"[Zabc]" ');
Zabc=[Zij]-[Zin]*inv([Znn])*[Znj]
as= -0.5+i*((3^0.5)/2);
As=[1 1 1;1 (as)^2 as;1 as (as)^2];
disp('calculation of sequence impedance matrix[Z012] ');
[Z012] =inv([As])*[Zabc]*[As]
zero_impedance_matrix =Z012(1,1)
positive_impedance_matrix =Z012(2,2)
negative_impedance_matrix =Z012(3,3)
disp('Modified Phase impedance matrix "[Z1abc]"');
a1=(Zabc(1,1)+Zabc(2,2)+Zabc(3,3))/3;
b1=(Zabc(1,2)+Zabc(1,3)+Zabc(2,3))/3;
Z1abc=[a1 b1 b1;b1 a1 b1;b1 b1 a1]
saa=2*[ng+nl];
sbb=saa;
scc=saa;
snn=2*ng;
sab=sqrt((saa)^2+Dab^2);
```

```
sac=sqrt((saa)^2+Dca^2);
sbc=sqrt((saa)^2+Dbc^2);
san=sqrt((nl+2*ng)^2+an^2);
sbn=sqrt((nl+2*ng)^2+bn^2);
scn=sqrt((nl+2*ng)^2+cn^2);
S=[saa sab sac san;sabsbbsbcsbn;sacsbcsccscn;sansbnscnsnn];
D=[Rdc Dab DcaDan;DabRdcDbcDbn;DcaDbcRdcDcn;DanDbnDcnRds];
P=zeros(4,4);
for m=1:4
for n=1:4
if m==n
P(m,n)=11.17689*log([S(m,n)]/D(m,n));
else
P(m,n)=11.17689*log([S(m,n)]/D(m,n));
end
end
end
disp('Total primitive Potential co-efficient matrix "Pmatrix"');
Pmatrix=P/10^-6
Pabc=zeros(3,3);
for m=1:3
for n=1:3
Pabc(m,n)= (P(m,n)-P(m,4)*P(4,n)/P(4,4))/10^-6;
end
end
disp ('Phase potential coefficient matrix [Cabc]');
Cabc = inv(Pabc)
disp ('shunt admittance matrix [Yabc]');
Yabc = (2*pi*60*Cabc)*i
load = 12000;
V= 12470;
PF = 0.9;
disp('case1')
Zabc = 2.5*Zabc
Yabc = 2.5*Yabc
[a] = eye(3)+0.5*Zabc*Yabc
[b] =Zabc
[c]=Yabc+.25*Yabc*Zabc*Yabc
[d]=eye(3)+.5*Zabc*Yabc
VLG=V/sqrt(3)
disp ('Voltage at the load end is Vabcg')
Vabcg=[VLG*cosd(0)+i*VLG*sind(0);VLG*cosd(-120)+...
i*VLG*sind(-120);VLG*cosd(120)+i*VLG*sind(120)]
% Vabcg=[7199.56;-3599.78-i*6235;-3599.78+i*6235]
I=load/(sqrt(3)*12.47)
theta = acosd(0.9)
disp ('current at the load end is Iabc')
Iabc=[I*cosd(0-theta)+i*I*sind(0-theta);I*cosd(-120-theta)+...
i*I*sind(-120-theta);I*cosd(120-theta)+i*I*sind(120-theta)]
%Iabc=[250-i*121.07;-229.86-i*155.98;-20.15+i*277.058]
disp('the line to ground voltage at the source end ')
Vlg=a*Vabcg+b*Iabc;
Vlgsource = Vlg
vlg=conj(Vlg)
f=[vlg(1,1) 0 0;0 vlg(2,1) 0;0 0 vlg(3,1)]
Vnew=sqrt(f*Vlg)
Vavg=[Vnew(1,1)+Vnew(2,1)+Vnew(3,1)]/3
```

```
Vmax=0;
for g=1:n
ifVmax>Vnew(g,1)
elseVmax=Vnew(g,1)
end
end
Vdeviation_max = Vmax-Vavg
Vunbalance_percentage = Vdeviation_max/Vavg *100
Iabc_source =c*Vabcg+d*Iabc
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%% single phase transformer %
Z1= 1.37+i*1.96;
Z2= .013+i*0.0187;
% Z1=.612+i*1.2;
% Z2=.0061+i*.0115;
Y= (1.92-i*8.52)*10^-4
N2= 240; N1=7200;
DT= 50*10^3
nt = N2/N1;
Zt = Z2+(nt^2)*Z1
a= 1/nt;
b= Zt/nt;
c=Y/nt;
d=Y*Zt/nt + nt;
A= nt;
B= Zt;
Vl= 240;
I2real= DT/Vl
I2img = -acosd(0.9)
I2= I2real*cosd(I2img)+i*I2real*sind(I2img)
Vsource= a*Vl +b*I2
Isource= c*Vl + d*I2
Vload = A*Vsource - B*I2
```

APPENDIX B: CONDUCTOR AND TRANSFORMER DETAILS

Table I. Conductor Data [See Ref.9]

Size	Stranding	Material	DIAM	GMR	RES	Capacity
			Inches	Feet	Ω/mile	Amps
1		ACSR	0.355	0.00418	1.38	200
1	7 STRD	Copper	0.328	0.00992	0.765	270
1	CLASS A	AA	0.328	0.00991	1.224	177
2	6/1	ACSR	0.316	0.00418	1.69	180
2	7 STRD	Copper	0.292	0.00883	0.964	230
2	7/1	ACSR	0.325	0.00504	1.65	180
2	AWG SLD	Copper	0.258	0.00836	0.945	220
2	CLASS A	AA	0.292	0.00883	1.541	156
3	6/1	ACSR	0.281	0.0043	2.07	160
3	AWG SLD	Copper	0.229	0.00745	1.192	190
4	6/1	ACSR	0.25	0.00437	2.57	140
4	7/1	ACSR	0.257	0.00452	2.55	140
4	AWG SLD	Copper	0.204	0.00663	1.503	170
4	CLASS A	AA	0.232	0.007	2.453	90
5	6/1	ACSR	0.223	0.00416	3.18	120
5	AWG SLD	Copper	0.1819	0.0059	1.895	140
6	6/1	ACSR	0.198	0.00394	3.98	100
6	AWG SLD	Copper	0.162	0.00526	2.39	120
6	CLASS A	AA	0.184	0.00555	3.903	65
7	AWG SLD	Copper	0.1443	0.00468	3.01	110
8	AWG SLD	Copper	0.1285	0.00416	3.8	90
9	AWG SLD	Copper	0.1144	0.00371	4.6758	80
10	AWG SLD	Copper	0.1019	0.0033	5.9026	75
12	AWG SLD	Copper	0.0808	0.00262	9.3747	40
14	AWG SLD	Copper	0.0641	0.00208	14.8722	20
16	AWG SLD	Copper	0.0508	0.00164	23.7262	10
18	AWG SLD	Copper	0.0403	0.0013	37.6726	5
19	AWG SLD	Copper	0.0359	0.00116	47.5103	4
20	AWG SLD	Copper	0.032	0.00103	59.684	3
22	AWG SLD	Copper	0.0253	0.00082	95.4835	2
24	AWG SLD	Copper	0.0201	0.00065	151.616	1
1/0		ACSR	0.398	0.00446	1.12	230
1/0	7 STRD	Copper	0.368	0.01113	0.607	310
1/0	CLASS A	AA	0.368	0.0111	0.97	202

2/0		ACSR	0.447	0.0051	0.895	270
2/0	7 STRD	Copper	0.414	0.01252	0.481	360
2/0	CLASS A	AA	0.414	0.0125	0.769	230
3/0	12 STRD	Copper	0.492	0.01559	0.382	420
3/0	6/1	ACSR	0.502	0.006	0.723	300
3/0	7STRD	Copper	0.464	0.01404	0.382	420
3/0	CLASS A	AA	0.464	0.014	0.611	263
3/8	INCH STE	Steel	0.375	0.00001	4.3	150
4/0	12 STRD	Copper	0.552	0.0175	0.303	490
4/0	19 STRD	Copper	0.528	0.01668	0.303	480
4/0	6/1	ACSR	0.563	0.00814	0.592	340
4/0	7 STRD	Copper	0.522	0.01579	0.303	480
4/0	CLASS A	AA	0.522	0.0158	0.484	299
250000	12 STRD	Copper	0.6	0.01902	0.257	540
250000	19 STRD	Copper	0.574	0.01813	0.257	540
250000	CON LAY	AA	0.567	0.0171	0.41	329
266800	26/7	ACSR	0.642	0.0217	0.385	460
266800	CLASS A	AA	0.586	0.0177	0.384	320
300000	12 STRD	Copper	0.657	0.0208	0.215	610
300000	19 STRD	Copper	0.629	0.01987	0.215	610
300000	26/7	ACSR	0.68	0.023	0.342	490
300000	30/7	ACSR	0.7	0.0241	0.342	500
300000	CON LAY	AA	0.629	0.0198	0.342	350
336400	26/7	ACSR	0.721	0.0244	0.306	530
336400	30/7	ACSR	0.741	0.0255	0.306	530
336400	CLASS A	AA	0.666	0.021	0.305	410
350000	12 STRD	Copper	0.71	0.0225	0.1845	670
350000	19 STRD	Copper	0.679	0.0214	0.1845	670
350000	CON LAY	AA	0.679	0.0214	0.294	399
397500	26/7	ACSR	0.783	0.0265	0.259	590
397500	30/7	ACSR	0.806	0.0278	0.259	600
397500	CLASS A	AA	0.724	0.0228	0.258	440
400000	12 STRD	Copper	0.726	0.0229	0.1619	730
450000	19 STRD	Copper	0.77	0.0243	0.1443	780
450000	CON LAY	AA	0.77	0.0243	0.229	450
477000	26/7	ACSR	0.858	0.029	0.216	670
477000	30/7	ACSR	0.883	0.0304	0.216	670
477000	CLASS A	AA	0.795	0.0254	0.216	510
500000	12 STRD	Copper	0.811	0.0256	0.1303	840
500000	19 STRD	Copper	0.814	0.026	0.1303	840
500000	CON LAY	AA	0.813	0.026	0.206	483

556500	26/7	ACSR	0.927	0.0313	0.1859	730
556500	30/7	ACSR	0.953	0.0328	0.1859	730
556500	CLASS A	AA	0.858	0.0275	0.186	560
600000	37 STRD	Copper	0.891	0.0285	0.1095	940
600000	CON LAY	AA	0.891	0.0285	0.172	520
605000	26/7	ACSR	0.966	0.0327	0.172	760
605000	54/7	ACSR	0.953	0.0321	0.1775	750
636000	27/7	ACSR	0.99	0.0335	0.1618	780
636000	30/19	ACSR	1.019	0.0351	0.1618	780
636000	54/7	ACSR	0.977	0.0329	0.1688	770
636000	CLASS A	AA	0.918	0.0294	0.163	620
666600	54/7	ACSR	1	0.0337	0.1601	800
700000	37 STRD	Copper	0.963	0.0308	0.0947	1040
700000	CON LAY	AA	0.963	0.0308	0.148	580
715500	26/7	ACSR	1.051	0.0355	0.1442	840
715500	30/19	ACSR	1.081	0.0372	0.1442	840
715500	54/7	ACSR	1.036	0.0349	0.1482	830
715500	CLASS A	AA	0.974	0.0312	0.145	680
750000	37 STRD	AA	0.997	0.0319	0.0888	1090
750000	CON LAY	AA	0.997	0.0319	0.139	602
795000	26/7	ACSR	1.108	0.0375	0.1288	900
795000	30/19	ACSR	1.14	0.0393	0.1288	910
795000	54/7	ACSR	1.093	0.0368	0.1378	900
795000	CLASS A	AA	1.026	0.0328	0.131	720

Table II Distribution Transformer No-Load (Core Losses) and Load (Copper Losses).

kVA	Phase	Sec. Volt	Primary Voltage	No- Load Losses (W)	Load Losses (W)	Tot. Losses (W)	% Z
15	S	120/240	4800/7620	34	280	314	2.58
25	S	120/240	4800/7620	43	397	440	2.58
50	S	120/240	4800/7620	103	564	667	1.97
100	S	120/240	4800/7620	165	1150	1315	2.10
167	S	120/240	4800/7620	267	1749	2016	2.37
75	3	120/208	4800x13200/7620	283	836	1119	2.43
150	3	120/208	13200/7620	328	2026	2354	2.37
300	3	120/208	13200/7620	639	3198	3837	2.50
500	3	120/208	4800x13200/7620	1140	4085	5225	3.45
1000	3	480Y/277	4160	1160	7601	8761	5.51
1500	3	480Y/277	4800x13200	1516	10294	11810	6.04
2000	3	480Y/277	4800x13200	1894	12933	14827	5.75
333	S	4800/8320	7620/13200	416	2937	3353	3.43
50	S	120/240	7620	107	675	782	1.92
100	S	120/240	7620	173	1074	1247	2.34
167	S	120/240	4800x13200/7620	231	1466	1697	2.72

This table is obtained from the name plate details of transformers of different sizes and capacity.

The values listed are based on ideal current and voltages across the transformer.

REFERENCES

[1] Jenkins, N. (1996). Embedded Generation-Part 2. *IEE Power Engine*, 233-239.

[2] L.Ramesh,S.P.Chowdhury,S.Chowdhury,A.A.Natarajan,C.T.Gaunt. (Jan 2009). Minimization of power Loss in Distribution Netoworks by Different Techniques. *International Journal of Electrical and Power Engineering* .

[3] Milanovic JV, David TM. (2002). Stability of Distribution Networks with Embedded Generators and Induction Motors. *IEEE PES Winter Meeting*, 1023-1028.

[4] U.S. Energy Information Administration. (2010). World Energy Demand and Economic Outlook. *International Energy Outlook*.

[5] T.N.Shukla,S.P.Singh,K.B.Naik. (2010). Allocation of Optimal distributed generation using GA for minimum system losses in radial distribution networks. *International Journal of Engineering,Science and Technology vol 2,No.3*, 94-106.

[6] Welch, C. (n.d.). *Fossil Fuels.* http://www.solcomhouse.com/fossilfuels.htm.

[7] Dugan R.C., McDermott T.E. and G.J. Ball. (2001). Planning for distributed generation. *IEEE Industrial Application Magazine vol 7*, 80-88.

[8] Department of Energy. (2000). Carbondioxide Emissions fromt the Generation of Electric power in the United States. *Environmental Protection Agency*.

[9] Patzek, T. W. (2002). *Energy Conversion: Typical Heat Values of Various Fuels.* Berkeley.

[10] Daniel A. Yarano& Alexandra L. Mertens. (2009). American Recovery and Reinvestment Act. *Wind Energy Provisions*.

[11] Hassan, A. Y. (1986). Islamic Technology:An illustrated history. In A. Y. Hassan, *Islamic Technology:An illustrated history* (p. 54). Cambridge University Press.

[12] Price, T. (2003). James Blyth – Britain's first modern wind power pioneer. *Wind Engineering vol 29 no.3*, 191-200.

[13] Brush, C. F. (2007). *A Wind Energy Pioneer.* Danish Wind Industry Association.

[14] Gipe, P. (1999). *Wind Energy Basics Revised: A Guide to Home- and Community-scale Wind Energy Systems.* Chelsea Green.

[15] Gipe, P. (2004). *Wind Power: Renewable Energy for Home, Farm and Business.* Vermont: Chelsea Green Publishing CompanyBrush, C. F. (2007). *A Wind Energy Pioneer.* Danish Wind Industry Association.

[16] T.Burton, D.Shape,N.Jenkins,E.Bossanyi. (2001). *Wind Energy Handbook.* Wiley.

[17] Patel, M. R. (2006). *Wind and Solar Power Systems.* Taylor and Francis Group Second Edition.

[18] Weibull.*Wind Speed Distribution.* http://www.reuk.co.uk/Wind-Speed-Distribution-Weibull.htm.

[19] Mathworks. *http://www.mathworks.com/help/toolbox/stats/wblpdf.html.*

[20] Nothern Power Systems (2009). *Specificaitons of Northwind100.* http://northernpower.com/wind-power-products/northern-power-100-wind-turbine.php.

[21] Alan Mullane, G.Lightbody,R.Yacamini. (2001). Adaptive Control of Variable Speed Wind Turbines. *Power Engineering*, 101-110.

[22] M.V. Bakshi, U.A. Bakshi. (2008). *Elements Of Power Systems.* Pune: Technical Publications.

[23] Kersting, W. H. (2002). *Distribution System Modeling and Analysis.* Florida: CRC Press LLC.

[24]. *Electrical Engineering Training Series losses in transmission lines*(2003). Integrated publishing and reviewing : http://www.tpub.com/neets/book10/41b.htm.

[25] EnergyInformationAdministration. (December 2009). *Annual Energy Outlook 2010.*