

Investigation of Optimal Allocation of Wind DG in Distribution System

A Dissertation submitted in fulfillment of the requirements for the Degree
of

MASTER OF ENGINEERING
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Submitted by

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DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "Investigation of Optimal Allocation of Wind DG In Distribution System", in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of Ms. Manbir Kaur. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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ABSTRACT

Distributed Generation (DG) has gained more importance to meet the increased load demand. Its integration in a distribution system in comparison to conventional system stacks numerous potential benefits related to losses reduction, improvement in voltage profile, etc. Some of the issues of distributed generation is its rating, technology, sizing, siting, mode of operation, penetration level, etc. The thesis focuses on one of the issue that is optimal allocation of DG unit as the placement of dg unit at non-optimal places leads to increase in system loss and reduction in bus voltage profile. Alternative sources of energy based distributed generation has one of the considerable benefit as environmental friendliness. Hence, allocation of distributed generation units in proper place is an important aspect for maximizing the benefits stated above. Analysis of distribution network using power flow study plays an important role in the power system. The optimal location of wind based dg unit is determined using newton raphson method for obtaining the voltage profile with the analytical approach. The analytical expression used are based on exact loss formula. The proposed methodology has been tested and validated on IEEE 14 bus and 33 bus distribution systems. Results are obtained for normal load and with the increased load. The outcomes shows that by proper placement of wind based dg unit at relevant bus location the real power losses are minimized and corresponding bus voltages are improved.

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LIST OF NOMENCLATURE

SYMBOL	DESCRIPTION
P_w	Active power in the wind
C_p	Power coefficient
v_{cin}	Cut in speed
v_{cou}	Cut out speed
V_r	Rated speed
P	Air density(1.225 kg/m ³)
A	Swept area of the blade in m ²
R	Radius of blade
λ	Tip speed ratio
L	Length of the blade
Ω	Angular speed of wind turbine
P_m	Mechanical power of wind turbine
P	Active power in MW
Q	Reactive power in MVAR
F	Rated frequency in Hz
P_{loss}	Real power loss
Q_{loss}	Reactive power loss
NB	Number of buses
NV	Number of PV buses
IT	Number of iterations
R_{ik}	Resistance in ohms
X_{ik}	Reactance in ohms
V	Bus voltage magnitude
P_{DG}	Real power generation from Distributed generation
P_D	Real power demand

LIST OF ABBREVIATIONS

ABBREVIATIONS	CLARIFICATIONS
DG	Distributed Generation
IEA	International Electrical Agencies
DR	Distribution Resources
HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
FSWT	Fixed Speed Wind Turbine
VSWT	Variable Speed Wind Turbine
SCIG	Squirrel Cage Induction Generator
WRIG	Wound Rotor Induction Generator
PMSG	Permanent Magnet Synchronous Generator
WRSG	Wound Rotor Synchronous Generator
DFIG	Doubly Fed Induction Generator
ULTC	Under Load Tap Changing
WECS	Wind Energy Conversion System
GA	Genetic Algorithm
K.E.	Kinetic Energy
WG	Wind Generator
PSO	Particle Swarm optimization

CHAPTER - 1

INTRODUCTION

1.1 Overview

Since last decade, Distributed Generation (DG) emerges as an innovative technology as it provides instant and clean electrical energy. It is situated on the customer side of the network or within distribution networks. In simple terms it can be termed as small-scale electricity agencies. DG can be defined as, [1]

“Distributed generation is considered an electrical source connected in a point very close to/or customer site and small enough in comparison with the centralized power plants.”

Continuous growth of DG units is because of environmental concerns, advantages due to integration with the traditional network and minimization in the capital investment due to technological investment.

1.1.1 Benefits of DG unit

The growing needs of DG unit in a system is due to the following advantages mentioned below:

- (a) Flexibility in reliability needs,
- (b) Flexibility in power quality needs,
- (c) Environmental friendliness,
- (d) Substitute for grid investments,
- (e) Lesser installation time
- (f) Easy start up.

1.1.2 Challenges of DG

Of the various benefits stated above certain challenges related to distributed generation are as follows:

- (a) Designing Issues: Requires efforts to redesign as there is change in pattern of power low, voltage magnitude.
- (b) Issue of network: Distribution network and transmission system have different design purpose.
- (c) Balancing of power: DSO should manage reactive generation due to intermittent nature of some DG sources.
- (d) Power Quality: Converters used to connect DG technologies as harmonics may be generated further causing disturbances on the grid.

- (e) Configuration Issues: The different in connection and also geographical constraints. DG installation needs power converters, proper protection schemes, more capital costs etc.

Major issues of Distributed Generator are its rating, technology, sizing, sitting, mode of operation, penetration level, etc.[2]

1.2 Distribution System

For providing power to consumer a system known as distribution system is tie between transmission system and consumer service. Figure 1.1 shows the system elements.

- (a) Substation: Distribution system is fed through substation. It is of various designs.
- (b) Distribution Transformers: Voltage level are step down to a level that is useful for consumers.
- (c) Feeders: A feeder connects the sub-station and area where power is distributed.
- (d) Distributor: Transferring power between distributor to consumer centers through a conductor. AB., BC., CD. and DA. in figure below are distributor.
- (e) Service mains: Distributors and the consumer premises have cables in between are service mains.

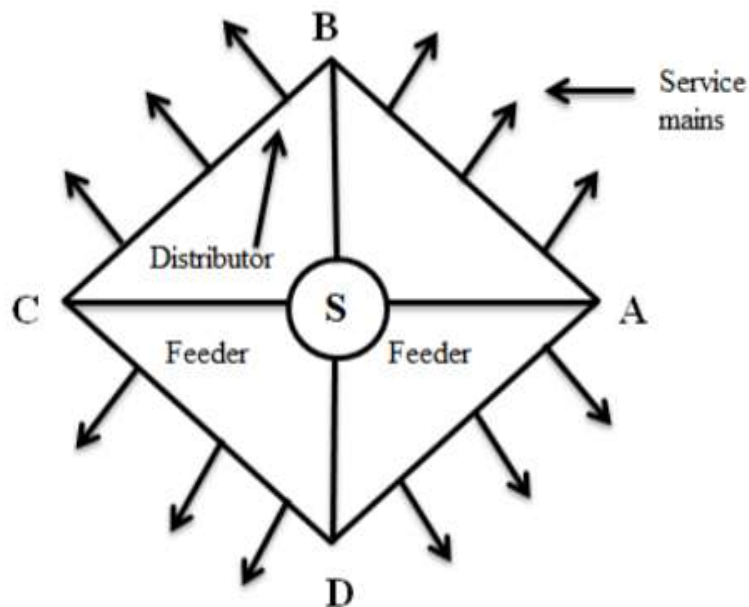


Figure 1.1 Distribution system

1.3 Literature Review

Various researchers analyzed impact of DG in system, wind generation effect in system, various solution and methodologies for obtaining the optimal location are discussed.

N. S. Rau *et al* [1] discussed installation of DG that leads power losses reduction and voltage profile improvement. The method proposed illustrates that proper placement that will have positive effects.

Laxmi Srivastava *et al.* [2] have elaborated the DG types.

Thomas Ackermann [3] investigated issues and aims of distributed power in competitive electricity markets.

M.H. Nehrir *et al.* [4] has investigated wind power DG addition to a distribution system resulting reduction in system losses for normal loads.

Keane *et al* [5] discussed a linear programming based method and discusses technical constraints. Result showed that siting is an important factor.

Mahat *et al.* [6] analyzed methodology for proper location of DG and used exact loss formula. The solution methodology was efficient as losses calculation were faster.

Victor *et al.* [7] formulaated an expression for variations in system losses with different levels of DG penetration. Also showed that the variation of losses is a function penetration level of DG.

Tring *et al.* [8] Developed relation of real power and voltage for voltage stability. ABCD parameters of distribution line through a grid is formulated.

Rajesh Katyal [9] provided detailed analysis of Indian wind grid code.

Fariba Shavakhi Zavareh *et al.* [10] provided information about wind generators impact on quality of power.

Mahmoud ebadian *et al.* [11] analyzed impact of wind farm on grid and their effect with regards to the inability of reactive power generation. The test is performed using IEEE 9 bus system.

I. S. Naser *et al.* [12] presented an analysis about impact of wind generation with different penetration levels on IEEE30-bus network. For investigating wind energy VCPI, is used.

Federico Milano [13] presented time domain simulations using static and dynamic continuous power flow technique networks for higher penetration of wind.

Kun yang *et al.* [14] carried an analysis to express the effect of wind generation with different levels of penetration on voltage profile on network. Results showed that effect of the different wind penetration level can affect favorably as well as unfavorably in the requirement of reactive power as well as voltage profile of system.

Sayed M. Sayeed et al. [15] studied voltage stability and transient stability of electric power system performed with determining the optimum location and rating of wind turbine. Test was performed on IEEE 9 bus system.

Willis [16] suggested 2/3 rule to determine DG size and placement on system with uniform load. Illustrated that a DG unit if placed at 2/3 distance out on the feeder reduce system losses.

K. N. Miu *et al.* [17] investigated scheme of a switch placement for minimizing system losses by DG placement with single and multiple number of DG units.

Nabavinaki *et al.* [18] suggested a method for proper location of DG units. The improvement in voltage profile and enhancement of power transfer capacity were handled through implementation of compensators and larger DG.

Kumar *et al.* [19] suggested optimization approach that is nonlinear with reduce fuel cost in electricity market with DG placement.

Atwa *et al.* [20] analyzed a method to determine optimally mix fuel of all DG types for energy losses reduction in system. But lack accuracy problem for higher quality solution.

Bansal *et al.* [21] obtained size and corresponding p.f. of various DG units and validated in different systems with size variation and complex. Outcome yielded that method had less computational time in comparison with exhaustive load flow method.

Singh *et al.* [22] suggested multi-location dg problem to reduce active power losses in system. The results found in this method showed that with proper DG placement had better voltage of buses.

Harrison *et al.* [23] discussed strategy of managing active network that control voltage, p.f.

C.J.Dente *et al.* [24] demonstrated the influence of voltage step limits with DG connected. The constraints of voltage steps were incorporate with flow of power for obtaining capacity of network.

Khodr *et al.* [25] discussed probabilistic approach in finding proper place of DG for change in hours. The methodology had been used in real systems for validation and demonstrates efficiency of method.

Goswami et al. [26] Discussed methodology based on nodal pricing variant as well as invariant loads. Analysis was for single and DG in multiple numbers. The results showed DG unit in smaller size better in comparison to the larger DG unit size.

Safigianni *et al.* [27] suggested methodology with modification in the network structure for multiple number of DG units location.

Akorede *et al.* [28] suggested an effective method for DG location in system. The fuzzy controller was used that reducing chance of GA convergence. Outcomes yielded that DG is proper alternative compared to substations upgradations.

Abu-Mouti and El-Hawary [29] discussed an optimization approach for size, location and power factor of DG. Comparison was done with other techniques.

Moradi and Abedini [30] formulated an approach with evolutionary method to find location of DG units.

Khatod *et al.* [31] presented technique based on EP for DG units. Results analyzed the importance of smaller size dg units compared to larger dg units.

Garcia and Mena [32] proposed an algorithm for the locating DG units. Evolutionary algorithm has been used with comparison to other algorithms.

Dehghanian *et al.* [33] analyzed approach based on multi objective where DG influences in placement were considered.

Sajjadi *et al.* [34] proposed technique where connection of DG units and capacitors have losses decrement and voltage stability was taken as objective function.

Mithulananthan *et al.* [35] presented expressions for sizes and locating DG units. With analyzing time varying demand. The result showed that proposed method is sufficient for loss reduction.

Mistry and Roy [36] proposed an approach with constriction factor for DG units connected. Results showed integration with multiple number of units reducing system losses.

Karimyan *et al.* [37] presented scheduling technique for sizing of DG unit in system. Feeder loads were increased with increased in size of dg units. The results analyzed that proper dg placement had reduction in active and reactive power losses.

Choudhury [38] discussed DG placement for reduction in loss and better voltage profile in system also effect of loads change along with voltage and frequency were considered.

1.4 Gap of the Study

Different works explained in literature survey about the placement of DG in a system but the extended work on this topic that marked as gap of the study is given below:

- A detailed analysis of the performance done on the normal load and varying load.
- The technique used is analytical approach as different techniques like GA gives near results but being computationally demanding and slow in convergence.

1.5 Objective

The main objective is to obtain optimum location of wind based DG unit with magnitude of voltage of the buses within limits and reduction in power losses.

1.6 Scope of the work

- To implement the Newton Raphson method for obtaining the voltage magnitude and angles.
- Obtaining the voltage magnitude with varying load.
- Wind DG placement on different buses for maintaining voltages within limits and reduction in losses.
- Detailed analysis of the performance of these methods carried on IEEE-14 & 33 bus systems for explaining effectiveness of the proposed techniques.

1.7 Organization of Work

This thesis has been organized into six chapters:

Chapter 1 includes DG benefits, key issues of DG, explained works carried out by different researchers, objective along with gap of study.

Chapter 2 discusses about distributed generation its definition, different types of DG, classification of Wind turbine and its modeling.

Chapter 3 explains about the needs of optimum location of DG, its benefits in system and its impact on the voltage profile and location and sizing issue of DG on power losses.

Chapter 4 discusses the methodology used, algorithm of the proposed method.

Chapter 5 analyze the results and discussion in detail about the performance of the system being used.

Chapter 6 is summarize as conclusion of the results and it also includes future scope.

CHAPTER - 2

DISTRIBUTED GENERATION

2.1 Introduction

DG refers to small scale power generation that are near to consumers or nearby distribution system. Often DGs are named as distributed resources (DR). But DR is purported to technologies that are not generating. [3] The categorization of DG based on the ratings is exemplified in figure 2.1.

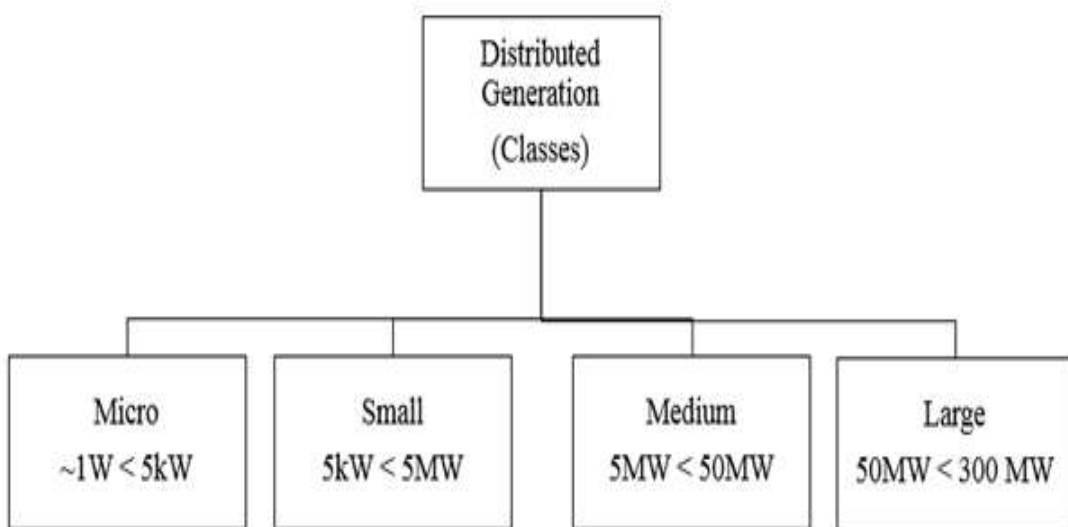


Figure 2.1: DG classification

2.2 Benefits of DG

DG unit integration have numerous advantages that are stated below:

- They are connected nearer to consumer side and helps in reducing losses of transmission.
- Increased load growth needs more generation i.e., met by DG units without increasing conventional generators generation.
- DGs are smaller in size and devices with better flexibility with easy installation.
- Each unit of DG can be functioned individually with not at all affecting operation failure of other unit's. Generation can made more or less with the addition or removal of DG unit in the system.
- Reduces the need of capacitors and voltage regulators with lesser cost of maintenance
- Without any external source of electricity easy to start DG.

2.3 Types of Distributed Generation

DGs are of different types as exemplified in figure.2.2 [1]

2.3.1 Conventional Generator

Output of micro turbine ranges from (25- 500) KW. Made from truck turbochargers or APUs. Often referred as combustion turbines. Accounting about the advantages of Microturbines compact size, light weight, fewer emissions, and the lower capital.

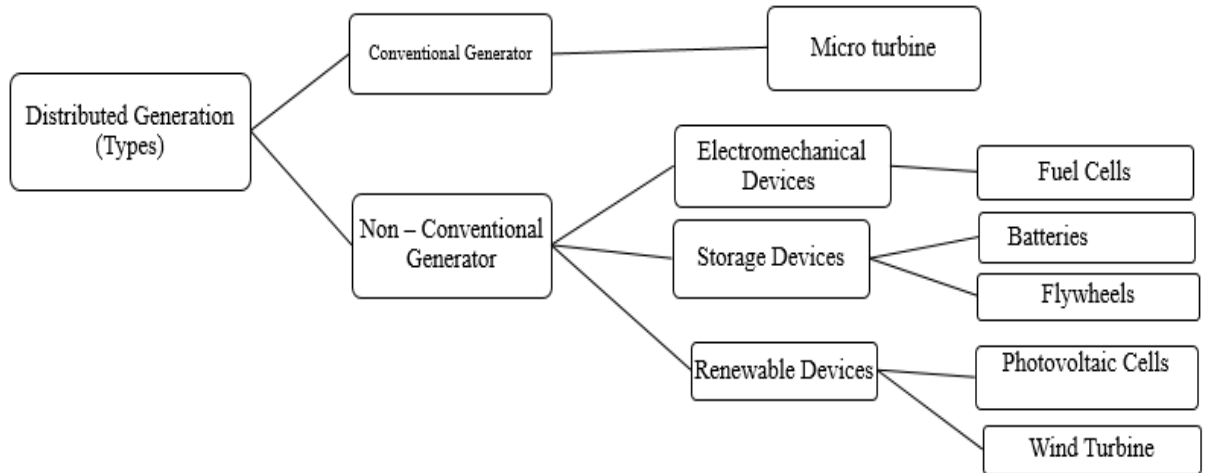


Figure 2.2: Types of DG

2.3.2 Non-Conventional Generator

This types of generators include electromechanical, renewable and storage device.

- (i) Electrochemical Devices: FC generate electricity through electrochemical processes converting chemical energy to thermal energy. The capacity of fuel cells ranges from 5 kW to 5 MW. It provides clean power.
- (ii) Storage Devices: These device are flywheels, batteries that are charged and it's used is when required. Storage with other DG types reduce demand during peak load. For protection from overcharge batteries have a charging controller which when full charge disconnects the charging process.
- (iii) Renewable Devices: These are mainly photovoltaic and Wind turbines. Solar radiation are used for generating energy. Wind generator generates electricity using wind power.

2.4 Wind based Distributed Generation

Wind source have gained more importance as DG sources. Wind has enhanced both stand-alone and grid-connected configurations. A detailed analysis with addition of wind source to system. [46] Generally, on weak parts of the systems wind power generated have positive effects.

2.4.1 Benefits of wind power

Wind source have numerous advantages that includes,

- Cleaner and unending source
- Local financial development
- Standard and scalable technology
- Minimize dependability on conventional fuels

2.5 Wind Turbine Classification

The classification of wind turbines are on the basis of their constructional feature and on the basis of their speed.

Constructional feature

- Horizontal Axis Wind Turbine
- Vertical Axis Wind Turbine

Wind speed

- Fixed Speed Wind Turbine
- Variable Speed Wind Turbine

2.5.1 Horizontal Axis Wind Turbine

HAWT is shown in figure.2.3 where on tower top lies main shaft of rotor. Gearbox converts low rotation into faster rotation. Blades are made rigid in order to avoid so that didn't droved by higher wind speed. Also, the considerable distance are maintained to place the blades.

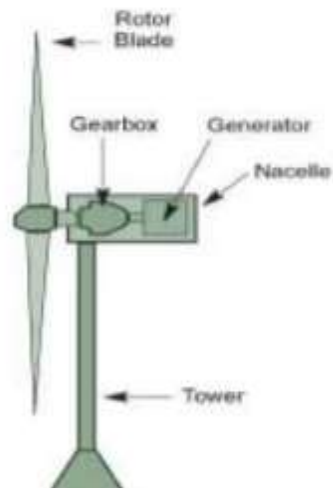


Figure 2.3: Horizontal Axis wind turbine

2.5.2 Vertical Axis wind turbine

VAWT is shown in figure.2.4, rotor shaft are vertically arranged. And due to this arrangement to be effective the turbine need to be pointed into the wind. On the sites with highly variable wind speed this types of wind turbines are used as this can utilize winds from each directions. As generator and gearbox are close to ground so, easy for maintenance.

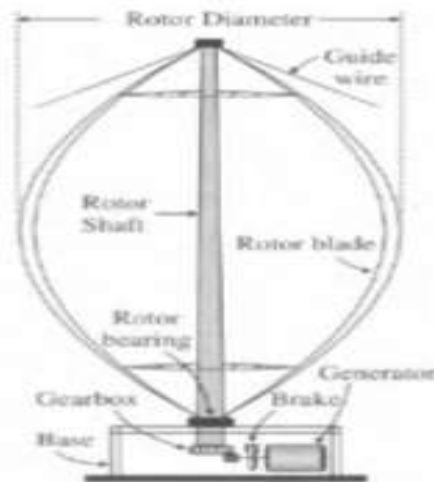


Figure 2.4 Vertical axis wind turbine

2.5.3 Fixed speed wind turbine

Schematic diagram is shown in figure 2.5. Generators are connected to grid directly. For reducing inrush current during start up a soft starter is used. The reactive power demand is reduced by a reactive power compensator.

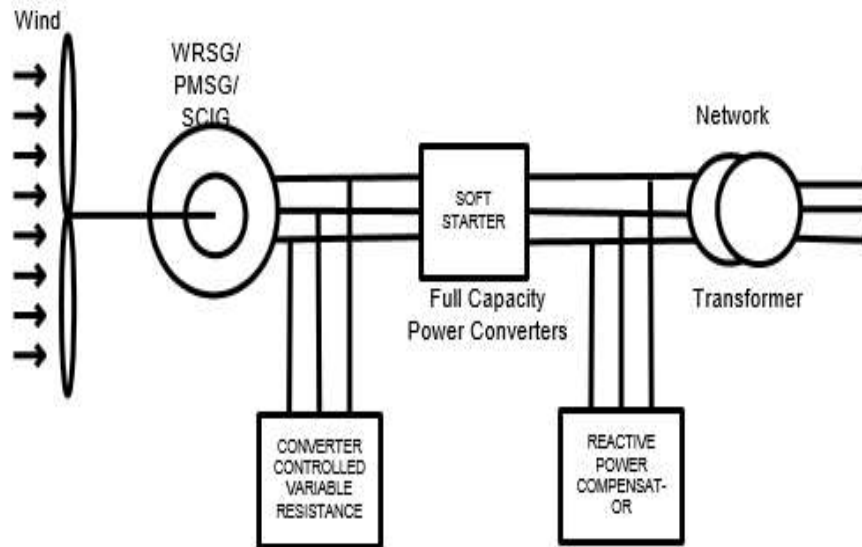


Figure 2.5 Fixed speed wind turbine

The speed of wind is made constant to the grid, for which wind turbulence will result variation in power affecting grid power quality. Advantage of a fixed speed wind turbine is that it is, simple in construction and due to which the investment cost is minimum.

2.5.4 Variable speed wind turbine

Power electronic equipment are used to control generator that makes it possible to control rotor speed. The power fluctuations due to variable wind speed are absorbed by change in rotor speed. Another advantage to be mention is that wind turbines varies the reactive generation which controls the grid voltage. The major disadvantage is that power electronics sensitive factor to faults or change in switch.

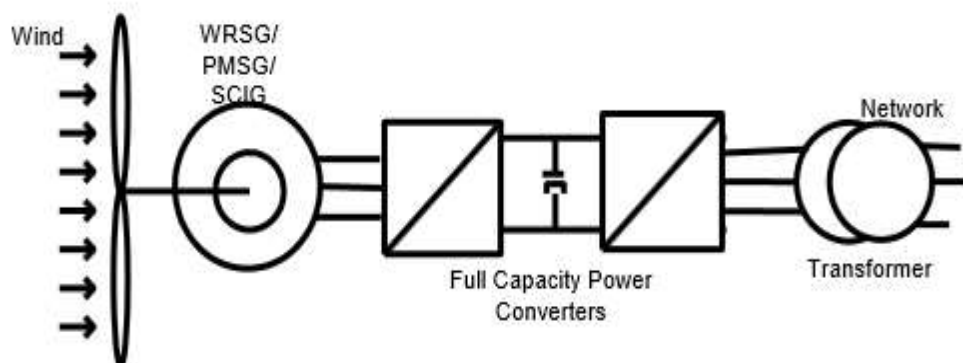


Figure: 2.6 Variable speed wind turbine

2.6 Wind Turbine Modeling

Explained the mathematical model of wind turbine along with the power characteristics.

2.6.1 Model of wind energy

Wind turbines production of electricity is due to wind power that helps generator to rotate. K.E. is extracted by wind turbine from blades. Wind power is given by,

$$P_{wind} = \frac{1}{2} \rho A v^3 \quad (2.1)$$

Where

ρ is air density (1.225 kg/m³),

A is area of blade and

v is the wind speed.

As all K.E. are not pull out from the wind mean air would stand still. Wind turbine reduces speed and it extracts a fraction of P_w expressed as power efficiency coefficient (C_p).

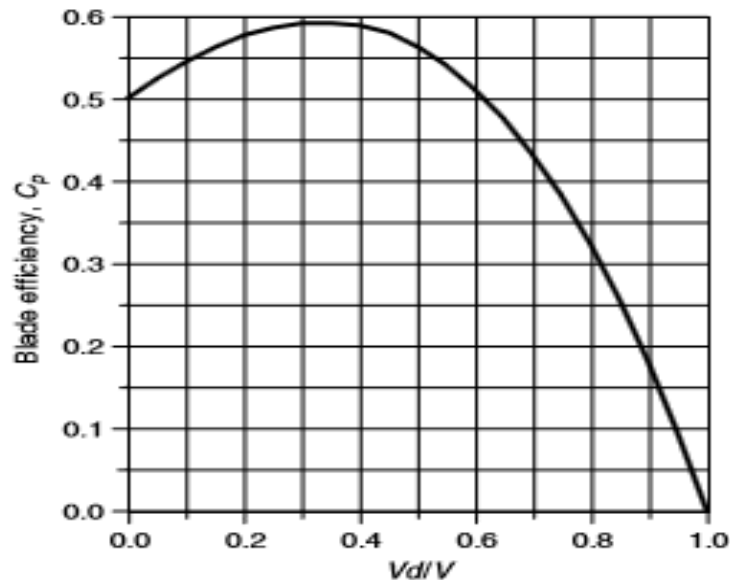


Figure 2.7: Power coefficient vs speed ratio

The power coefficient (C_p) basically describes the efficiency and values varies between 0.3-0.45. Therefore, power output turbine is given by,

$$P_{wind} = \frac{1}{2} \rho A v^3 C_p \quad (2.2)$$

It can be observed from figure 2.7 that maximum efficiency of rotor is 59.3%, known as the Betz efficiency.

2.6.2 Power Characteristics of Wind Turbine

Figure 2.9 shows the operating mode of wind turbine,

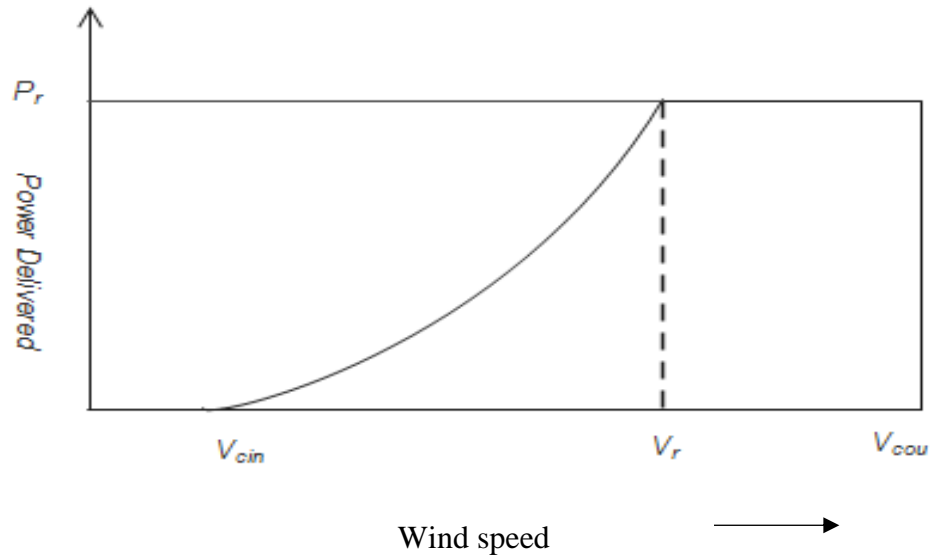


Figure 2.8 Operating mode of wind turbine

The P_w is the mechanical power being generated and v_w is the wind speed. At V_{cin} turbine operates. At V_r turbine produces nominal power equal to the rated output. At V_{cou} turbine is allowed to operate before being shut down. In order to prevent the damage from excessive wind the turbine must be stopped above the cut-out speed.

The variation of wind power output with wind speed is expressed in equation (2.3).

$$P_w = \begin{cases} 0, & v < v_{cin} \\ \frac{1}{2} A v_r^3 C_p, & v_{cin} < v_r < v_{cou} \\ 0, & v > v_{cou} \end{cases} \quad (2.3)$$

No power is generated at wind speeds that is below cut in speed; at wind speeds between rated speed and cutout speed the output power is same as the rated power of the generator; above cut out speed the turbine is shut down. For, delivering the power to grid at different wind speeds, there is need to properly control the wind generator with variable speed operation when the speed of wind reaches beyond the rated speed.

CHAPTER – 3

OPTIMAL LOCATION OF DISTRIBUTED GENERATION

3.1 Introduction

The major issue is to minimize losses as maximum measure of power generated is squared as losses. 70% of losses occurs in distribution side and 30% of losses occurs in transmission lines. In order to enhance the overall proficiency there is need to belittle losses. The measure being taken for minimization of system losses in distribution side: [46]

(a) Compensation of reactive power

It is generally employed at load side or substation. With the compensation of the Var the current flow will be minimum that will leads to reduction in power losses.

(b) Feeders Reinforcement

In distribution system, power is stepped down and then fed to distribution transformer through feeders. If the feeder length is more it will lead to increment in power loss and high voltage regulation. In this a large feeder is divided into smaller feeders such that the losses in the existing feeder will minimized.

(c) Conductors grading

With the increase in the resistance of conductor leads to increment in losses. As resistance is proportional on length and area of cross – section of conductor hence needs proper section of the size of conductor. In conductors grading technique, the replacement of conductor is accessed by current carrying capacity of the conductor.

(d) Network reconfiguration

This method is normally used for low voltage distribution system with the basic key of operation is switching operation. In this tie switch is closed in order to transfer the load from one feeder to another. Allows balancing of loads, voltage profile improvement, losses reduction, etc.

(e) Placement of Distributed Generation

DG allocation techniques are employed in interconnected systems where distributed resources are available that can be either renewable sources i.e. wind, solar, biomass etc. or non-renewable sources that is diesel engine, micro turbine. Allocation of these in improper place have negative effect on system loss costs, etc.

Among the following placement of dg units have gained more importance for enhancing the power quality, reliability and system security. Along with generating active power also provides services like voltage regulation. With the minimization of losses accompanies easier utilization of fossil fuel and will led to reduced emission of air pollutant and greenhouse gasses. [41] DG connection needs to consider its type, number, capacity, optimal location, network connection etc. Needs appropriate evaluation of DG impact in network operation characteristics.

3.2 DG units - types

DGs have their own characteristics. Subjected to active and reactive power generation capabilities categorized as: [42]

Type - 1: Can inject only active power. Photo voltaic, fuel cell, micro turbine comes in this category. The units can increased the MWh profit but did not support the voltage profile improvement in the system.

Type - 2: Capable of injecting both active and reactive power such as voltage source converter based dg unit, dg unit based synchronous machine.

Type - 3: Inject active power but consume reactive power and also supports in voltage profile improvement. Induction generator based wind farms are categorized as type 3.

3.3 Placement of DG

Number of studies indicate the selection of location of DG in non – optimal place leads to maximize system losses as compared to system without DG. Hence, with the optimum location of DG utilities have an advantage of system loss reduction with better voltage profile [6]

Various issues are faced by power system such as high loss, poor power quality and low reliability apart from meeting the increased load demand day by day and in all that issues DG is considered as one of the viable option. More, than that standard and smaller size DG will allow system planner to integrate it in lesser time in comparison to conventional solution. Proper DG location can be consider as optimum compensation of active power as capacitor

placement for reactive power compensation. Unlike capacitor placement DG placement has emerged relatively new.

3.4 Location and sizing issues

Figure 3.1 shows variation in the power loss with the change in size of DG.

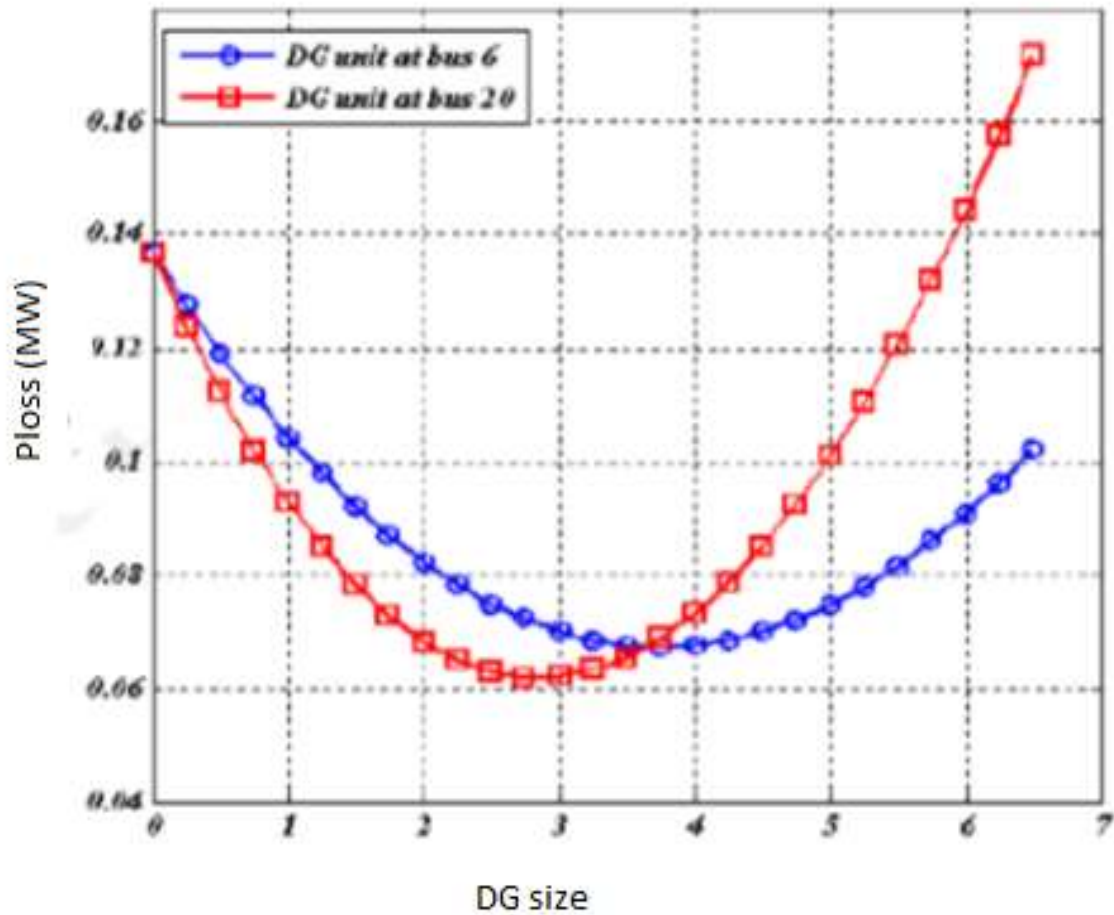


Figure 3.1: loss v/s DG size

From figure shown above it can be stated that for bus, with increase in DG capacity there is reduction in losses but as size is increased more system losses and more increased in size leads overshooting of losses found in base case. Utmost the size be within the boundary of distribution system.

If an effort is made to integrate DG of higher capacity with intention of power exportation beyond the substation will lead higher system losses. Hence, undoubtedly size of distribution system plays key role in the placement. The losses is mainly due to reason that it was initially deign so that flow of power is via sending end to load and there is gradual decrement of sizes of conductor. Hence, use of higher size will result excess flow of power in the conductors of smaller sized that will lead to increase in system losses.

CHAPTER - 4

SOLUTION METHODOLOGY

4.1 Introduction

The proper siting and sizing of wind unit leads to loss minimization with voltage within limits. The proposed method of location of wind-based unit is discussed. The wind- DG comes in type - 3. The bus is treated as load buses where it is connected. In this methodology load flow analysis calculated for two times, one for the base case that is without and with DG placement to obtain final solution.

4.2 Computational Procedure

For obtaining the optimum location of the wind DG the methodology used includes the following steps:

- 1 Run load flow without wind DG.
2. Compute the voltage profile, angles and losses of the system.
3. Increment in load in step of 10% to obtain weakest buses.
4. Load flow analysis to obtain voltage profile after DG placement
5. Compute losses after placement of DG.
6. Find bus with minimum loss.
7. End process.

4.2.1 Flow Chart of the proposed method

Figure 4.1 illustrates flow chart of the method for obtaining optimum location of wind DG unit in system with the objective of voltage within the limits and loss reduction for normal load and varying loading conditions

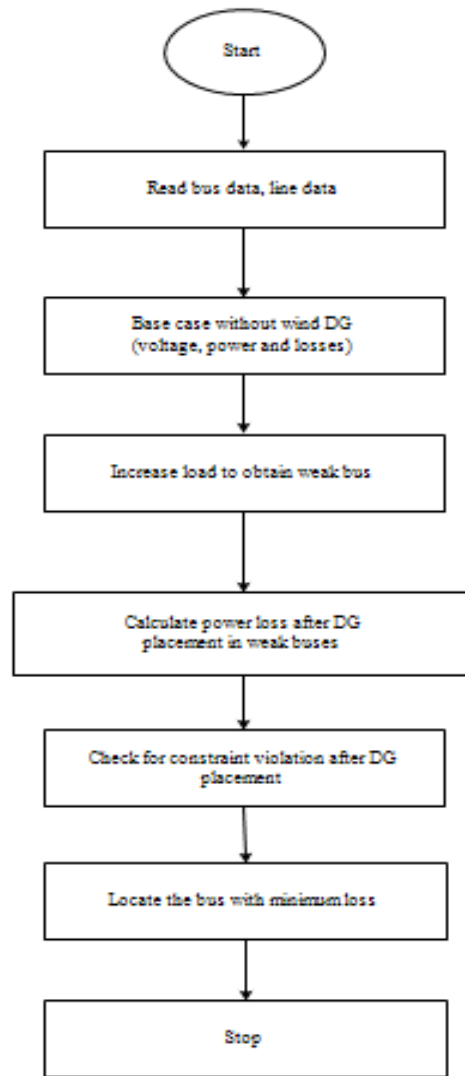


Figure 4.1 Flow chart.

4.3 LOAD FLOW ANALYSIS

4.3.1 Purpose of Load-flow Studies

The load flow calculation is mainly done to obtain steady-state analysis of system. by checking if voltages are in limits under normal state or contingency conditions. To find if there is any need to add more generation, capacitive, or inductive VAR support. Also necessary to plan in advance, economic schedule, power exchange.

4.3.2 Newton Raphson Method

The load flow solution must satisfy the following non-linear algebraic equations

$$f_i(V, \delta) = 0 \quad (4.1)$$

At each bus except slack bus real and reactive power needs to be evaluated

$$f_i(V, \delta) = P_i^s - P_i(V, \delta) = 0 \quad \text{For all PQ and PV buses} \quad (4.2)$$

$$f_i(V, \delta) = Q_i^s - Q_i(V, \delta) = 0 \quad \text{For all PQ buses} \quad (4.3)$$

The computational procedure for Newton Raphson method is as follows [45]:

1. Read bus data, line data, IT (number of iterations), ϵ (tolerance in convergence).
2. Ybus formation.
3. Initially, $|V_m|$ ($m=NV+1 \dots NB$) and δ_i ($m=2,3, \dots, NB$)
4. Iteration count set to $R = 0$;
5. Compute $P_k, \Delta P_k$ using

$$P_k = \sum_{n=1}^{nb} V_m V_n [G_{mn} \cos(\delta_m - \delta_n) + B_{mn} \sin(\delta_m - \delta_n)] \quad (m = 2, 3, \dots, nb)$$

$$\Delta P_k = P_k^s - P_k \quad (m = 2, 3, \dots, nb)$$

Compute $Q_k, \Delta Q_k$ using

$$Q_k = \sum_{n=1}^{nb} V_m V_n [G_{mn} \sin(\delta_m - \delta_n) - B_{mn} \cos(\delta_m - \delta_n)]$$

$$\Delta Q_k = Q_k^s - Q_k$$

6. If $\max |\Delta P_k|$ ($m = 2, 3, \dots, nb$) and $|\Delta Q_k|$ ($m=nv+2, nv+3 \dots nb$) $\leq \epsilon$ then GOTO step 15
7. Compute Jacobian matrix elements

When $m = n$

$$H_{mm} = \frac{\partial P_k}{\partial \delta_m} = -Q_k - B_{mm} V_m^2$$

$$N_{mm} = V_m \frac{\partial P_k}{\partial V_m} = P_k + G_{mm} V_m^2$$

$$J_{mm} = \frac{\partial Q_k}{\partial \delta_m} = P_k - G_{mm} V_m^2$$

$$L_{mm} = V_m \frac{\partial Q_k}{\partial V_m} = Q_k - B_{mm} V_m^2$$

When $m \neq n$

$$H_{mn} = \frac{\partial P_k}{\partial \delta_m} = V_m V_n [G_{mn} \sin(\delta_m - \delta_n) - B_{mn} \cos(\delta_m - \delta_n)]$$

$$N_{mn} = V_k \frac{\partial P_k}{\partial \delta_m} = V_m V_n [G_{mn} \cos(\delta_m - \delta_n) + B_{mn} \sin(\delta_m - \delta_n)]$$

$$J_{mn} = \frac{\partial Q_k}{\partial \delta_m} = V_m V_n [-G_{mn} \sin(\delta_m - \delta_n) - B_{mn} \cos(\delta_m - \delta_n)]$$

$$L_{mn} = V_k \frac{\partial Q_k}{\partial \delta_n} = V_m V_n [G_{mn} \sin(\delta_m - \delta_n) - B_{mn} \cos(\delta_m - \delta_n)]$$

8. Compute $\Delta\delta_m$ ($m = 2, 3, \dots, nb$) and $\frac{\Delta V_m}{V_m}$ ($m = nv + 1, nv + 2, \dots, nb$) using

$$\begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \frac{\Delta V}{V} \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

9. Modify δ_m and V_m ,

$$\delta_m = \delta_m + \Delta\delta_m \quad (m = 2, 3, \dots, nb)$$

$$V_m = V_m + \frac{\Delta V_m}{V_m} V_m \quad (m = nv + 1, nv + 2, \dots, nb)$$

10 Set bus count $m=2$

11. If PQ bus then check limits of V_i and set according

$$V_m = V_m^{\min} \quad \text{if } V_m < V_m^{\min}$$

$$V_m = V_m^{\max} \quad \text{if } V_m \geq V_m^{\max}$$

12 If PV bus then compute Q_i and check the limits of Q_i and set accordingly

$$Q_k = Q_k^{\min} \quad \text{if } Q_k \leq Q_k^{\min}$$

$$Q_k = Q_k^{\max} \quad \text{if } Q_k \geq Q_k^{\max}$$

If limits are violated then PV bus is converted temporarily into PQ bus using

$$\Delta V_m = \frac{V_m}{L_{mm}} \left[\Delta Q_k - \sum_{n=2}^{nb} J_{mn} \Delta\delta_n - \sum_{\substack{n=nv+1 \\ n \neq 1}}^{nb} L_{mn} \frac{\Delta V_n}{V_n} \right]$$

And specified voltage magnitude of PV bus is updated as

$$V_m = V_m^s + \Delta V_m$$

13. Increment bus count, $m = m+1$

If $m \leq nb$ then GOTO step 11

14. Advance the count $R = R + 1$

If $r \leq R$ then GOTO step 5 and repeat

15. Active and reactive power computation of slack bus

$$P_1 = \sum_{n=1}^{nb} V_1 V_n [G_{1n} \cos(\delta_1 - \delta_n) + B_{1n} \sin(\delta_1 - \delta_n)]$$

$$Q_1 = \sum_{n=1}^{nb} V_1 V_n [G_{1n} \sin(\delta_1 - \delta_n) - B_{1n} \cos(\delta_1 - \delta_n)]$$

16. Stop.

4.4 Calculation of losses by analytical approach

To have reduction in losses by proper allocation of wind- DG unit in system. The objective function can be modeled mathematically as

$$\text{Min } S_{loss} = \sum_{i=1}^N P_{loss} + Q_{loss} \quad (4.4)$$

Exact real power loss is given by

$$P_{loss} = \sum_{i=1}^N \sum_{k=1}^N [a_{ik} (P_i P_k + Q_i Q_k) + b_{ik} (Q_i P_k + P_i Q_k)] \quad (4.5)$$

Where,

$$a_{ik} = \frac{R_{ik}}{V_i V_k} * [\cos(\delta_i - \delta_k)]$$

$$b_{ik} = \frac{R_{ik}}{V_i V_k} * [\sin(\delta_i - \delta_k)]$$

Exact Reactive power loss is given by

$$Q_{loss} = \sum_{i=1}^N \sum_{k=1}^N c_{ik} (P_i P_k + Q_i Q_k) + d_{ik} (Q_i P_k - P_i Q_k) \quad (4.6)$$

Where,

$$c_{ik} = \frac{X_{ik}}{V_i V_k} * [\cos(\delta_i - \delta_k)]$$

$$d_{ik} = \frac{X_{ik}}{V_i V_k} * [\sin(\delta_i - \delta_k)]$$

R_{ik} and X_{ik} are obtained from the Z bus matrix

$$Z_{ik} = R_{ik} + jX_{ik} \quad (4.7)$$

Where,

P_i, Q_i , are active and reactive power flow at bus i in kW and kVAR

P_k, Q_k are active and reactive power flow at bus k in kW and kVAR

R_{ik}, X_{ik} are resistance and reactance of line connecting i^{th} and k^{th} bus

V_i and V_k are bus voltage magnitude at bus i and bus k respectively

δ_i and δ_k are bus voltage angle at bus i and bus k respectively

4.4.1 Operational Constraints

Objective function is to satisfy the operational constraints they are

- (a) Equality Constraints
- (b) Inequality Constraint

(i) Equality constraints

Active and Reactive power balancing constraints are in relation to power flow equation that are nonlinear

The power balance constraints is formulated as follows

$$P_{DGk} = P_{Dk} + P_k \quad (4.8)$$

$$Q_{DGk} = Q_{Dk} + Q_k \quad (4.9)$$

Where,

P_{DGk} , active power generation by DG placed at bus k.

Q_{DGk} , reactive power generation from DG placed at bus k

(i) Inequality Constraints

Inequality Constraints lies between acceptable limits to satisfy the objective function.

As there is dependency of voltage with reactive power. Hence, the operating voltage profile of each bus should be within the limits.

Limits of bus voltage

Bus voltage limit is given by

$$V_{k \min} \leq V_k \leq V_{k \max} \quad (4.10)$$

Where,

$V_{k \min}$ and $V_{k \max}$ are minimum and maximum voltage respectively.

V_k is the voltage in k^{th} bus.

Capacity of DG

The capacity of DG is given as follows

$$P_{DGk \min} \leq P_{DGk} \leq P_{DGk \max} \quad (4.11)$$

Where,

$P_{DGk \min}$ and $P_{DGk \max}$ are minimum and maximum generation in kW

CHAPTER 5

RESULTS

5.1 INTRODUCTION

In this chapter analysis is being done for proper location of wind DG unit. Test systems are IEEE - 9 bus, IEEE - 14 bus and IEEE - 33 bus systems for investigation of study.

In first case test performed on IEEE 9 bus system in PowerWorld simulator and hit and trial methodology has been used to find the optimum location in 9 bus system.

In second case NR is used to obtain initial voltage and angle. The losses are calculated with the exact loss equation formulated in sections 4.3 and 4.4. Weakest buses, are obtained by increasing the loads in steps, which is, 25% load increment for IEEE 9 bus and 10% increment for IEEE 14 and 33 systems. With that priority list can be formed instead of performing analysis on all the buses. It will save the computational time as the DG will be connected at the buses that are more sensitive.

In order to arrive at the optimum bus location the following system parameters are investigated:

- (i) Steady-state voltage magnitudes and angle at each bus.
- (ii) Real power losses.

The outcomes are yielded for the following cases:

- (i) Performance of the system without wind DG unit with normal load and increased loading conditions.
- (ii) Performance of the system with wind DG unit.

5.2 Test system I: IEEE 9 bus

5.2.1 Performance of the system without installation of wind generator

IEEE 9 bus test system is shown in figure 5.1 consisting of three generator bus, three load buses and nine transmission lines. The data of the system is listed in appendix – A.

Total Real Power Loading: 259 MW

Total Reactive Power Loading: 73.5 MVar

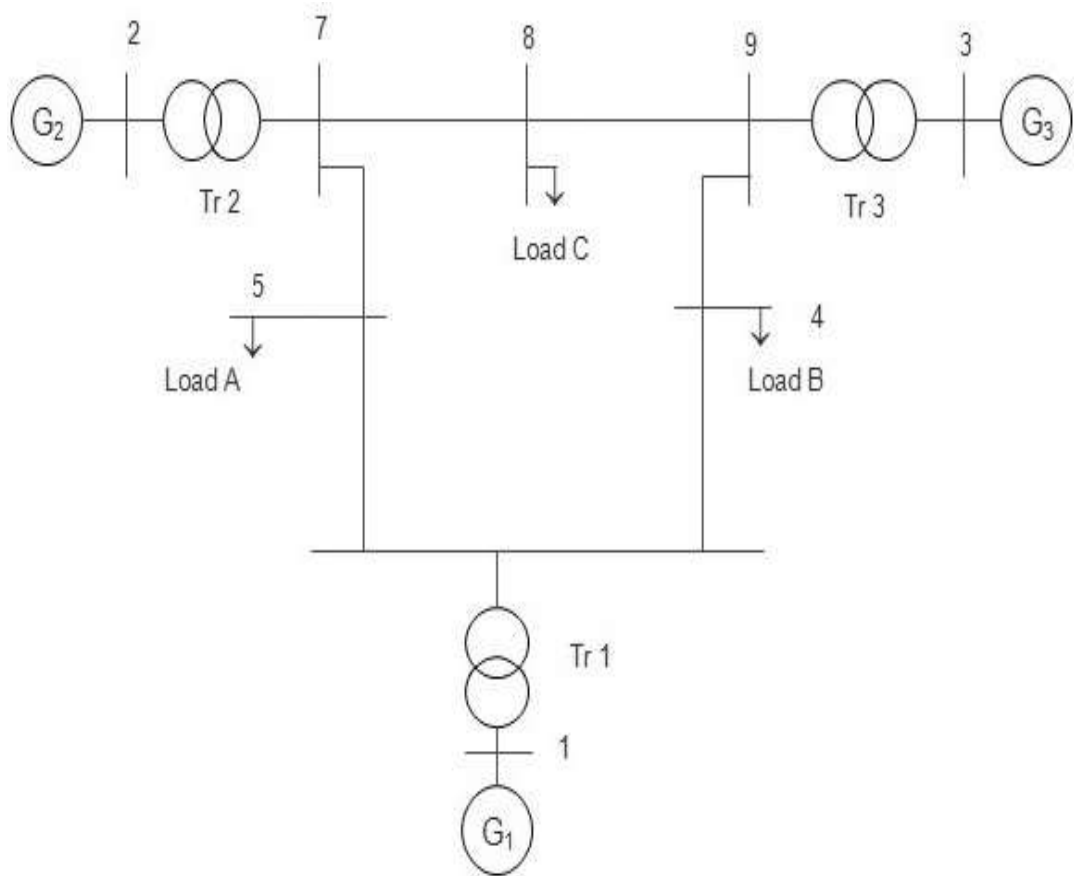


Figure 5.1 IEEE 9 bus single line diagram

The load flow analysis on the test system is performed with variation in load demand from 25% to 100%. The result obtained is tabulated in table II.

Table 5.I Voltage profile of the buses

Bus No.	Normal load		25% load increase	
	Voltage	Angle	Voltage	Angle
1	1.040	0.0	1.040	0.0
2	1.025	0.9280	1.025	0.363
3	1.025	0.4665	1.025	-0.85
4	1.025	-0.2217	1.016	-0.469
5	0.995	-0.398	0.977	-0.860
6	1.012	-0.3368	0.997	-0.799
7	1.025	-0.3720	1.017	-0.198
8	1.015	-0.728	1.002	-0.552
9	1.032	0.1907	1.02	-0.357

Bus No.	50% load increase		100% load increase	
	Voltage	Angle	Voltage	Angle
1	1.040	0.0	1.040	0.0
2	1.025	-0.236	1.025	-0.1263
3	1.025	-0.675	1.025	-0.17446
4	1.002	-0.726	0.971	-0.1134
5	0.95	-0.1345	0.908	-0.2062
6	0.975	-0.1260	0.924	-0.2100
7	1.00	-0.802	0.984	-0.1843
8	0.986	-0.1216	0.949	-0.2413
9	1.01	-0.949	0.99	-0.2021

* voltage are in p.u. and angle in deg

5.2.2 Performance of the system with wind generators at different locations with varying load conditions

The wind generators are connected at load buses that is at bus no 5, 6 and 8 and the change in voltage profile in the buses is shown. As this buses were found to be weakest buses. In order to obtain the optimal location for wind generator for varying loading conditions.

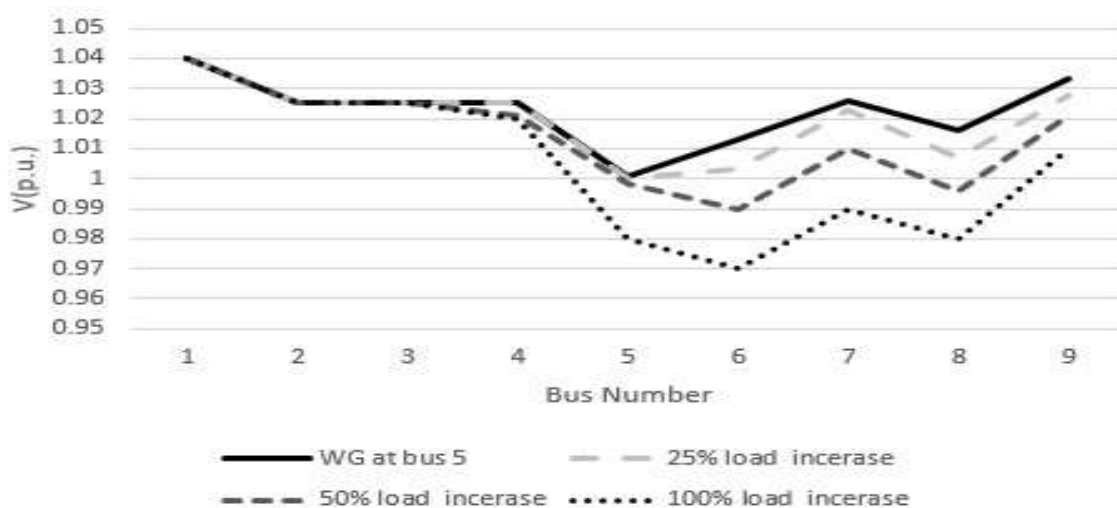


Figure 5.2 Voltage profile with WG at bus 5

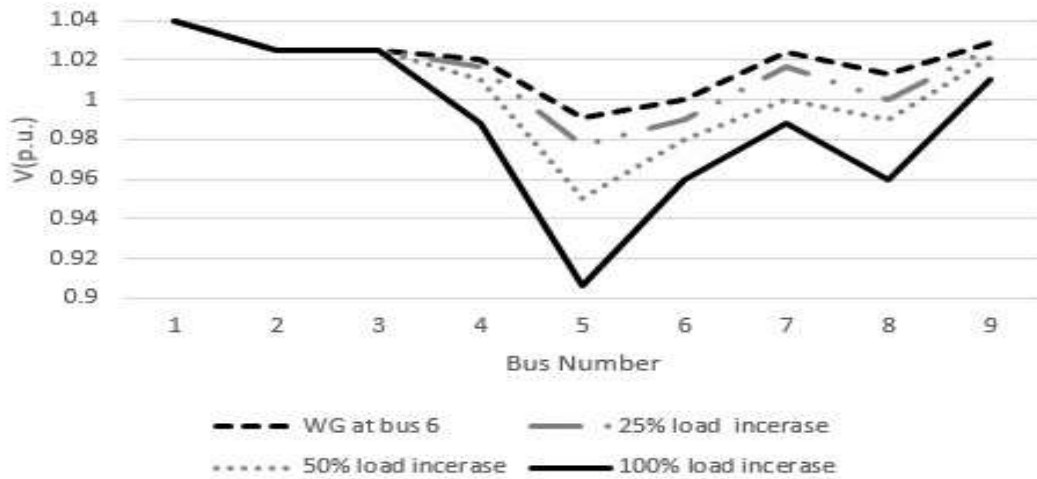


Figure 5.3 Voltage profile with WG at 6th bus

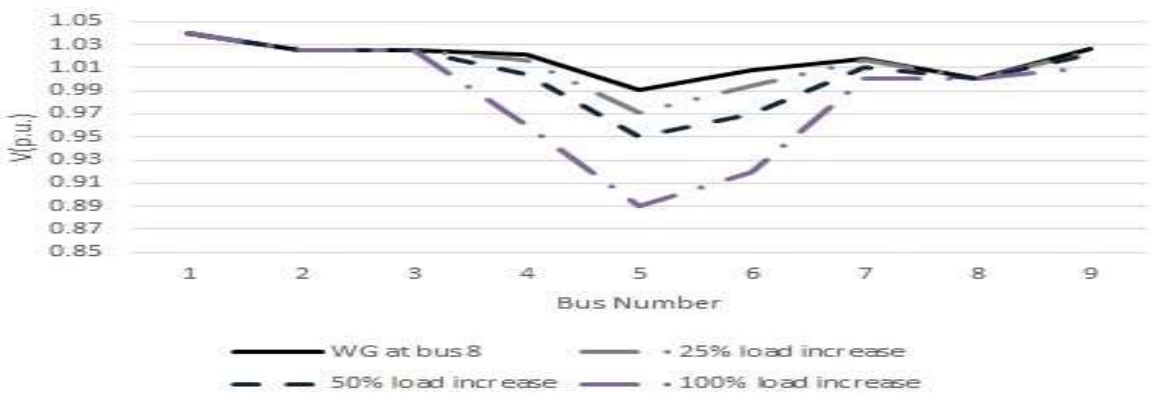


Figure 5.4: Voltage profile with WG at 8th bus

It was observed from figures 2, 3 and 4 that voltage profile of the buses are better when the wind generator was connected at the bus 5 wherein, connected at buses 6 or 8. In order to enhance the voltage stability, the best location of wind turbine is the weakest bus which contains the largest load and that is bus 5.

5.2.3 Network with wind generator with variation in wind power and load in a day at different penetration level

Increased in load demand up to 150% and wind source penetration is being investigated and results are depicted in figures 5 and 6. It can be analyzed from figure 5 and 6 that the system is within the limit at lower wind penetration.

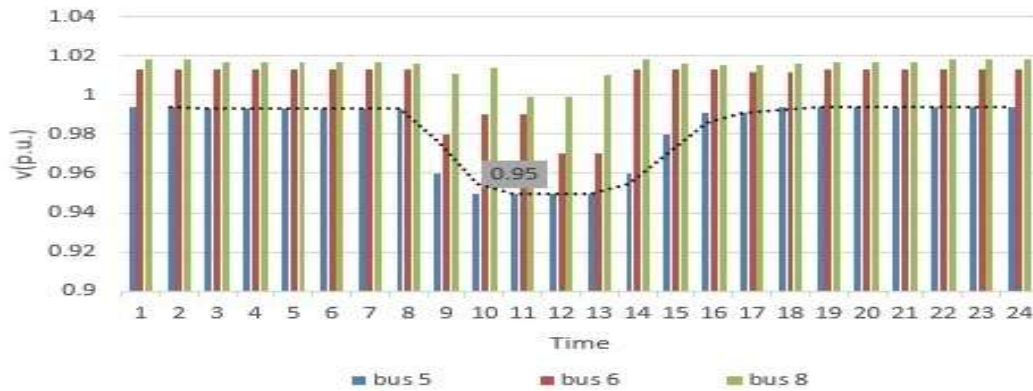


Figure 5.5: Voltage at different buses with lower penetration level

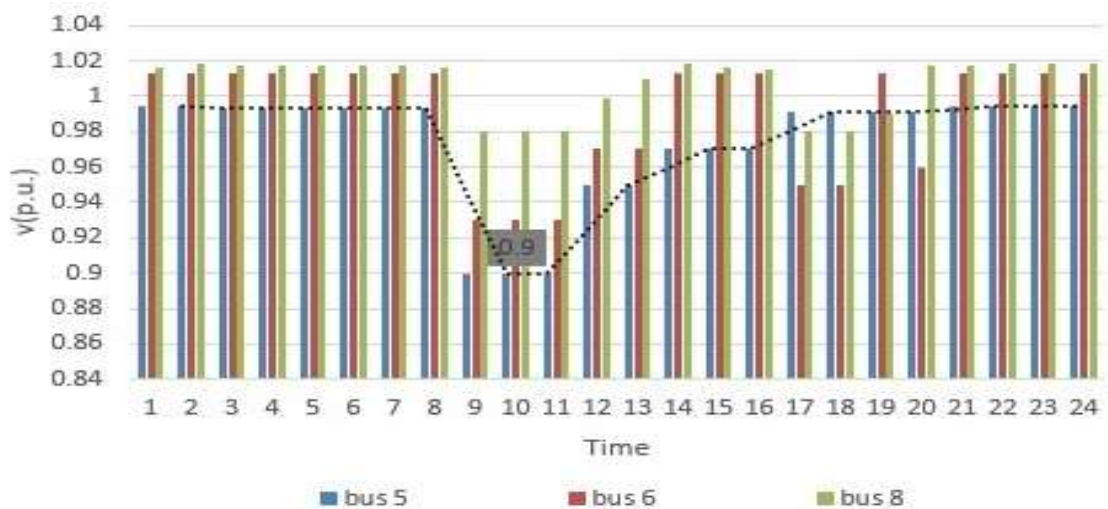


Figure 5.6: Voltage at different buses with higher penetration level

5.2.3 System losses

Active power losses were calculated with and without wind generator at different locations and it is found that it is minimum when connected at bus 5.

Table 5.2 Active Power Losses

Cases	Active power loss (MW)
Without WG	4.6
WG at bus 5	4.5
WG at bus 6	4.7
WG at bus 8	5.1

It can be derived from the graphs and tabulated results that the voltage profile obtained at bus 5 is more prominent than it is at bus 6 and bus 8 at different loading condition. The voltage profile of the buses are in limit at lower penetration level than higher penetration levels.

Losses are also minimum when connected at bus number 5. Location of wind generator at Bus 5 can be considered as the optimum choice. It can thus be concluded that optimum location and penetration level of wind generator are to be consider for a better system voltage profile.

5.3 Test system II: IEEE 14 bus

5.3.1 Performance of the system without installation of wind DG

Standard IEEE-14 bus system is shown in figure 5.7 consisting of six generator bus, nine load buses and twenty lines. The generator buses are 1, 2, 3, 6 and 8 with the slack bus connected to node 1.

Total Real Power Loading: 259 MW

Total Reactive Power Loading: 73.5 MVar

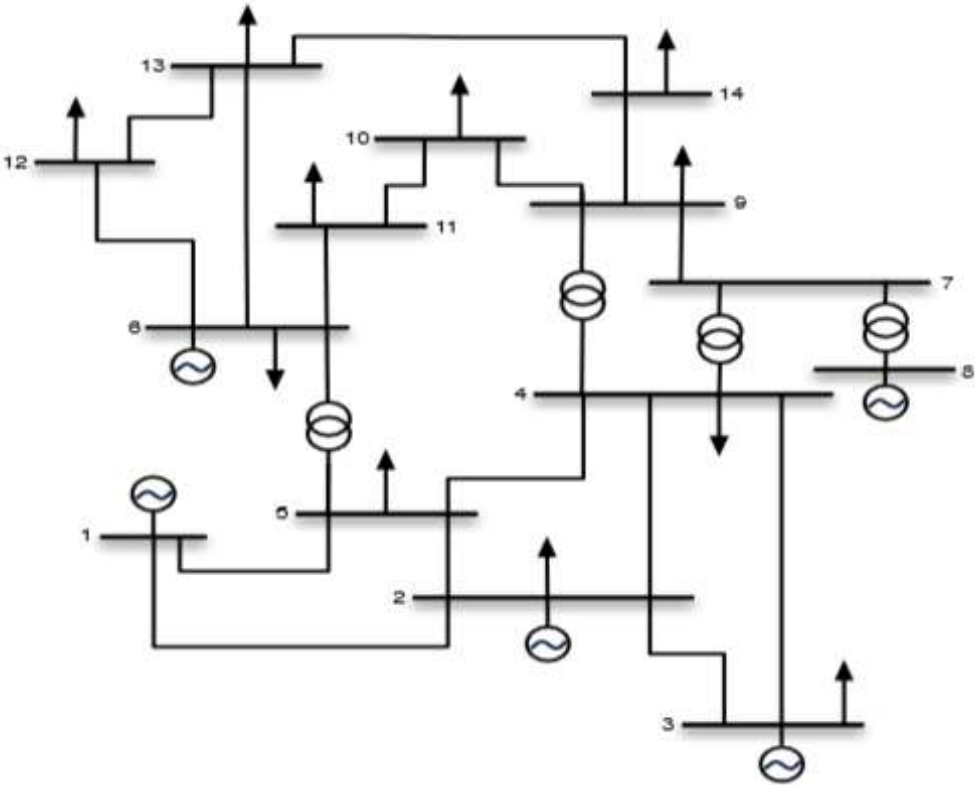


Figure 5. 7: IEEE 14 bus single line diagram

Table 5.3 Voltage profile and angle of the buses for normal and increased load

Bus No.	Normal load		10% load increment	
	Voltage	Angle	Voltage	Angle
1	1.06	0.0	1.06	0.0
2	1.045	-0.0871	1.025	-0.1223
3	1.01	-0.2225	0.98	-0.297
4	1.0132	-0.1788	0.9824	-0.2607
5	1.0166	-0.1529	0.988	-0.22
6	1.07	-0.2521	1.04	-0.3561
7	1.0457	-0.231	1.017	-0.3297
8	1.08	-0.231	1.06	-0.3297
9	1.035	-0.2587	0.999	-0.3661
10	1.029	-0.2624	0.9972	-0.3723
11	1.0461	-0.2593	1.013	-0.3682
12	1.0533	-0.267	1.02	-0.3771
13	1.0466	-0.2676	1.0127	-0.3782
14	1.0193	-0.2805	0.9813	-0.3983

* voltage are in p.u. and angle in deg

Table 5.4 Voltage profile and angle of the buses with increased load

Bus No.	20% load increment		30% load increment	
	Voltage	Angle	Voltage	Angle
1	1.06	0.0	1.06	0.0
2	1.015	-0.1457	0.995	-0.1986
3	0.96	-0.3531	0.96	-0.4739
4	0.964	-0.3152	0.9325	-0.4194
5	0.9717	-0.2674	0.9399	-0.3571
6	1.04	-0.445	1.02	-0.5842
7	1.0029	-0.4055	0.978	-0.5274
8	1.05	-0.4055	1.04	-0.5274
9	0.9859	-0.4528	0.9578	-0.5834
10	0.9856	-0.4647	0.9573	-0.595
11	1.0072	-0.4628	0.9826	-0.6017
12	1.017	-0.4737	0.9918	-0.626
13	1.0071	-0.4742	0.9808	-0.6235
14	0.9669	-0.495	0.9362	-0.6454

*voltage are in p.u. and angle in deg

5.3.2 System performance with installation of Wind DG

With installation of wind - DG unit the change in voltage profile on the increased loads is given

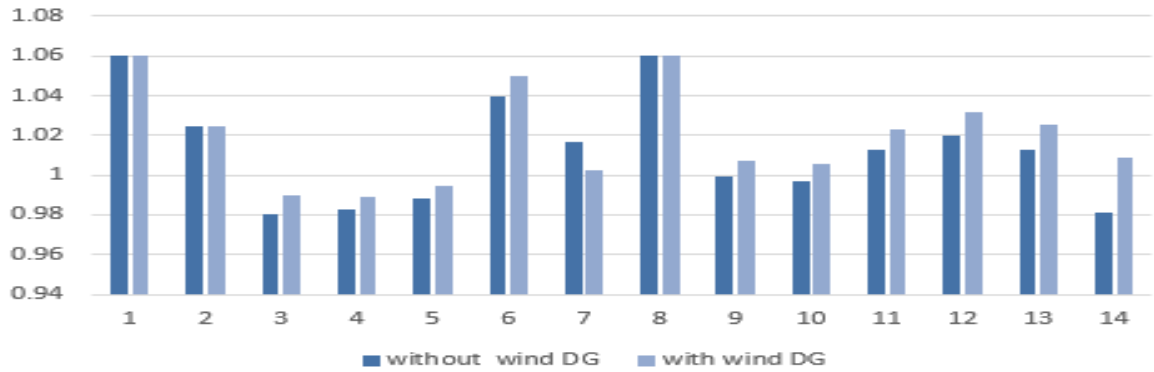


Figure 5.8: voltage with and without wind DG with 10% loads increment

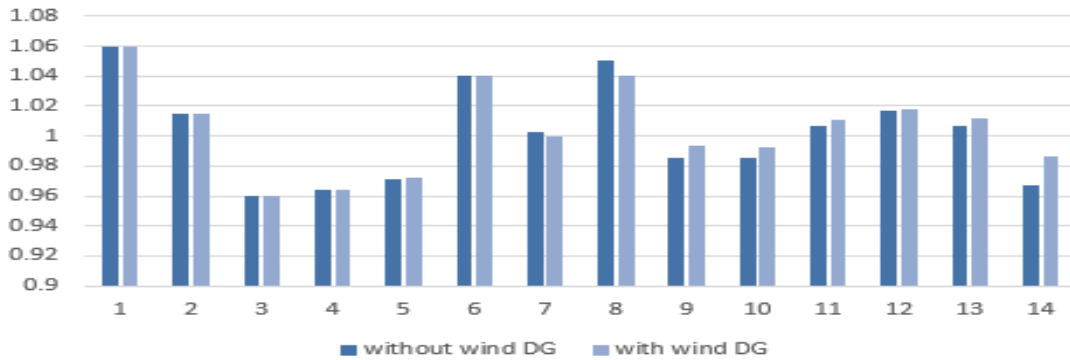


Figure 5. 9: voltage with and without wind DG with 20% load increment

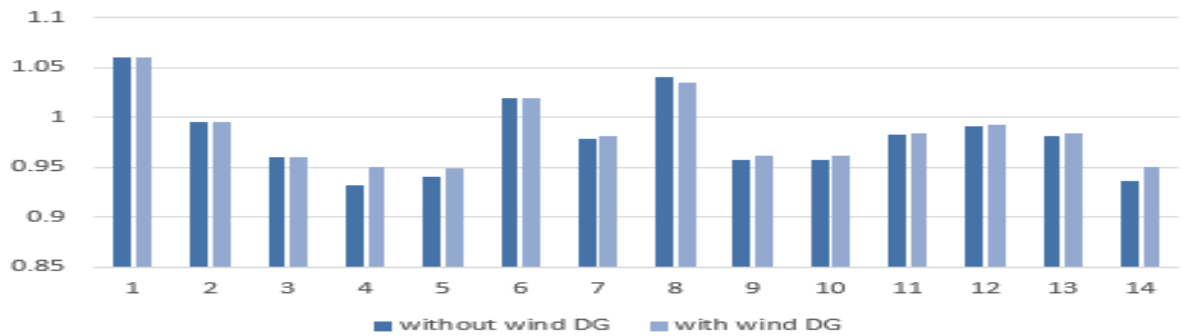


Figure 5. 10: voltage with and without wind DG with 30% load increment

Table 5.5 Reactive power in bus with and without wind DG

Bus No	Reactive Power without wind-DG	Reactive Power With wind-DG
1	17.5297	16.8281
2	31.5787	26.1725
3	20.6127	18.6297
4	3.9	3.9
5	-1.6	-1.6
6	18.8908	17.0354
7	0	0
8	26.305	23.6116
9	-16.6	-16.6
10	-5.8	-5.8
11	-1.8	-1.8
12	-1.6	-1.3
13	-5.8	-2.5
14	-5	-2

5.3.2 Losses with the wind DG located at different location

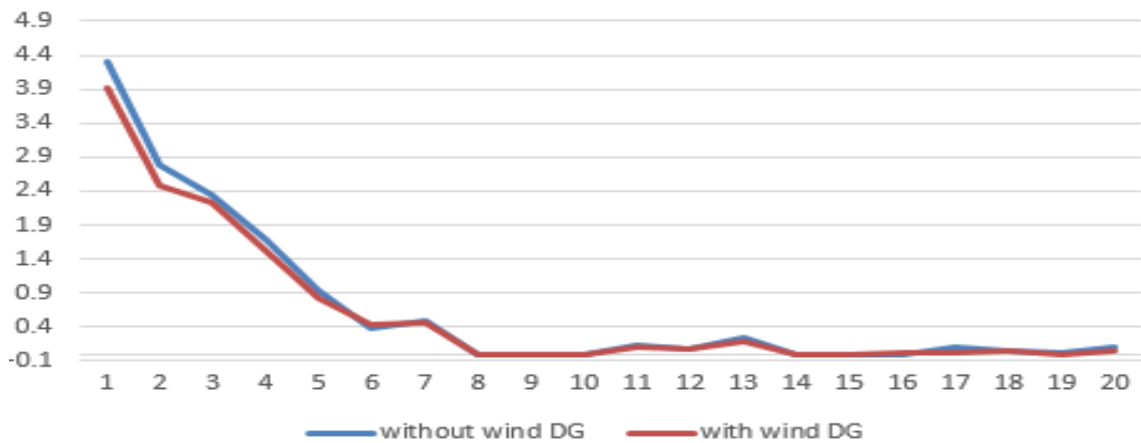


Figure 5.11: Active power line losses

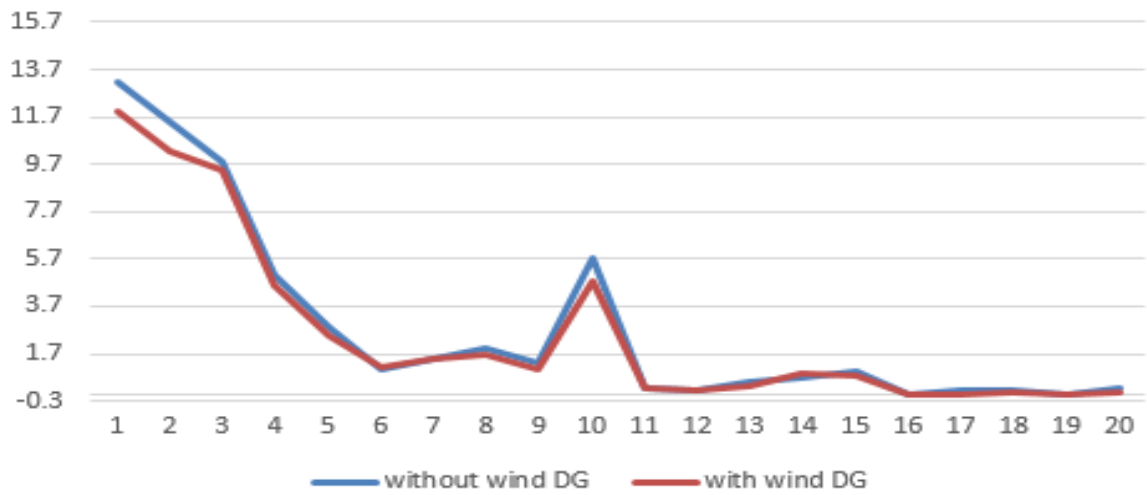


Figure 5.12: Reactive power line losses

It can be resulted from the table and figures given above that the system voltage profile are within the limits with the installation of wind DG unit and losses are minimized when wind DG unit was connected at bus 14.

Table 5.6 Voltage profile of the buses

Bus No.	Normal load		10% Load increment	
	Voltage	Angle	Voltage	Angle
1	1.00	0	1.00	0
2	0.9916	0.0444	0.9907	0.057
3	0.9791	0.0532	0.9742	0.1501
4	0.9676	-0.0193	0.9586	0.1501
5	0.9595	-0.1909	0.9468	0.0308
6	0.9496	-0.5958	0.9267	-0.31
7	0.9496	-0.5958	0.9209	-0.3714
8	0.9496	-0.5958	0.9178	-0.363
9	0.9428	-0.5636	0.8994	-0.2253
10	0.9334	-0.6699	0.8782	-0.2231
11	0.9317	-0.6734	0.8749	-0.1938
12	0.9304	-0.6884	0.8724	-0.174
13	0.9282	-0.6125	0.8702	-0.087
14	0.918	-0.588	0.8888	-0.0624
15	0.9218	-0.4794	0.8638	0.0461
16	0.9186	-0.3551	0.8606	0.1704
17	0.914	-0.2231	0.8545	0.3024
18	0.913	-0.2231	0.854	0.3024
19	0.9901	0.0831	0.9892	0.0957
20	0.9846	-0.0674	0.9838	-0.0548
21	0.9831	-0.1205	0.9822	-0.1079
22	0.9831	-0.1205	0.9822	-0.1079
23	0.9779	0.1033	0.973	0.2002
24	0.9779	0.1033	0.973	0.2002
25	0.9779	0.1033	0.973	0.2002
26	0.9492	-0.5732	0.9263	-0.2874
27	0.9487	-0.5417	0.9258	-0.2559
28	0.941	-0.5278	0.9181	-0.242
29	0.9348	-0.6833	0.9119	-0.3975
30	0.9299	-0.6844	0.907	-0.3986
31	0.9187	-0.79	0.8958	-0.5042
32	0.9177	-0.9049	0.8948	-0.6191
33	0.9177	-0.9049	0.8948	-0.6191

* voltage in p.u. and angle in deg

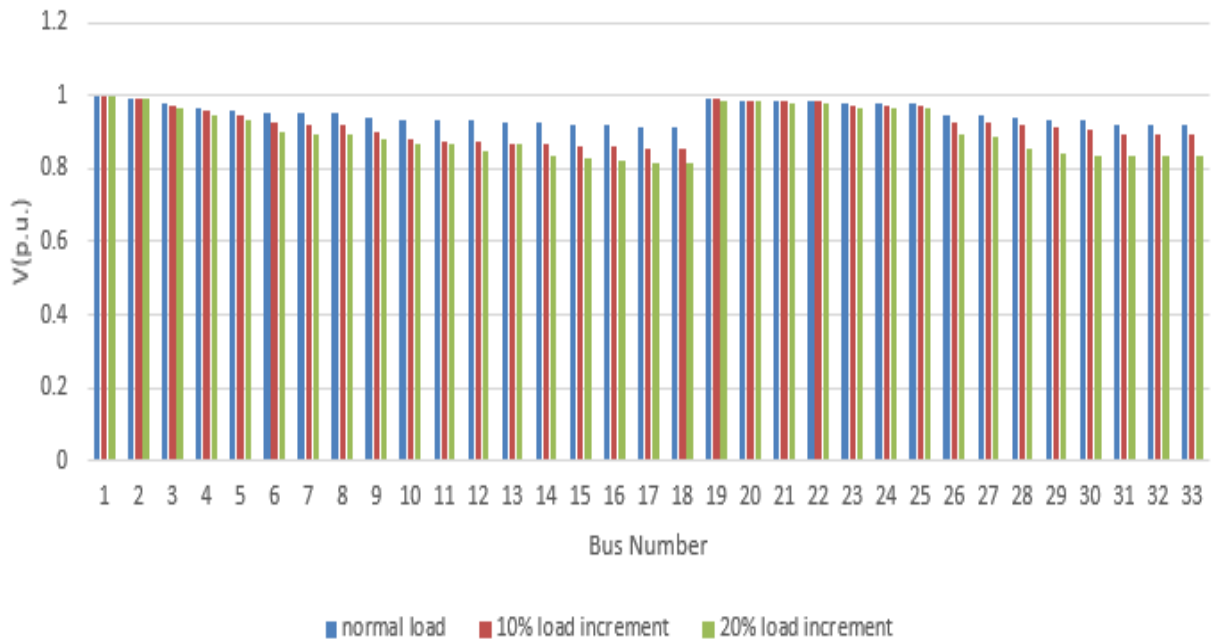


Figure 5.14 voltage profile with increased load

Above figure shows the voltage profile variation and few buses were found to be weakest buses as more sensitive to change with the increase in load.

5.4.3 Voltage variation with the installation of wind-DG

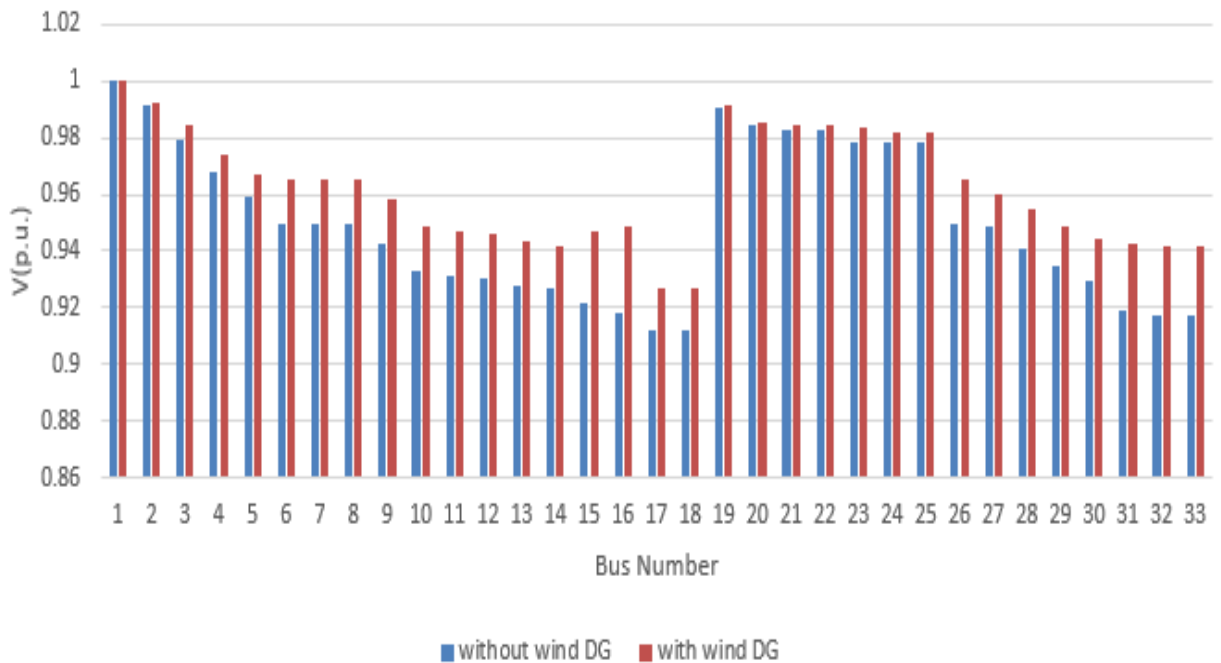


Figure 5.15: voltage profile variation with and without wind DG

5.4.4 Improvement in System performance

With the wind DG the losses are calculated at all the buses and it was found that there is reduction in losses with the installation of wind DG unit

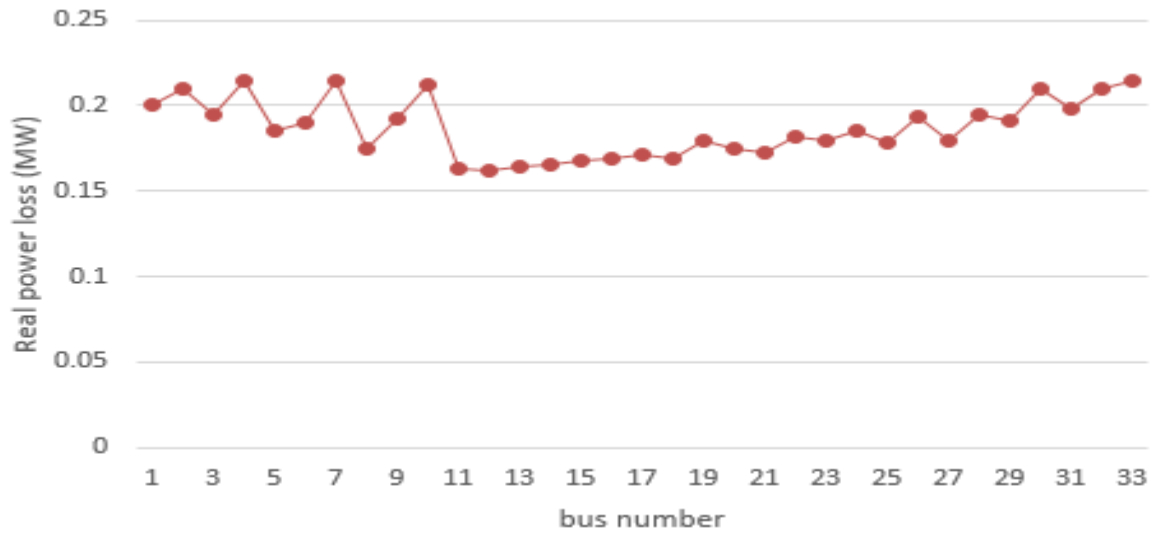


Figure 5.16: Power loss of the 33 bus distribution system

System voltage are within limits with the installation of wind DG unit and losses are minimized when wind DG unit was connected at bus 12. Also voltage profiles are more appropriate when connected at bus 12 in comparison to other buses. Thus, bus number 12 can be considered as the optimum bus location for the wind DG unit.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1. Conclusion

The wind energy impact on power system particularly on voltage of buses and losses of the system was discussed. It is observed that placement of wind DG unit at improper places leads to increase in power loss and poor voltage. Wind DG unit is modeled as load bus. The Newton raphson method was used for performing load flow analysis with loss calculation. The conclusion drawn are mentioned below:

- The magnitude of voltage and system losses are taken as a main concern and the change in system performance is observed in a system.
- Loads were increased on a steps to obtain the system performance for obtaining the weakest buses, that is, the buses are more sensitive to a change in load.
- With the weakest buses it will restrict the solution space to a few buses simultaneously reducing the computational time.
- Voltage profile improvement in the buses when wind power was connected with increased loading condition and voltages were found to be within the limits.
- System losses were minimum with location of wind based DG unit properly chosen.

6.2 Future Scope

The works that can be carried further are stated below:

- Integration of wind DG with other DG types.
- Method proposed in work with integrated in test system with larger size for its cogency and effective.
- Various power loss minimization methods that can be incorporated.

LIST OF PUBLICATIONS

1. Presented and published a paper in National Conference on Advanced Computational Methods in Electrical Engineering.
 - Kavita Yadav and Manbir Kaur, “Investigation of Voltage Profile of Grid Integrated with Wind Turbine Generator”, IJERT, Vol.4, National Conference on Advanced Computational Methods in Electrical Engineering (ACMEE-2016)
2. Kavita Yadav and Manbir Kaur, “Investigation of Optimal Allocation of Wind DG in Distribution System”, American Journal of Electrical Power and Energy Systems. [Communicated]

REFERENCES

- [1] N. S. Rau and Y. H. Wan, "Optimum location of resources in distribution planning." IEEE Transactions on Power Systems, Vol. 9, No. 4, pp. 2014-2020, Nov. 1994.
- [2] L. Srivastava, L. Yadav, "Optimal Placement of Distributed Generation: An Overview and Key Issues", IEEE, International Conference on Power, Signals, Controls and Computation (EPSCICON), 8 – 10 January 2014.
- [3] A. Thomas, A. Göran, S. Lennart, "Distributed generation: a definition", Electric Power System Research, vol. 57, pp. 195-204, Dec 2001.
- [4] M. H. Nehrir and C. Wang, "Analytical approaches for optimal placement of distributed generation sources in power systems," IEEE Transactions on Power Systems, Vol. 19, No. 4, pp. 2068-2076, Nov. 2004. [{8}
- [5] A. Keane and M. O'Malley, "Optimal allocation of embedded generation on distribution networks," IEEE Transactions on Power Systems, Vol. 20, No. 3, pp. 1640-1646, Aug. 2005.
- [6] N. Acharya, P. Mahat and N. Mithulananthan, "Analytical approach for DG allocation in primary distribution network," International Journal of Electrical Power and Energy Systems, Vol. 28, No. 10, pp. 669-678, Dec. 2006.
- [7] H. Victor, M. Quezada, J.R Abbad and T. G. S. Roman, "Assessment for energy distribution losses for increasing penetration of distributed generation," IEEE Transactions on Power Systems, Vol. 21, No. 2, pp. 533-540, May 2006.
- [8] T. T. Chuong, "Voltage Stability Investigation of Grid Connected Wind Farm," International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering, vol. 2, no. 6, pp. 532–536, 2008.
- [9] R. Katyal and U. Chief, "Indian wind grid code," 2009.
- [10] F. S. Zavareh, H. Fotoohabadi, and R. Sedaghati, "Improvement of Voltage Profile of Grid Integrated Wind Distributed Generation by SVC," International Journal of Computer, Electrical, Automation, Control and Information Engineering, Vol. 9, no. 3, pp. 788–792, 2015.
- [11] M. Ebadian, A. Edrisian, and A. Goudarzi, "Investigating the effect of high level of wind penetration on voltage stability by quasi-static time- domain simulation," vol. 4, no. 2, 2014.

- [12] I. S. Naser, a. Garba, O. Anaya-Lara, and K. L. Lo, "Voltage stability of transmission network with different penetration levels of wind generation," Univ. Power Eng. Conf. (UPEC), 2010 45th Int., pp. 3–7, 2010.
- [13] F. Milano, "Assessing Adequate Voltage Stability Analysis Tools for Networks with High Wind Power Penetration," no. April, pp. 2492–2497, 2008.
- [14] K. Yang, A. Garba, C. S. Tan, and K. L. Lo, "The Impact of the Wind Generation on Reactive Power Requirement and Voltage Profile," no. April, pp. 866–871, 2008.
- [15] S. M. Sayed, M. M. Aly, M. Abdel-akher, and M. Ieee, "Capacity and Location Effects of Wind Turbine Energy Systems on Power Systems Stability," International Journal on Power Engineering and Energy (IJPEE) ,Vol. 4, pp. 343–347, January 2013.
- [16] H. L. Willis, "Analytical methods and rules of thumb for modeling DG-distribution interaction," In Proceedings IEEE Power Engineering Society Summer Meeting, Vol. 3, pp. 1643-1644, Jul. 2000.
- [17] Y. Mao, K. N. Miu, "Switch placement to improve system reliability for radial distribution systems with distributed generators," IEEE Transactions on Power Systems, Vol. 18, No. 4, pp. 1446-1352, Nov. 2003.
- [18] H. Hedayati, S. A. Nabavinaki and A. Akbarimajd, "A method for placement of DG units in distribution networks," IEEE Transactions on Power Delivery, Vol. 23, No. 3, pp. 1620-1628, Jul. 2008.[15]
- [19] T. Gozel and M. H. Hocaoglu, "An analytical method for sizing and siting of distributed generators in radial systems," Electric Power Systems Research, Vol. 79, No. 6, pp. 912-918, Jun. 2009.
- [20] A. Kumar and W. Gao, "Optimal distributed generation location using mixed integer non- linear programming in hybrid electricity markets," IET Generation Transmission and Distribution, Vol. 4, No. 2, pp. 281-298, Feb. 2010.
- [21] Y. M. Atwa, E. F. El-Sadany, M.M. A. Salama and R. Seethapathay, "Optimal renewable resources mix for distribution system energy loss minimization," IEEE Transactions on Power Systems, Vol. 25, No. 1, pp. 360-370, Feb. 2010.
- [22] D. Q. Hung, N. Mithulananthan and R. C. Bansal, "Analytical expressions for DG allocation in primary distribution networks," IEEE Transactions on Energy Conversions, Vol. 25, No. 3, pp. 814-820, Sep. 2010.
- [23] T. N. Shukla, S. P. Singh, V. Shrinivasrao and N. B. Naik, "Optimal sizing of distributed generation placed on radial distribution system" International Journal of Electrical Components and Power System, Vol. 38, No. 3, pp. 260-274, Jan. 2010.[21]

- [24] L. F. Ochoa, C. J. Dent and G. P. Harrison, "Distribution network capacity assessment: Variable DG and active network," *IEEE Transactions on Power Systems*, Vol. 25, No. 1, pp. 87-95, Feb. 2010.
- [25] C. J. Dent, L.F. Ochoa and G. P. Harrison, "Network distributed generation capacity analysis using OPF with voltage step constraints," *IEEE Transactions on Power systems*, Vol. 25, No. 1, pp. 296-304, Feb. 2010.
- [26] H. M. Khodr, M. R. Silva, Z. Vale and C. Ramos, "A probabilistic methodology for distributed generation location in isolated electrical service area," *Electric Power Systems Research*, Vol. 80, No. 4, pp. 390-399, Apr. 2010.
- [27] R. K. Singh and S. K. Goswami, "Optimum allocation of distributed generations based on nodal pricing for profit, loss reduction, and voltage improvement including voltage rise issue," *International Journal of Electrical Power and Energy Systems*, Vol. 32, No 6, pp. 637-644, Jul. 2010.
- [28] G. N. Koutroumpetis and A. S. Safigianni, "Optimum allocation of the maximum possible distributed generation penetration in a distribution network," *Electric Power System Research*, Vol. 80, No. 12, pp. 1421-1427, Dec. 2010.
- [29] M. F. Akorede, H. Hizam, I. Aris and M.Z. A. Ab Kadir, "Effective method for optimal allocation of distributed generation units in meshed electric power systems," *IET Generation Transmission Distribution*, Vol. 5, No. 2, pp. 276-287, Feb. 2011.
- [30] F. S. Abu-Mouti and M. E. El-Hawary, "Optimal distributed generation allocation and sizing in distribution systems via artificial bee colony algorithm," *IEEE Transactions on Power Delivery*, Vol. 26, No. 4, pp. 2090-2101, Oct. 2011.
- [31] M. H. Moradi and M. Abedini, "A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems," *International Journal of Electrical Power and Energy Systems*, Vol. 34, No. 1, pp. 66-74, Jan. 2012.
- [32] D. K. Khatod, V. Pant and J. Sharma, "Evolutionary programming based optimal placement of renewable distributed generators," *IEEE Transactions on Power systems*, Vol. 28, No. 2, pp. 683-695, May 2013.
- [33] J. A. M. Garcia and A. J. G. Mena, "Optimal distributed generation location and size using modified teaching-learning based optimization algorithm," *International Journal of Electrical Power and Energy Systems*, Vol. 50, pp. 65-75, Mar. 2013.

- [34] P. Deghanian, S. H. Hosseini, M. Moeini-Aghtaie and A. Arabali, "Optimal sizing of DG units in power systems from a probabilistic multi-objective optimization perspective," *International Journal of Electrical Power and Energy Systems*, vol. 51, pp. 14-26, Mar. 2013.
- [35] S. M. Sajjadi, M. R. Haghifam and J. Salehi, "Simultaneous placement of distributed generation and capacitors in distribution networks considering voltage stability index," *International Journal of Electrical Power and Energy Systems*, Vol. 46, pp. 366-375, Nov. 2013.
- [36] D. Q. Hung, N. Mithulananthan and R. C. Bansal, "Analytical strategies for renewable distributed generation integration considering energy loss minimization," *Applied Energy*, Vol. 105, pp. 75-85, May. 2013.
- [37] K. D. Mistry and R. Roy, "Enhancement of loading capacity of distribution system through distributed generator placement considering techno-economic benefits of load growth," *International Journal of Electrical Power and Energy systems*, Vol. 55, pp. 505-515, Jan. 2014.
- [38] P. Karimyan, G. B. Gharepetian, M. Abedi and A. Gavili, "Long term scheduling for optimal allocation and sizing of DG unit considering load variations and DG type," *International Journal of Electrical Power and Energy Systems*, Vol. 54, No. 1, pp. 277-287, Jan. 2014.
- [39] P. Alemi and G.B. Gharehpetian, —DG Allocation Using an Analytical Method to Minimize Losses and to improve voltage Security,|| 2nd IEEE International Conference on Power and Energy (PECon 08), pp. 1575-1580, December 2008.
- [40] Raj Kumar Singh, Nalin B. Dev Choudhury, —Optimal Allocation of Distributed Generation in Distribution Network with Voltage and Frequency Dependent Loads,|| IEEE Region 10 Colloquium and the Third ICIIS, Kharagpur, india, December 2008.
- [41] J.L. Del Monaco, "The role of distributed generation in the critical electric power infrastructure", in: *Proceedings of the Power Engineering Society Winter Meeting IEEE*, vol. 1, pp. 144–145, Feb 2001.
- [42] Vivek Kumar Shrivastava, O.P.Rahi, Vaibhav Kumar Gupta, and Sameer Kumar Singh, "Optimal Location of Distribution Generation Source in Power System Network," *IEEE Fifth Power India Conference*, 22 Dec. 2012.
- [43] Soumya A, A. Amudha," Optimal Location and Sizing Of Distributed Generators In Distribution System." *International Journal of Engineering Research & Technology (IJERT)*, Vol. 2 Issue 2, February- 2013

- [44] S. Kansal, V. Kumar, and B. Tyagi, "Electrical Power and Energy Systems Optimal placement of different type of DG sources in distribution networks," *International journal of Electrical. Power Energy Syst.*, vol. 53, pp. 752–760, 2013.
- [45] D.P. Kothari and J.S. Dhillon, *Power system Optimization*, New Delhi; Prentice-Hall, India, 2006.
- [46] Gurpreet Kaur, R.K. Sharma," Different techniques of loss minimization in Distribution Syetem", *International journal of enhanced research in science, technology and engineering*. Vol. 2, issue 2, 2013.

APPENDIX A

IEEE 9 BUS SYSTEM

Table A.1: Line data – IEEE 9 bus system

Line No.	From Bus	To Bus	Line Impedance		Half line charging Susceptance (p.u.)
			Resistance (p.u.)	Reactance (p.u.)	
1	1	4	0.0000	0.0576	0.0000
2	4	5	0.0100	0.0850	0.0880
3	5	7	0.0320	0.1610	0.0153
4	4	6	0.0170	0.0920	0.0790
5	6	9	0.0390	0.1700	0.1790
6	7	2	0.0000	0.0625	0.0000
7	7	8	0.0085	0.0720	0.0745
8	8	9	0.0119	0.1008	0.1045
9	9	3	0.0000	0.0586	0.0000

Table A.2: Load data – IEEE 9 bus system

Bus Number	Generation		Load		Voltage (p.u.)
	Real Power (MW)	Reactive Power (MVar)	Real Power (MW)	Reactive Power (MVar)	
1	163	6.65	0.0	0.0	1.04
2	85	-10.8	0.0	0.0	1.025
3	72	27	0.0	0.0	1.025
4	0.0	0.0	0.0	50	1.0
5	0.0	0.0	125	50	1.0
6	0.0	0.0	90	30	1.0
7	0.0	0.0	0.0	0.0	1.0
8	0.0	0.0	100	35	1.0
9	0.0	0.0	0.0	0.0	1.0

APPENDIX B

IEEE 14 BUS SYSTEM

Table B.1: Line data – IEEE 14 bus system

Line No.	From Bus	To Bus	Line Impedance		Half line charging Susceptance (p.u.)	Transformer Tap
			Resistance (p.u.)	Reactance (p.u.)		
1	1	2	0.01938	0.05917	0.0264	1
2	2	3	0.04699	0.19797	0.0219	1
3	2	4	0.05811	0.17632	0.0170	1
4	1	5	0.05403	0.22304	0.0246	1
5	2	5	0.05695	0.17388	0.0173	1
6	3	4	0.06701	0.17103	0.0064	1
7	4	5	0.01335	0.04211	0.0	1
8	5	6	0.0	0.25202	0.0	0.932
9	4	7	0.0	0.20912	0.0	0.978
10	7	8	0.0	0.17615	0.0	1
11	4	9	0.0	0.55618	0.0	0.969
12	7	9	0.0	0.11001	0.0	1
13	9	10	0.03181	0.08450	0.0	1
14	6	11	0.09498	0.19890	0.0	1
15	6	12	0.12291	0.25581	0.0	1
16	6	13	0.06615	0.13027	0.0	1
17	9	14	0.12711	0.27038	0.0	1
18	10	11	0.08205	0.19207	0.0	1
19	12	13	0.22092	0.19988	0.0	1
20	13	14	0.17093	0.34802	0.0	1

Table B.2: Load data – IEEE 14 bus system

Bus No.	Type	Bus Voltage		Generation		Load		Reactive Power limits	
		Magnitude (p.u.)	Phase angle (deg)	Real Power (MW)	Reactive Power (MW)	Real Power (MW)	Reactive Power (MW)	Qmin (MVar)	Qmax (MVar)
1	1	1.060		0	0	0.0	0.0	0.0	0.0
2	2	1.045	0	40	42.4	21.2	12.7	-40	30
3	2	1.010	0	0.0	23.4	34.2	19.0	0.0	40
4	3	1.0	0	0.0	0	47.8	-3.9	0.0	0.0
5	3	1.0	0	0.0	0	7.6	1.6	0.0	0.0
6	2	1.070	0	0.0	12.2	11.2	7.5	-6.0	24
7	3	1.0	0	0.0	0.0	0.0	0.0	0.0	0.0
8	2	1.090	0	0.0	17.4	0.0	0.0	-6.0	24
9	3	1.0	0	0.0	0.0	29.5	16.6	0.0	0.0
10	3	1.0	0	0.0	0.0	9.0	5.8	0.0	0.0
11	3	1.0	0	0.0	0.0	3.5	1.8	0.0	0.0
12	3	1.0	0	0.0	0.0	6.1	1.8	0.0	0.0
13	3	1.0	0	0.0	0.0	13.5	5.8	0.0	0.0
14	3	1.0	0	0.0	0.0	14.9	5.0	0.0	0.0

APPENDIX C

IEEE 33 BUS SYSTEM

Table C.1 Line data – 33 bus system

Branch Number	Sending-end	Receiving-end	Resistance (Ω)	Reactance (Ω)
1	1	2	0.0922	0.0470
2	2	3	0.4930	0.1511
3	3	4	0.4660	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	0.2144	0.2351
8	8	9	1.0300	0.7400
9	9	10	1.0440	0.7400
10	10	11	0.1966	0.0650
11	11	12	0.3744	0.0238
12	12	13	1.2680	1.1550
13	13	14	0.2416	0.7129
14	14	15	0.2910	0.5260
15	15	16	0.5463	0.5450
16	16	17	1.1890	1.7210
17	17	18	0.8320	0.5420
18	2	19	0.0640	0.1565
19	19	20	1.4042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.8980	0.7091
24	24	25	0.8960	0.7011
25	6	26	0.2030	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0590	0.9337
28	28	29	0.8042	0.6006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.9630
31	31	32	0.2105	0.3619
32	32	33	0.5410	0.5302

Table C.2 Load data – 33 bus system

Node Number	Real Power (MW)	Reactive Power (MVar)
1	0.0	0.0
2	100	60
3	90	40
4	120	80
5	60	30
6	60	20
7	200	100
8	200	100
9	60	20
10	60	20
11	45	30
12	60	35
13	60	35
14	120	80
15	60	10
16	60	20
17	60	20
18	90	40
19	90	40
20	90	40
21	90	40
22	90	40
23	90	50
24	420	200
25	420	200
26	60	25
27	60	25
28	60	20
29	120	70
30	200	600
31	150	70
32	210	100
33	60	40

Base kV= 12.66 and Base MVA= 100

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