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POWER LOSS REDUCTION IN THE DISTRIBUTION SYSTEM WITH A WIND BASED DISTRIBUTED GENERATION

By

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DEDICATION

To my God and The Church.

"Study to show yourself approved to God, a workman that needs not to be ashamed, rightly dividing the word of truth." 2 Timothy 2:15 (NKJV)

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ABSTRACT

Distribution system operating environments are changing rapidly due to the integration of the intermittent renewable in to the power grid at the distribution side of the power system. Therefore, with increasing number of wind based distributed generators (DFIGs) being installed within distribution systems, the traditional methods for distribution system modeling, DFIG placement & sizing, network reconfiguration needs to be reviewed and better practical ones developed to cater for the intermittent renewable power.

The combined participation factors, realized by the Newton Raphson method, capture network parameters, load distributions and DFIG capacities (sizes) and locations have been formulated considering real and reactive power. A distributed slack bus model taking into consideration network sensitivity is proposed in the research as compared to the distributed slack bus models based on the DFIG capacity, DFIG domains and the single slack bus model.

DFIG placement and sizing using a particle swarm optimization method (PSO) and a hybrid of GA and PSO (HGAPSO) and by load flow method are compared. With simulated results, the optimal location of the DFIG is the primary distribution system, with the HGAPSO giving improved results as compared to the ordinary PSO and the load flow.

The active distribution network reconfiguration problem with an objective function of reducing real and reactive power losses in the presence of DFIG and uncertain loads proves the practicability of such a method in reducing power losses and in improvement of the voltage profile .Here an hybrid method of bacterial foraging and differential evolution (HBFDE)is applied.

The proposed methods, as applied to the IEEE 33 Bus Radial distribution system ,are found to be effective in the power loss reduction in the power system wind based distributed generation.

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ABREVIATIONS

ABC-Artificial Bee Colony

AC-Alternating Current

ACO -Ant Colony Optimization

ADNR- Active Distribution Network

ADNR- Active Distribution Network Reconfiguration

BF-Bacterial foraging

BPSO-Binary Particle Swarm Optimization

CERTS- Consortium for Electricity Reliability Technology Solutions

CPF-Continuous Power Flow

DE-Differential evolution

DG-Distributed Generator

DGs-Distributed Generators

DIFG-Doubly Fed Induction Generator

DLF- Distribution Load Flow

DNR-Distribution Network Reconfiguration

DPC-Direct Power Control

EP-Evolutionary Programming

EPRI-Electric Power Research Institute

FACTS- Flexible Alternative Current Transmission Systems

FGA-Fuzzy Genetic Algorithm

FL-Fuzzy Logic

FRT-Fault Ride Through

GA-Genetic Algorithm Optimization

GS-Gauss Siedel

HBCO-Honey Bee Colony Optimization

HBFDE- Hybrid of bacterial foraging and Differential evolution

HCBMOP-Hybrid and Constraint Based Multi Objective Programming.

HDP-Heuristic Dynamic Programming

HGAPSO-Hybrid of Genetic Algorithm and Particle Swarm Optimization

HPSOWM-Hybrid Particle Swarm Optimization with Wavelet Mutation

IEEE-Institute of Electrical and Electronics Engineers

INC-Interface Neuro Controller

IPM-Interior Point Method

IPPs-Independent Power Producers

KPLC-Kenya Power Lighting Company

LVRT- Low Voltage Ride Through

MAMD-Multiple Attribute Making Decision

MC-Monte Carlo

MIHDE-Mixer Integer Hybrid Differential Evolution

MINLP-Mixed Integer Non Linear Programming

MOPSO-Multiple Objective Particle Swarm Algorithm

MPPT-Maximum Power Point Tracking

NGF-Natural Gas Foundation

NSGA-Non-Dominated Sorting GA

OPF-Optimal Power Flow

PCC-Point of Common Coupling

PMSG-Permanent Magnet Synchronous Generator

PSO-Particle Swarm Optimization

PWM-Pulse Width Modulation

RBFNNs-Radial Basis Function Neural Networks

SA-Simulated Annealing

SCIG-Squirrel Cage Induction Generator

SFIG-Singly Fed Induction Generator

SPV-Solar Photo Voltaic

STATCOM-Static Synchronous Compensator

TS-Tabu Search

VSC-Voltage Source Converter

VSHDE-variable scaling hybrid differential evolution

WECC-Wind Energy Control Council

WECS- Wind Energy Control Systems

WTG-Wind Turbine Generator

WT-Wind Turbine

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Chapter 1

INTRODUCTION

This is an introduction chapter to the research area with a statement of the problem, a justification of the study, the objectives and the research questions .Finally an organization of the thesis is outlined.

1.1 Problem Statement.

The traditional Distribution System design has various inherent drawbacks. The design does not take into account DG introduction especially the intermittent wind based DFIGs. Also the penalty factors used in economic power dispatch and unit commitment by **J.J.Grainger and W.D Stevenson ,2003,[1]** are derived using the method of Lagrange Multipliers without taking into consideration the reactive power losses. However ,these losses can no longer be ignored in the commercially viable DFIG used in the integration of wind energy into the grid.

Due to load growth, load demand exceeds the predetermined threshold capacity of distribution systems; therefore distribution system design should either do an addition of new substations, DGs or expand the existing substations' capacities [2]. This must take into consideration the type, position and the size of the DFIG so as to maintain the system voltage stability. In modern practical power systems where reactive power injection plays a critical role in voltage stability control, the reactive power losses need to be incorporated into the load flow problem. This is not accounted for in the existing literature especially where intermittent renewable like wind is involved.

The method of connecting DG with electric power system affects DG control schemes. The **IEEE Standard 1547** provides the minimum technical requirements of interconnecting distributed resources with electric power system[3].The requirements are functional requirements and do not specify any particular connection method or equipments. To achieve some specified planning and operating goals for a wind based distributed generation through automatic or manual control, regulation of electric power injections(both real and reactive) from the DFIGs within power systems is required.

This thesis, therefore, as one of the objectives , has developed combined participation factors taking in consideration both real and reactive power losses by using DFIG sizing and locations, network parameters and load distribution parameters. Then a Newton Raphson algorithm for distributing the slack in a Wind based DFIG Distribution system is formulated using the combined participation factors. Further, real and reactive loss reduction is done using a hybrid of GA and PSO (HGAPSO) for DFIG placement &sizing. Finally, the active network reconfiguration problem is revisited taking into consideration DFIG placement and uncertain loads using a hybrid of Bacterial Foraging and Differential Evolution (HBFDE).

1.2 Justification

Global wind resource potential is 72TW which is five times the world's energy use. Only 4-10% of this resource can be used in an economically viable way(that is a maximum of 7.2TW).As at **5th February 2014,the Global Wind Energy Council(GWEC)[4]** statistics revealed that the global wind installed capacity was 318,137MW,which means a growth of 12.5% from 2013. This means over 6.90TW (96%) of the economically viable wind energy remains unexploited. By 2020, 1900 GW (28%) of the viable wind energy will be used economically. Due to this, there is increased penetration of wind energy into the grid with the capability of the wind power to supply the peak load being 20%.

Statistics from the Kenya Power and Lighting Company (KPLC) indicate that wind energy constitutes about 20% of the 1700 MW additional power that Kenya is working towards injecting into the national grid, over the next five years. The Lake Turkana Wind Power Project(LTWPP) is the largest of the three wind power plants that are expected to roar into life in the next two years, churning out 300 MW. Using the latest wind turbine technology, LTWP will upon full commissioning in 2014 will provide reliable and continuous clean power to satisfy up to 17% of Kenya's total power needs. In the light of these national and world statistics, there is need to solve the technical challenges facing the integration of wind energy into the power grid at the distribution side and transmission end of the existing power system.

Wind energy is the world’s most developed renewable energy resource due to the need of providing energy security and the climatic change problem. Assuming that 10% of households would install wind turbines at a cost competitive with the grid side electricity at 12 pence 19 cents /KWh by 2020 ,production of 1.5 KWh p.a will save 0.6 million Tonnes of CO2 emission.Also,120.8 GW global wind capacity produce 260Twh and saves 158 Million Tones of CO2 p.a .Also,20% of the worlds viable wind energy can satisfy the worlds electricity demand by the year 2020 if the challenges facing its integration to the grid are addressed[4].

The Doubly Fed Induction Generator (DFIG) based wind turbine with variable-speed variable-pitch control scheme is the most popular wind power generator in the wind power industry and can be operated either in grid connected or stand alone mode. A thorough understanding of the modeling, control, and dynamic as well as the steady state analysis of this machine in both operation modes is necessary to optimally extract the power from the wind and accurately predict its performance. Thus new strategies and methods for distribution system expansion planning ,which include DFIG placement, DFIG sizing and network reconfiguration , need to be studied.

1.3 Objectives

The main objective of this research is to optimize real and reactive losses in the presence of the DFIG.The objective is further divided in to the following sub objectives:

- To formulate combined participation factors for reactive and real power loss allocation for DFIGs.
- To formulate a distributed slack bus model for the distribution system with DFIGs.
- To evaluate the impacts of introducing distributed slack bus models for reactive power loss to wind based DFIG placement and sizing.
- To design new strategies for network reconfiguration with wind based DFIG and uncertain loads.

1.4 Research Questions

The following research questions have been addressed so as to fulfill the objectives:

- How can the reactive power loss participation factors for DFIGs be formulated?
- What are the differences between the participation factors of reactive power and real power loss contributions and how can these kinds of participation factors is combined to form a combined participation factor?
- How can reactive power loss distribution to a distributed slack bus model be applied in power flow study?

- How can an Algorithm for DFIG placement and sizing be formulated?
- How does the presence of the Wind based DFIG in the power grid affect the Distribution Network reconfiguration problem?

1.5 Thesis Organization

This thesis has six chapters. **Chapter 1** is an introduction to the research area ,a statement of the problem , a justification of the study .Then, the objectives and the research questions are presented .Finally an organization of the thesis is outlined.

In **Chapter 2** a general overview of the power system is done beginning with the typical power system, the distribution system, distributed generation, wind based distributed generation technologies, Reactive power and power systems optimization.

Chapter 3 brings out the combined participation factors and the NR based distributed slack bus model with DFIGs.A background for the participation factors is first given then the real reactive and the combined participation factors. DFIG based network sensitive and DFIG distributed slack domain based participation factors are presented and their corresponding distributed slack bus modes with DFIG compared. The Voltage profiles for all the DFIG based DSBMs are compared and finally a chapter conclusion is given.

In **Chapter 4** the DFIG placement and sizing problem is solved using an hybrid of GA and PSO (HGAPSO) and the results compared with those obtained by doing the placement using load flow and ordinary PSO.A chapter conclusion is then drawn.

Chapter 5 deals with active distribution network reconfiguration problem taking into consideration wind based DFIG and uncertain loads. A hybrid of bacterial foraging (BF) and

Differential evolution (DE) (HBFDE) is formulated and then applied for a stochastic wind scenario and the results compared with those of a deterministic case. The voltage profiles are also compared and a chapter conclusion is made.

In **chapter 6** general thesis conclusions are made, contributions of this work are outlined plus the beneficiaries of the work and finally recommendations for future work are made.

1.6 Scope of the Research Work

This research covers the power loss reduction and voltage profile improvement in the distribution system environment. The losses in the generation and transmission side of the power system are not in the scope of this work. Moreover the losses understudy is only the technical losses.

The economic implications of power loss reduction are not considered in this research. This being an area of study of its own has been suggested as an avenue for further work on this subject.

Other benefits of the suggested methods of power loss reduction are taken as constraints in the problem formulations. Such benefits have not been considered in this work.

This thesis serves as bench mark of the simulated methods, Thus there is no case study or implementation of the proposed methods that has been done. However the significance of this research work in load flow analysis, power system planning, renewable energy integration , smart grid implementation and modern electric machines cannot be overlooked.

Chapter 2

POWER SYSTEMS OVERVIEW

This chapter gives a general overview of the power system beginning with the typical power system, the distribution system, distributed generation, wind based distributed generation technologies, Reactive power and power systems optimization.

2.1 Distribution System

This section gives a general overview of the traditional power system buses and a review of the power system buses. It will give a glimpse on how the modern power system is different from the typical power network. We begin with the typical power system.

2.1.1 Typical power system [5]

A power system generally consists of the generation transmission and distribution system. The sections are illustrated in the **Figure 2.1**. For many years, power systems were vertically and centralized operated systems. The large thermal and nuclear power plants generate most of the power due to their scale and economic merits. The electric power is transmitted and distributed to consumers over long distances at different voltage levels. The centralized and hierarchical control is applied to allow real time monitoring and control of the system.

The existing power system structures are changing due to [6]:

- Geographical and environmental constraints
- Stability and security problems of large plants
- Rapidly growing demand related investment
- Privatization

- Deregulation
- Competitive energy markets
- Emergence of advanced generation techniques with small ratings employed with environmental benefits and increased profitability

A distribution system is meant to provide reliable power in cost effective manner to the consumers. Conventional distribution system planning follows well established strategies such as expanding existing substations, building new substations, adding new feeders and/or reconfiguring the existing distribution system, load switching and capacitor placement which need additional investment in generation and transmission infrastructure to meet the increasing load demand.

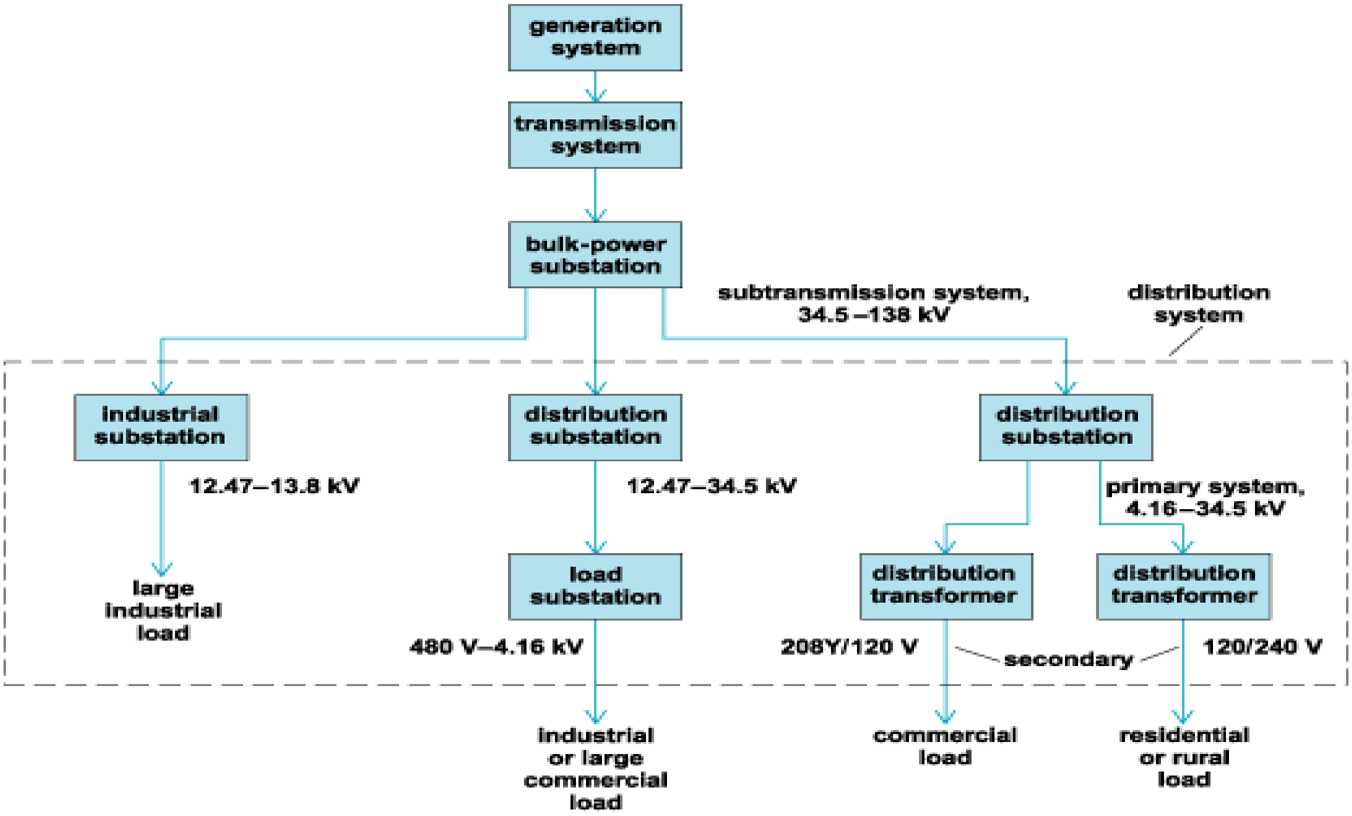


Figure 2.1: Typical Power System [5]

2.1.2 Power System Buses

A given power network has various parameters, which are either specified or unknown. These are real power (P), reactive power (Q), voltage (V), and power angle (δ). At any given bus, two variables are specified while the other two are variable. The two basic buses are [5] [7]:

- Power controlled (PQ) bus /Load bus is a bus whose real power P and reactive power Q are specified and voltage magnitude V and angle δ are calculated.
- Voltage-controlled bus (PV bus) is a bus for which the voltage magnitude (V) and the injected real power (P) are specified. The unknown variables are reactive power (Q) and angle (δ).

2.2 Distributed Generation

In this section the background of distributed generation and the respective technologies are discussed and then the wind based distributed generators which are the ones of concern in this thesis are reviewed.

2.2.1 Background of Distributed Generation

In recent years, deregulation and liberalization of energy market, increasing petroleum fuel prices and associated environmental concerns has attracted the attention of researchers/developers to incorporate distributed generation (DG) in distribution system planning.

Distributed Generation is a relatively small power generation source (from a few KW up to 10 MW), usually, connected in the distribution network or at the consumer side for the purpose of reducing power losses, improving voltage profile and power quality, peak shaving, eliminating the need of reserve margin with improved environmental concerns and increasing the network capacity.

The disadvantages of Distributed Generation include the stability, complex protection strategies and the islanding problems [8]. However the major driving forces for the increasing penetration of DG in distribution system are technical, economical and environmental benefits [9].

2.2.2 Distributed Generation Technologies

Gopiya et al, 2012 [6] carried out a comparative study of the planning and operation of the distributed generation in the distribution networks. The advances in DG technologies and increase in their sizes play significant role in power distribution systems.

As per the current definition, DG is very diverse and range from 1kW PV installation, 1 MW engine generators to 1000 MW offshore wind farms or more. All DG based on hydro, solar biomass, ocean and geothermal energy are renewable DGs while others are conventional DGs. For centralized generation, synchronous generator, asynchronous generator and power electronic converter interfaces can also be used as DG. The fuel cell, wind, solar PV and small hydro are emission free DGs and require no fuel and are environmental friendly.

The most suitable DGs considering environmental concerns, fuel cost, maintenance costs and output power are identified as wind, SPV, biomass, small hydro etc.This thesis considers the wind based DGs.The wind based DGs are discussed in the next section.

2.2.3 Wind Generation Technologies

There are two major classifications amongst wind generation units; fixed speed generation and variable speed generation [10]. The fixed speed generators have a design speed for which they have maximum efficiency whereas for other speeds their efficiency is lower. But variable speed generators have the maximum power tracking capability that extracts maximum available power out of the wind at different speeds thereby resulting in more efficient operation. Also the variable speed generators reduce mechanical stresses on the turbine thus increasing the lifetime of the turbine. It also helps damp out oscillations in torques more efficiently. Thus variable speed generators are more commonly installed.

Amongst the variable speed generators there are two major kinds, synchronous generators with direct power electronic converters and doubly fed induction generators with rotor side power electronic converters. Both have the above mentioned advantages of variable speed generators but the power electronic ratings of the two machines are different.

In a doubly fed induction generator the power electronic converter has a rating of about 30% of the machine rating whereas for the synchronous generator the rating of the power electronic converter is the same as machine rating thereby resulting in higher costs. Thus DFIGs are the preferred choice for installation.

2.3 Doubly Fed Induction Generators (DFIG) and Reactive Power.

The DFIG is the thematic generator in this thesis since it is commercially viable. The generator is capable of producing both real and reactive power. In this section, the DFIG is discussed and the effects of reactive power to the distribution system revisited.

2.3.1 DFIG Overview

The Doubly Fed Induction Machine is shown in **Figure 2.2** [10]. It consists of a wind turbine that is connected through a gear train to the rotor shaft of the induction generator. The rotor terminals of the induction machine are connected to the four-quadrant power electronic converter capable of both supplying real/reactive power from the grid to the rotor as well as supplying power from the rotor to the grid. The converter consists of two separate devices with different functions, the generator side converter and the grid side converter.

The generator side converter controls the real and reactive power output of the machine and the grid side converter maintains the DC link voltage at its set point. These converters are controlled respectively by the Generator side controller and the Grid side controller. The DFIG also has a wind turbine control that maximizes the power output from the turbine via pitch control and sends this computed maximum power output to the converter. The Power electronic converter is connected to the grid through a transformer that steps up the voltage to the grid. The stator side of the induction generator is also connected to the grid through a step up transformer.

In case the system reliability requires that additional reactive power be injected a STATCOM may be connected at this point of interconnection. The DFIG consists of a three phase induction generator with three phase windings on the rotor. The rotor is connected to a converter which supplies power to the rotor via the slip rings. The power electronic converter is capable of handling power flow in both directions which permits the DFIG to operate at both sub synchronous and super synchronous speeds.

2.3.2 Effects of reactive power to Distribution system with DFIG

Voltage control and reactive-power management are two aspects of a single activity that both supports reliability and facilitates commercial transactions across transmission and distribution networks [11].On an alternating-current (AC) power system, voltage is controlled by managing production and absorption of reactive power.

There are three reasons why it is necessary to manage reactive power and control voltage. First; both customer and power-system equipment are designed to operate within a range of voltages, usually within±5% of the nominal voltage. At low voltages, many types of equipment perform poorly; light bulbs provide less illumination, induction motors can overheat and be damaged, and some electronic equipment will not operate at. High voltages can damage equipment and shorten their lifetimes. Second, reactive power consumes transmission and generation resources. To maximize the amount of real power that can be transferred across a congested transmission interface, reactive-power flows must be minimized. Similarly, reactive-power production can limit a generator's real-power capability. Third, moving reactive power on the transmission system incurs real-power losses. Both capacity and energy must be supplied to replace these losses.

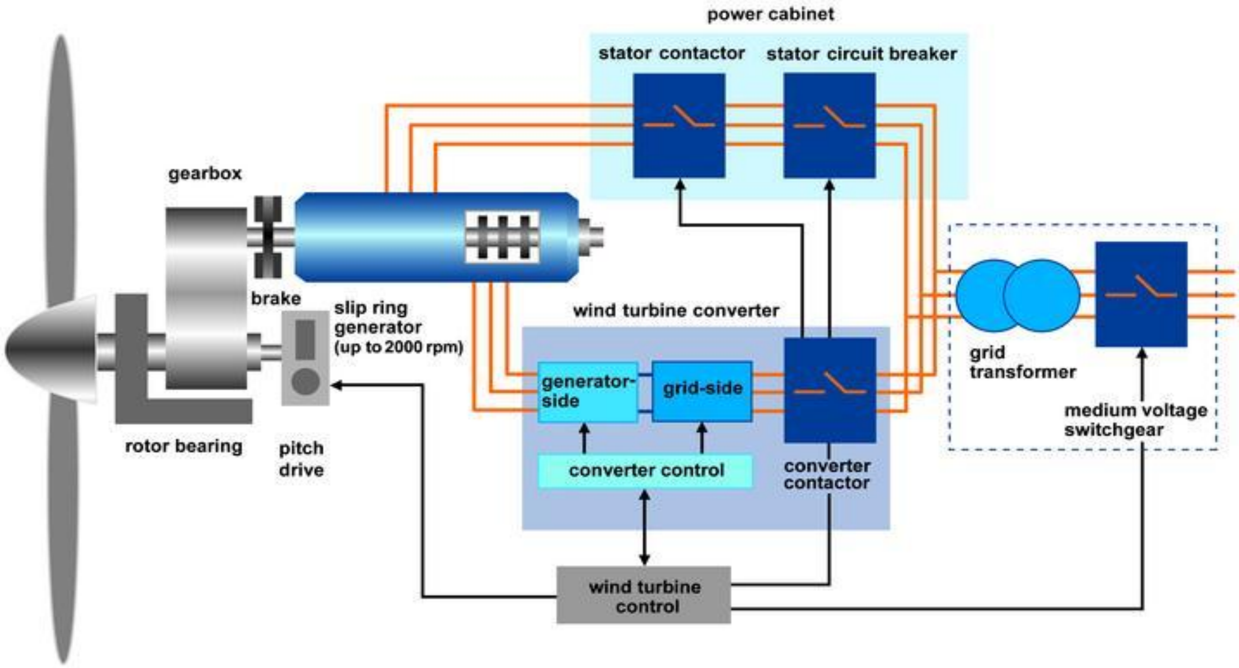


Figure 2.2 DFIG Schematic Diagram [10]

Voltage control is complicated by two additional factors. First, the transmission system itself is a nonlinear consumer of reactive power, depending on system loading. At very light loading the system generates reactive power that must be absorbed, while at heavy loading the system consumes a large amount of reactive power that must be replaced. The system's reactive-power requirements also depend on the generation and transmission configuration. Consequently, system reactive requirements vary in time as load levels and load and generation patterns change. The bulk-power system is composed of many pieces of equipment, any one of which can fail at any time. Therefore, the system is designed to withstand the loss of any single piece of equipment and to continue operating without impacting any customers. That is, the system is designed to withstand a single contingency. Taken together, these two factors result in a dynamic reactive-power requirement. The loss of a generator or a major transmission line can have the compounding effect of reducing the reactive supply and, at the same time, reconfiguring flows such that the system is consuming additional reactive power.

At least a portion of the reactive supply must be capable of responding quickly to changing reactive-power demands and to maintain acceptable voltages throughout the system. Thus, just as an electrical system requires real-power reserves to respond to contingencies, so too it must maintain reactive-power reserves. Loads can also be both real and reactive. The reactive portion of the load could be served from the transmission system. Reactive loads incur more voltage drop and reactive losses in the transmission system than do similar-size (MVA) real loads.

Distributing generation resources throughout the power system can have a beneficial effect if the generation has the ability to supply reactive power. Without this ability to control reactive-power output, performance of the transmission and distribution system can be degraded.

Doubly fed Induction generators (DFIGs) are an attractive choice for small, grid-connected generation, primarily because they are relatively inexpensive. They do not require synchronizing and have mechanical characteristics that are appealing for application as wind based DGs. They also absorb reactive power rather than generate it, and are not controllable. If the output from the DFIG fluctuates (as wind does), the reactive demand of the generator fluctuates as well, compounding voltage-control problems for the transmission system. DFIGs can be compensated with static capacitors, but this strategy does not address the fluctuation problem or provide controlled voltage support.

2.4 Distribution System Optimization

Optimization is a mathematical formulation that is concerned with finding of minima or maxima of functions subject to the so called constraints. Some decision making analysis involves determining the action that best achieves a desired goal or objective. This finding means the actions that optimizes (i.e. minimizes or maximizes) the value of an objective function. Optimization is applied in the deregulated power industry to find best allocation of DG and other devices. There are many optimization techniques available for the distribution system planning in the presence of DG as discussed below. For determining global optimal solution to the complex multi-objective optimization problem, one has to consider the basic conflicts resulting between accuracy, reliability and computational time. So, some trade-off is necessary to arrive at the compromised solution by satisfying all the objectives [6, 12].In the following subsections, the power system optimization methods are presented and then a comparison is made.

2.4.1 Classification of Optimization Techniques

Past literature has revealed various solution techniques/methodologies that can be employed for optimal allocation and are classified into four categories [6, 12]:

- **Analytical approaches**: These are also called the traditional methods. They include Mathematical Model and Numerical Solution
- **Artificial intelligent search techniques**: These methods are motivated by the existing biological laws. Examples include Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Algorithm (ACO), Tabu Search (TS), Evolutionary programming (EP), Fuzzy Logic (FL), and Differential Evolution (DE)
- **Conventional techniques**: Probabilistic based Mixed Integer Nonlinear Programming (MINLP), Monte-Carlo (MC) simulation, Artificial Bee Colony (ABC), Bacterial Foraging (BF), Distribution Load Flow (DLF), Optimal Power Flow (OPF), Continuation Power Flow (CPF), Index Based Planning(IBP), and Bacterial Foraging (BF)
- **Hybrid based techniques**: These are a combination of the any two of the analytical artificial intelligent or conventional methods. They include HGAOPF, HGAPSO, HGATS, Fuzzy-GA, HPSO-Ordinal optimization, HBFDE,GASA etc.

2.4.2 Comparison

Gopiya et al,2012[12] provided a general overview of the power system optimization methods and **K.Y Lee,2008 [6]** and [12] all the optimization methods are discussed and compared. This comparison includes the merits and demerits, areas of application and the operators involved.

One of the first and most widely used optimization techniques is GA, but it suffers from divergence and local optima. PSO is the next popular technique used because of its simplicity, less computation time and fast convergence characteristics. PSO is efficient for solving those problems for which the accurate mathematical modelling is difficult but prone to local minima and premature convergence. Artificial intelligence based optimization techniques like SA, EP, TS, PSO, and ACO can handle the integer variables very well. SA provides better solution but the computation time is excessively large. TS is an efficient technique to achieve either optimal or sub-optimal solution in the short duration. ACO algorithm is more heuristic than the conventional technique and needs further investigation on its performance.

Hybrid methods of optimization are the latest. They have succeeded in enhancing the strengths and eliminating the weaknesses of the various methods. For example, combined HGAOPF is better than SGA in terms of solution quality and number of iteration. However the method is computationally demanding and less robust .Combined GA and simulated SA(GASA) is effective for variable and intermittent forms of generation. However, its computational efficiency to reduce the world models of distribution systems into a set of linear equations is usually very difficult. The proposed Probabilistic approach with MINLP can closely mimic the actual loss calculations resulting in more accurate solutions taking into consideration the uncertainty. The method is however computationally demanding and less robust. HGATS gives better solution in terms of solution quality and number of iteration HGAPSO escapes from local minima and also Increases the diversity of variable values.

Hence it can be concluded that analytical approaches are not suitable for multi-objective complex optimization problems. When optimization problems are solved by conventional technique like mixed integer nonlinear programming, the nonlinear and integer variables will demand more computation time and are less robust. Many recent publications use hybrid optimization techniques to obtain an efficient and reliable solution to the problem by adding their strengths and discarding the weaknesses.

2.5 Chapter Conclusion

This chapter has provided the basic concepts which will be applied in chapters 3 4 and 5 in loss reduction and voltage profile improvement in active distribution systems with DFIGs.The following conclusions can be made:

- Integration of distributed generation with intermittent power into the grid demands the conventional power system to be looked at again and better analysis and design tools formulated.
- Reactive power can no longer be ignored in the optimization of power in the modern power system due to its increased need in maintaining the voltage profile.
- The pure methods of power system optimization are strong and weak at the same time .Therefore ,the hybrid optimization methods are the state of art for the modern power systems because they provide efficient and reliable solution to the problem by adding their strengths and discarding the weaknesses.

The next three chapter of this thesis aims at modelling the active distribution network with regard to the integration of wind energy into the grid so as to provide a solution to some the three power loss problems as evident in the smart grid.

Chapter 3

DFIG BASED DISTRIBUTED SLACK BUS MODEL

In this chapter, the combined participation factors and the NR based distributed slack bus model with DFIGs are presented .A background for the participation factors is first given then the real reactive and the combined participation factors. DFIG based network sensitive and DFIG distributed slack domain based participation factors are presented and their corresponding distributed slack bus modes with DFIG compared.

3.1 Participation Factors

This section provides a background of participation factors, real ,reactive and combined factors, the penalty factors with network sensitivity and the available applications of participation factors in power systems.

3.2.1 Back Ground in Power Systems

Participation factors are no dimensional scalars that measure the interaction between the modes and the state variables of a linear system .Participation factors were introduced by **Varghese, P´erez-Arriaga and Schweppe,1982, [13],[14],[15]** as a means for ranking the relative interactions between system modes and system states. The concept is one element of the Selective Modal Analysis (SMA) approach introduced by these authors, and its first applications were in the field of electric power systems for analysis, order reduction and controller design.

Other definitions of participation factors were introduced by Abed **et al, 1999 [16]** so as to achieve a conceptual framework that does not hinge on any particular choice of initial condition.

The initial condition is modeled as an uncertain quantity, which can be viewed either in a set-valued or a probabilistic setting. If the initial condition uncertainty obeys a symmetry condition, the new definitions are found to reduce to the original definition of participation factors.

In this thesis, a participation factor is a simple algebraic ratio. It is a weight attached to each DFIG bus such that, the total unaccounted power shall be distributed to that bus multiplied by its respective participation factor. In a means to deal with the distributed slack bus problem, we can distribute the real power deficit among all generating buses. While doing so we take care that the individual generating limits of the DFIGs are not exceeded. Once this is done, the burden on the slack bus is tremendously reduced and now it can enter the optimal cost criteria region. To do this many factors come into picture. The capacity of the individual generators, the distance from the point of demand, the interconnection index, the dependency of other grids on the said system and so on. Each of them individually or bunched together can be used to decide on a parameter which shall dictate how to divide the power loss among the buses. The change in this parameter will cause change in the system ELD scheme altogether. This parameter is called the **participation factor** which when multiplied with the loss of the system decides how much loss be transferred to the respective bus. Every different system can have a different participation factor. But the sum of all the real and reactive power participation factors in a system must be unity. Only generator buses have a participation factor parameter.

3.2.2 Real Power Participation Factors

Real power participation factor is a simple algebraic ratio of the total real power loss associated with a certain generator, DFIG, and the total real power loss in the power system. **S .Tong and K.Miu, [18-21]** defined the real power participation factor, *K_i*, for source *i*, is as:

$$K_p = \frac{P_{Gi}^{loss}}{P_{loss}} \qquad i = 0,1,2 \dots . m \tag{3.1}$$

Where

$$\sum_{i=o}^{n} K_p = 1$$

$$P_{Gi}^{loss} = P_{Gi}^{loss\ a} + P_{Gi}^{loss\ b} + P_{Gi}^{loss\ c}$$

Where,

0 The substation index,

n The number of participating DFIGGs in the system, in this case

P_{loss} The total real power loss in the system,

P_{Gi}^{loss} The real power loss associated with generator i,

$P_{Gi}^{loss,p}$ The real power loss associated with generator *i*, phase p.

These real participation factors are applied in this thesis to distribute real power loss to participating sources including the DFIGs and to maintain the voltage profile.

3.2.3 Reactive Power Participation Factors

With the introduction of DFIG sources, the effects of the reactive power can no longer be ignored. The method of real power participation factor does not provide a procedure for distributing the reactive losses in the various DFIG buses at the same time maintaining the voltage stability. This section will investigate the criteria of applying optimized reactive power loss distribution to a distributed slack bus model in power flow study by modelling the relation:

$$K_q = \frac{Q_{Gi}^{loss}}{Q_{loss}} \qquad i = 0,1,2 \ldots .m \tag{3.2}$$

Where

$$\sum_{i=o}^{m} K_q = 1$$

$$Q_{Gi}^{loss} = Q_{Gi}^{loss\ a} + Q_{Gi}^{loss\ b} + Q_{Gi}^{loss\ c}$$

Where

0 the substation index

n the number of participating DFIGs in the system

Q_{loss} The total reactive power loss in the system

Q_{Gi}^{loss} The reactive power loss associated with generator *i*

$Q_{Gi}^{loss,p}$ The reactive power loss associated with generator *I*, phase *p*

These reactive power participation factors are applied in this thesis to distribute reactive power loss to participating sources including the DFIGs and to maintain the voltage profile.

3.2.4 Penalty Factors

In this thesis, non-negative participation factors are desired. However, rate of power loss with respect to DFIG input (sensitivities) can be negative, since penalty factors for real power in [1] are defined as;

$$L_{p}=\frac{1}{1-\frac{\partial P_{l}}{\partial QP_{i}}} \tag{3.3}$$

Thus the penalty factors for reactive power is defined as

$$L_{q}=\frac{1}{1-\frac{\partial Q_{l}}{\partial Q_{Gi}}} \tag{3.4}$$

It is noted that in economic dispatch [1] with line loss considerations, these penalty factors were derived through the method of Lagrange multipliers. These penalty factors based on sensitivities are nonnegative, and reflect the impact of transmission system loss to real power injections from units, which are dispersed throughout the system. In this research, these penalty factors will be derived using both real and reactive power and used in this research to obtain nonnegative combined participation factors. That is**,** for the penalty factors, the combined penalty factor is given by

$$L = L_p + L_q \tag{3.5}$$

3.2.5 Network Sensitivity Combined Participation Factors

The network sensitivity combined participation factors incorporate the concept of network sensitivities and penalty factors to distribute the slack. These participation factors implicitly include effects of network parameters and load distribution through the sensitivities of system real power loss to real power injections and reactive power loss to reactive power injections. Since the sensitivities can be negative, penalty factors are applied to keep participation factors nonnegative.

The sensitivities, $\partial P_{loss}/\partial P_i$ where P_{loss} represents real power loss and $\boldsymbol{P_i}$ represents the real power injection to bus i, is addressed. They will be derived and computed at each power flow iteration as follows.

For real power,

$$\begin{bmatrix} \dfrac{\partial P_{loss}}{\partial P} \\ \dfrac{\partial P_{loss}}{\partial Q} \end{bmatrix} = \left[J^T \right]^{-1} \begin{bmatrix} \dfrac{\partial P_{loss}}{\partial \delta} \\ \dfrac{\partial P_{loss}}{\partial |V|} \end{bmatrix} \tag{3.6}$$

For reactive power,

$$\begin{bmatrix} \dfrac{\partial Q_{loss}}{\partial P} \\ \dfrac{\partial Q_{loss}}{\partial P} \end{bmatrix} = \left[J^T \right]^{-1} \begin{bmatrix} \dfrac{\partial Q_{loss}}{\partial \delta} \\ \dfrac{\partial Q_{loss}}{\partial |V|} \end{bmatrix} \tag{3.7}$$

Where:

J is the Jacobian matrix for three-phase power flow with a single slack bus

Since R, X values of network components, voltage phase angles θ and voltage magnitudes V are included in J , the system network parameters, and load distribution are implicitly included in the sensitivities and hence in the combined participation factors

The network sensitivity participation factors incorporate the concept of network sensitivities and penalty factors to distribute the slack(real and reactive power losses).These participation factors implicitly include effects of network parameters and load distribution through the sensitivities of system real and reactive power losses and real and reactive power injections. Since the sensitivities can be negative, penalty factors are applied to keep participation factors non negative.

Since balanced and unbalanced systems are considered in actual load flow analysis, phase sensitivities on the same bus could be different. Therefore, the average phase sensitivity or maximum phase sensitivity can be utilized. Also, for a single slack bus model, the system loss is independent of the real and reactive power injections of the reference bus, whose penalty factor is set as one.

Thus, the penalty factors are defined as:

Based on average phase sensitivity

$$L_0 = 1$$

$$L_P = \frac{1}{1 - \frac{1}{3}\left(\frac{\partial P_{loss}}{\partial P_{Gi}^a} + \frac{\partial P_{loss}}{\partial P_{Gi}^b} + \frac{\partial P_{loss}}{\partial P_{Gi}^c}\right)} \qquad i=1,\ 2\ \ldots m \qquad (3.8a)$$

$$L_q = \frac{1}{1 - \frac{1}{3}(\frac{\partial Q_{loss}}{\partial Q_{Gi}^a} + \frac{\partial Q_{loss}}{\partial Q_{Gi}^b} + \frac{\partial Q_{loss}}{\partial Q_{Gi}^c})} \qquad i=1,\ 2\ \ldots m \qquad (3.8b)$$

Based on maximum phase sensitivity

$$L_0 = 1$$

$$L_P = \frac{1}{1 - \frac{1}{3} Max(\frac{\partial P_{loss}}{\partial P_{Gi}^a}, \frac{\partial P_{loss}}{\partial P_{Gi}^b}, \frac{\partial P_{loss}}{\partial P_{Gi}^c})} \qquad i=1,\ 2\ \ldots m \qquad (3.9a)$$

$$L_q = \frac{1}{1 - \frac{1}{3} Max(\frac{\partial Q_{loss}}{\partial Q_{Gi}^a}, \frac{\partial Q_{loss}}{\partial Q_{Gi}^b}, \frac{\partial Q_{loss}}{\partial Q_{Gi}^c})} \qquad i=1,\ 2\ \ldots m \qquad (3.9b)$$

In the equations (3.8) and (3.9), all penalty factors are nonnegative. At first glance, the sensitivity values are not necessarily nonnegative; however, when calculating in per unit with realistic power distribution components, the sensitivity values are less than one, which results in nonnegative.

These penalty factors also capture DFIGs’ effects to system losses through sensitivities. When a participating source is installed far from load centers, more loss occurs on the path to serve the same amount of load from this source; then, its sensitivity should be larger than the sources, who are installed closer to load centers. In other words, a larger sensitivity value results in a larger penalty factor.

In addition, since sensitivities or these penalty factors only represent the ratios of system real power loss changes, the associated real power load served by each participating source, the generator load, also need to be included in its participation factor to scale its associated real power loss. Therefore, network sensitivity real power participation factors with applied penalty factors are determined as [18-21]

$$K_p = \frac{L_p P_{Gi}^{load}}{\sum_{j=0}^{m} L_p P_{Gi}^{load}} \quad i=0,\ 1,\ 2,\ m \qquad (3.10)$$

Since J changes at each iteration, Lp and the participation factors are iterative. The real power load associated with generator i, is a set value before power flow calculations, which can be considered as generator i 's scheduled output to serve a desired amount of load.

A corresponding reactive power participation factors can also be defined similarly.

Hence, the combined participation factor can be defined by the equation:

$$K = \frac{L_p P_{Gi}^{load}}{\sum_{j=0}^{m} L_p P_{Gi}^{load}} + j\ \frac{L_q Q_{Gi}^{load}}{\sum_{j=0}^{m} L_q Q_{Gi}^{load}} \qquad i=0,\ 1,\ 2\ \ldots m \qquad (3.11)$$

Where

K is the combined participation factor.

3.2.6 DFIG Domains Combined Participation Factors

The concept of generator domains and commons originates from a transmission system approach in [18-21]. Each generator's contribution to loads and losses can be distinguished using generator domains and commons. Generator domains and commons were determined by post processing a power flow solution or from available system measurements.

This thesis will adapt the transmission based concepts of generator domains and commons to the DFIG based distribution systems. Since the loads and network are unbalanced in distribution systems, the buses and branch flows supplied by the same source may be different across phases. Thus, to emphasize and clarify individual phases to capture unbalanced situations encountered in distribution systems, generator domains will be extended to multi-phase DFIG domains in this thesis.

The concept of multi-phase generator domains strives to distinguish the loss and load associated with each participating source. As such, an associated loss with each participating source can be quantified. The effects of network parameters, load distributions and generator capacities are explicitly included in these participation factors. The generator domain participation factors are defined by equation (3.1)

In the distributed slack bus model with DFIG the real and reactive power outputs of participating generators are iterative. DFIG domains and loss contributions vary with changing source injections. Thus, the participation factors are iterative during power flow calculations. The process for determining three-phase generator domains presented in [21] will be applied to the DFIG.

3.2.7 Applications of Participation Factors in present work

Participation factors have been applied to assign the system loss to multiple generators during power flow calculations. In previous works, these participation factors are constant values and can be determined by different methods. The participation factors are related to the characteristics of turbines on each generator bus and load allocation, combined cost and reliability criteria in power flow for fair pricing and scheduled generator outputs. The participation factors are also applied to minimize active power generation using the nonlinear version of the Interior Point Method (IPM).

With increasing interest on reactive power dispatch and control in distribution systems, reactive power control for DGs also has become possible [22, 23].The amount of reactive reserves at generating stations is a measure of the degree of voltage stability. With this perspective, an optimized reactive reserve management scheme based on the optimal power flow presented in [24] show that detailed models of generator limiters, such as those for armature and field current limiting must be considered in order to utilize the maximum reactive power capability of generators, so as to meet reactive power demands during voltage emergencies. Participation factors for each generator in the management scheme are predetermined based on the V-Q curve methodology and the results prove that the proposed method can improve both static and dynamic voltage stability.

Optimization Algorithms for reactive power have been presented in [25] by exact loss formula, in [26] by PSO and by GA in [27] .In [28, 29], the management of reactive power generation to improve the voltage stability margin using modal analysis technique is done and the simulation results show that after the optimal reactive power re-scheduling, the active/reactive power losses are decreased. All these optimization methods provide no means of distributing the slack to various DGs in the power system for a distributed generation scenario with intermittent renewable and uncertain loads.

Pushpendra Singh, L S Titare and L D Arya, 2013 [17] developed a DE-based algorithm optimizes a set of reactive power control variables and maximizes reactive reserve available at generating buses using generation participation factors. Voltage dependent reactive power limits have been accounted. The optimal settings of reactive power control variables have been obtained for next interval predicted loading condition. These optimized settings satisfy the operating inequality constraints in predicted load condition as well as in present base case loading conditions. Obtained results using DE have been compared with those obtained using another population based techniques PSO and CAPSO.

3.2 Single Slack Bus Model

The traditional power flow analysis identifies the slack bus as the reference for the voltage angles of all buses and the power-balancing bus that makes up for the difference between the scheduled generation and the combined loads and losses. Hence, the slack bus is considered a voltage source with a large power capacity [18-21].While this model is viable for the utility connected operation ,where the utility bus can be assumed as an“infinite power source “with respect to the DER units, it exhibits severe limitations for the islanded ADN. The slack bus in an islanded ADN is essentially a grid-forming (PV bus) DER unit whose generation capacity is comparable to the other operating DERunits.If the reference bus output power ,i.e., the slack, exceeds its DER unit nominal capacity, it becomes essential to distribute the system slack among other participating units, based on a pre-specified criterion. The single slack bus (SSB) model does not allow for slack distribution analysis since it assigns all the system slack to one bus.

3.3 Distributed Slack Bus Model

In balanced transmission systems, distributed slack buses were introduced to remedy the inadequacy of a single slack bus.[18-21].The concept of DSB-based power-flow analysis for balanced transmission networks [30]–[31] and unbalanced distribution grids [18]–[21] has been addressed in the technical literature.

Several criteria have been developed to distribute the slack among the participating sources including constant participation factors based on the source scheduled output [21],[30-31] , iteratively calculated participation factors based on the source domains and commons [18]–[21] and iteratively calculated participation factors based on the real power network sensitivity and penalty factors for real power .

The existing three-phase DSB models are incorporated in phase-frame power-flow algorithms, which are less computationally efficient than their sequence-frame counterparts [32], [33]. In addition, deploying these models permit the grid-forming DG units (PV buses) to share only the system real slack. Such a practice is not the best option for an islanded ADN where the DG fleet may consist of power-controlled (PQ) DG units, intermittent renewable and varying loads.

In addition, distributing the reactive slack for the DFIGs has not yet been addressed in the technical literature[32,34] .This research thesis also demonstrates that distributing the reactive slack can significantly reduce the reference bus output, and thus prevent its power capacity limit violation. As such, the main contribution of this work is introducing a DSB model that can efficiently deal with unbalanced three-phase networks, distribute the reactive slack, and incorporate the PQ controlled DG units in the real and reactive slack sharing through the combined participation factors.

3.3.1 DFIG Based Distributed Slack Bus Model

Although the voltage and current unbalance in a distribution Grid could be significant, the power unbalance (which is defined as the ratio of the negative-plus the zero-sequence power components to the positive-sequence power component) is much smaller. Thus, it is reasonable to assume that the total system three-phase power slack is approximately three times its positive-sequence counterpart. Hence, the DFIG based distributed slack bus model in this thesis is defined based on the positive-sequence powerflow, and is incorporated with the positive-sequence power-how equations [32] where the bulk of the power system slack is associated with.

Based on the adopted control strategy, a DFIG unit can be categorized as a grid-forming (voltage-controlled) unit that dictates the voltage and a power-controlled (PQ) unit that exchanges pre-specified real and reactive power with the system [32]. The latter can be further divided, based on the DFIG capacity, into a large or a small PQ unit. To formulate the Distributed Slack Bus model, the DFIG units that participate in compensating the System slack must be predetermined. The participating units are classified as [32].

- PV and large PQ units with spare real power capacity to compensate for the system real slack. The ratio of the real slack contribution of each participating unit to the total system real slack is the “real-power participation factor” as in equation (3.1).
- Large PQ units with spare reactive power capacity to compensate for the system reactive slack. The “reactive-power participation factor,” is defined as the ratio of the reactive slack contribution of each participating unit to the total system reactive slack as in equation (3.2).

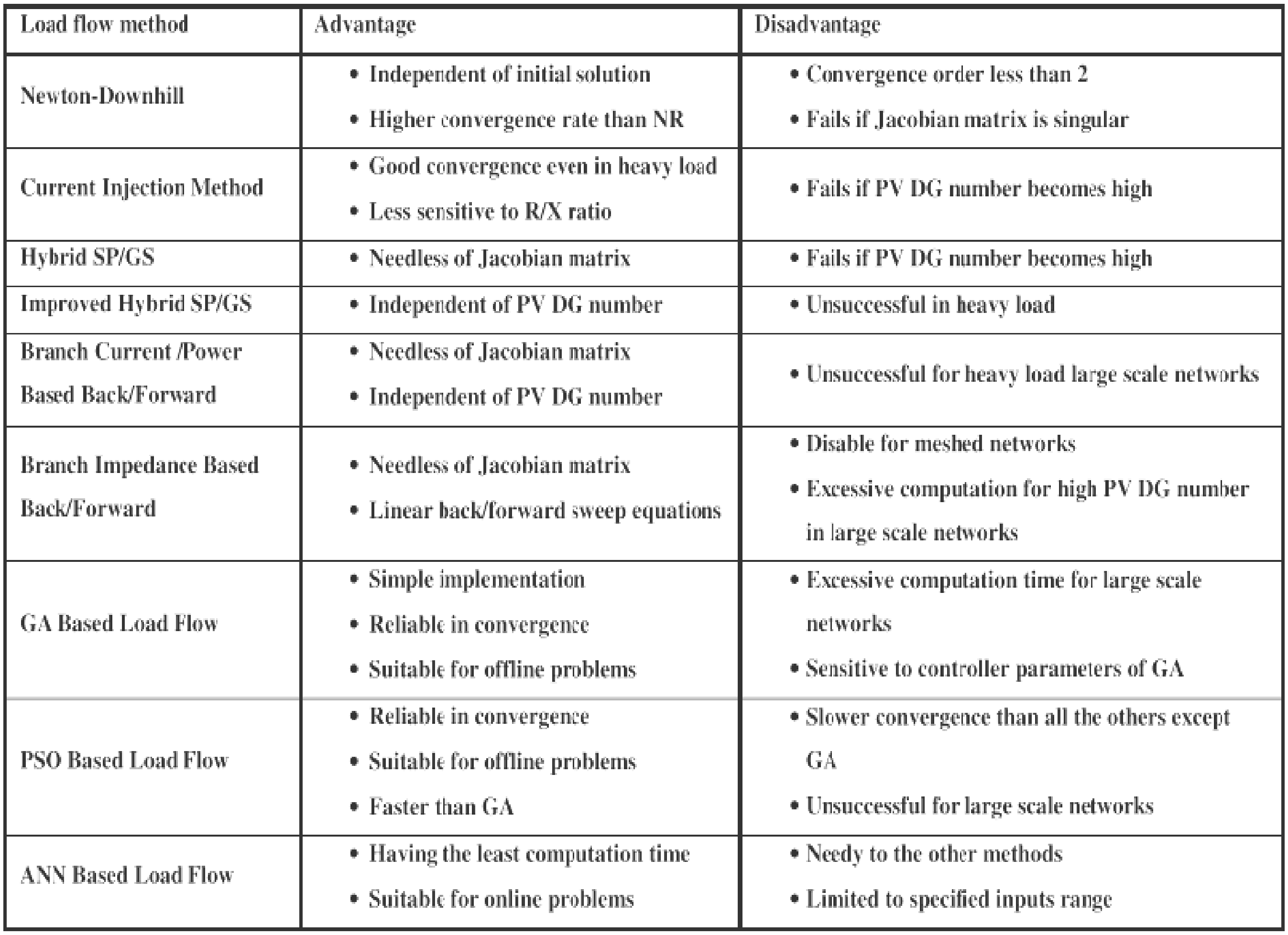
3.4 Solution Algorithm for Reactive Power Participation Factors

The real power participation factors developed in [18-21] for the general distributed generator will be applied for the DFIG Real power and thus in this section only the reactive power distributed slack model for the Newton Raphson(NR) method is developed to distribute the reactive slack .The Newton Raphson(NR) method choice for the distributed slack bus model in this thesis since ,as compared to the Gauss Siedel method(GS),NR has the following merits[5,7]:

- Its rate of convergence is fast and therefore requires less number of iterations to obtain the solution.
- It is independent of the number of buses of the system hence it can be applied on large practical systems.
- The convergence of the method is not affected by the selection of the slack bus; hence there is freedom of distributing the slack bus.
- It is more accurate and reliable when used for large systems.

A general comparison of NR with other load flow study methods is as shown in the Table 3.1

Table 3.1 Comparison of load flow methods for new distribution networks [1, 5, 7]



Load flow method	Advantage	Disadvantage
Newton-Downhill	• Independent of initial solution • Higher convergence rate than NR	• Convergence order less than 2 • Fails if Jacobian matrix is singular
Current Injection Method	• Good convergence even in heavy load • Less sensitive to R/X ratio	• Fails if PV DG number becomes high
Hybrid SP/GS	• Needless of Jacobian matrix	• Fails if PV DG number becomes high
Improved Hybrid SP/GS	• Independent of PV DG number	• Unsuccessful in heavy load
Branch Current /Power Based Back/Forward	• Needless of Jacobian matrix • Independent of PV DG number	• Unsuccessful for heavy load large scale networks
Branch Impedance Based Back/Forward	• Needless of Jacobian matrix • Linear back/forward sweep equations	• Disable for meshed networks • Excessive computation for high PV DG number in large scale networks
GA Based Load Flow	• Simple implementation • Reliable in convergence • Suitable for offline problems	• Excessive computation time for large scale networks • Sensitive to controller parameters of GA
PSO Based Load Flow	• Reliable in convergence • Suitable for offline problems • Faster than GA	• Slower convergence than all the others except GA • Unsuccessful for large scale networks
ANN Based Load Flow	• Having the least computation time • Suitable for online problems	• Needy to the other methods • Limited to specified inputs range

A Newton Rapson Solver Incorporating the distributed slack model with iterative participation factors is used .This algorithm works for both network sensitivity and DFIG domain participation factors. The steps for the algorithm are as follows:

Step 1: Choose an initial guess at $x^{(0)}$

Step 2: Set the iteration counter at $k = 0$

Step 3: Set desired Q_{Gi}^{load} $and\ \ initial\ K_q$

Step 4: Evaluate $F^{(K)}(X^{(K)})$

Step 5: Stop if $\left|F^{(K)}\right| \leq Tolerance$

Step 6: Evaluate $\mathrm{J}_{\mathrm{e}}^{(\mathrm{k})}=\frac{\partial \mathrm{F}}{\partial \mathrm{x}}$

Step 7: Solve $J_e^{(k)} \Delta x^{(k)} = -F^{(k)}$

Step 8: Let $x^{(k+1)} = x^{(k)} + \Delta x^{(k)}$

Step 9: Let $k = k + 1$

Step 10: Check real and reactive power limits of the participating DFIGs.If the calculated real/reactive power output of a DFIG violated its limits, this DFIGs cannot be considered as a participating source which accounts for slack and is modelled as a constant PQ injection Then go to **Step 3**

Step 11: Upgrade calculation information. For sensitivity participation factors, calculate sensitivities and for generator domain participation factors, find positive power flow directions and distinguish generator domains for the substation and participating DFIGs.

Step 12: Calculate reactive power participation factors $K_q^{(k)}$ and $K_0^{(K)}$,and go to **Step 4.**

For real power participation factors, the same algorithm is used but with **Step 3** with the **desired**P_{Gi}^{load} $and\ \ initial\ K_P$.

3.5 Flow Chart for the Solution Algorithm of reactive Power participation factors

The flow chart diagram for the algorithm to determine the reactive power participation factors is as shown in Fig 3.1

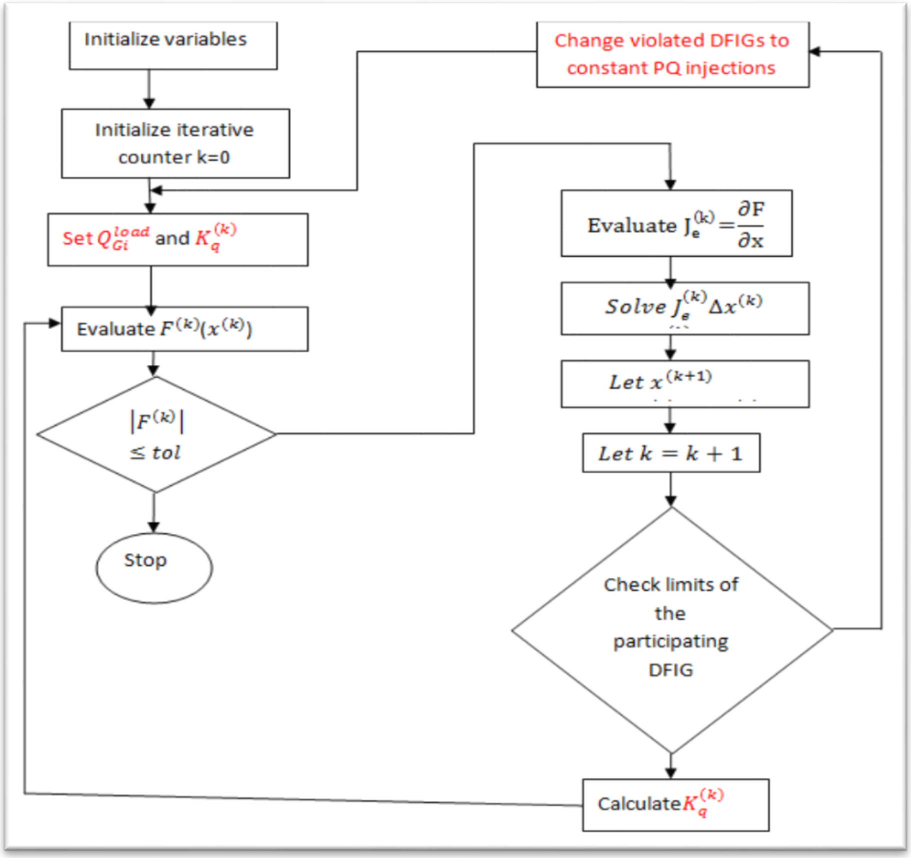


Fig 3.1: Flow Chart for the Solution Algorithm of reactive Power participation factors [5, 7].

3.6 Simulation Results and Analysis

The results presented in this section include those of the effects of combined participation factors on power loss and voltage profile plus the effected of the proposed DSB the power losses and voltage profile.

3.7.1 Participation factors and Power loss

Simulation results including the real and reactive power participation factors, real and reactive power outputs obtained using the different slack bus models of the 33 bus radial distribution system are as shown in the Table 3.1 and Table 3.2 below for cases 1 and case 2 respectively. From these numerical simulation results, the impacts of different slack bus models for distributed generation with DFIGs were observed. For the single slack bus model, both cases keep the DFIGs at the same output out 1.5MW and 750KVAR.The combined participation factors is 1, that of the substation.

The distributed slack bus model with non-iterative participation factors based on scheduled DFIG capacity alone has the same real and reactive participation factors values in both cases. Thus, with the same DFIG output, the amount of the output attributed to loads compared to the system losses are the same even though the DFIG is located at different locations. The combined participation factor is better than the corresponding real and reactive factors. Since this method does not capture the effects of DFIG locations on power system studies, it is not recommended. However it is better than the single slack bus model.

The distributed slack bus model with sensitivity participation factors were computed in two ways; based on average sensitivities and maximum phase sensitivities. The resulting real reactive and combined participation factors were slightly different between these two methods. It is noted that both methods assigned larger participation factors to the DFIG on Bus 18than when the DFIG was placed on Bus 19. Thus the sensitivity and penalty factor approach performed, as expected, with respect to attributing higher losses to the DFIG at bus 18, the primary distribution system. . The sensitivity measures are significant enough to fully capture the effects of DFIG locations by assigning real reactive and combined participation factors to the respective DFIGs.

DFIG domains DSB does not capture the economic aspects of the network and also the details of all network parameters. However this method confirms the optimal place for the slack bus is the primary distribution system at high losses

The following key is used to interpret the results in tables 3.1 and 3.2

A-Single slack Bus Model [5, 7, 20]
B-Distributed Slack bus model based on DFIG capacity [36]
C-Distributed Slack bus model based on average sensitivity [This method]
D-Distributed Slack bus model based on maximum sensitivity [[This method]
E-Distributed Slack bus model based on DFIG domain [17, 21]

Unlike the existing DSB models, the proposed formulation the DFIG based DSB Simultaneously distributes both real and reactive slack by the application of the combined participation factors. From Table 3.1 and 3.2, the magnitude of the combined participation factor is greater than the individual real and reactive participation factors, hence a better strategy to distribute the slack.

Also this model Involves DFIG units, with control strategies for the reactive power so as to compensate the total slack hence an alternative way to control the voltage profile. In addition, this DSB model guarantees the power flow solution to adhere with the DFIG operating limits.

Case A

Table 3.1:33 Bus Radial Distribution System with DFIG on Bus 18 to Service 1500KW 750KVAR Load

	A[5,7,20]	B[36]	C[This Method]	D[This Method]	E[17,21]
Sub Par K_O	1	0.7515	0.7468	0.7497	0.6749
DFIG par K_P=18	0	0.2485	0.2532	0.2503	0.3251
DFIG par K_q=18	**0**	**0.2356**	**0.2448**	**0.2709**	**0.3099**
Com.K	**1**	**0.3424**	**0.3552**	**0.3688**	**0.4492**
Ø(deg)	0	43.47	44.03	47.26	43.63
$P_{sub}^{out}\ (MW)$	475.052	470.554	470.554	471.554	468.593
$P_{DFIG}^{out}(KW)$	1.5000	1.5232	1.5232	1.5232	1.5629
$Q_{DFIG}^{out}(KVAR)$	750.0000	750.0083	750.0128	750.0156	750.0165
$P_{loss}^{sys}\ (KW)$	221.4340	221.4238	221.4238	221.4238	220.4225
$Q_{loss}^{sys}(KVAR)$	150.1784	150.1780	150.1776	150.1770	150.1765

Case B:

TABLE 3.2:33 Bus Radial Distribution System with DFIG on Bus 19 to Service 1500KW 750KVAR Load

	A[5,7,20]	B[36]	C[This method]	D[This method]	E[17,21]
Sub. Par K_O	1	0.7515	0.7633	0.7555	0.9866
DFIG par K_p=19	0	0.2485	0.2367	0.2445	0.0134
DFIG par K_q=19	**0**	**0.2296**	**0.2295**	**0.2386**	**0.0108**
Comb.K	**1**	**0.3384**	**0.3297**	**0.3416**	**0.0172**
Ø(deg)	0	42.74	44.12	44.30	38.87
$P_{sub}^{out}\ (MW)$	476.1162	471.6651	471.6651	471.6651	476.2040
$P_{DFIG}^{out}(KW)$	1.5000	1.5265	1.5565	1.5565	1.5012
$Q_{DFIG}^{out}(KVAR)$	750.0000	750.0083	750.0128	750.0156	750.0165
$P_{loss}^{sys}\ (KW)$	221.4340	221.4344	221.4340	221.4341	220.9992
$Q_{loss}^{sys}(KVAR)$	150.1784	150.1780	150.1776	150.1770	150.1765

3.7.2Voltage Profile

In this section the voltage profiles are compared.First the change in voltage profile by the introduction of the reactive power participation factors is presented and then the voltage profile improvement with DFIG Installations.

3.7.2.1 Voltage Profiles for the participation factors

The improvement of the voltage profile when combined participation factors are used instead of the real power ones is shown in Fig 3.2.It is clear that the introduction of the reactive power in the formulation of the participation factors leads to a significant improvement of voltage profile.

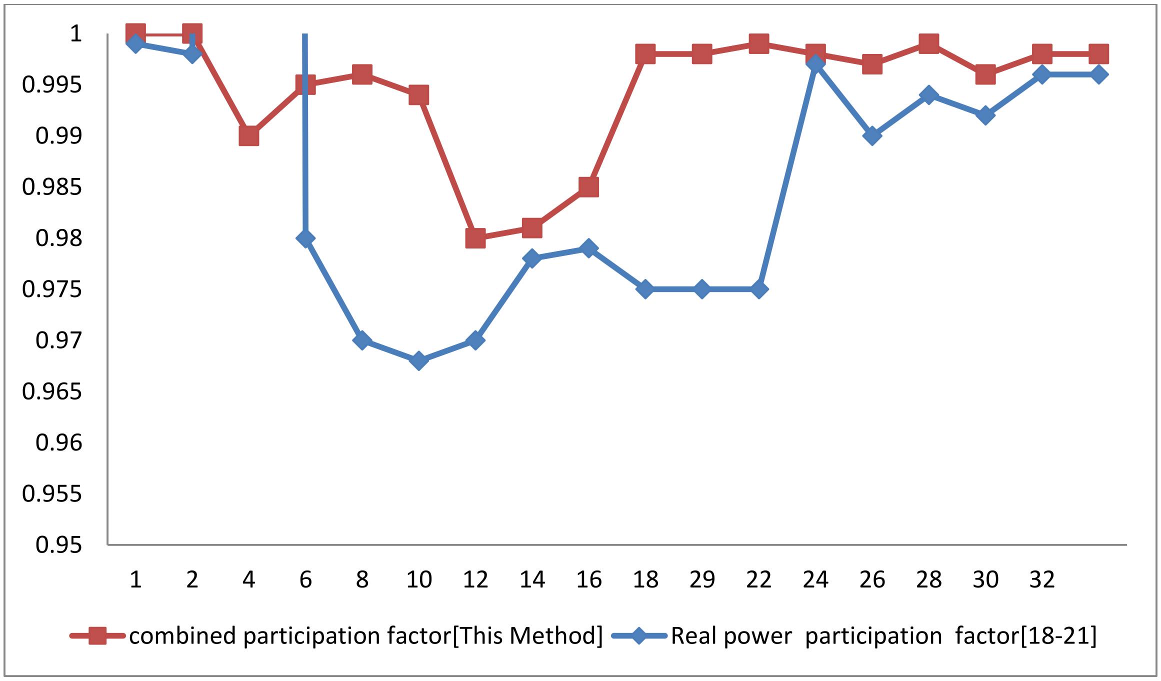


Figure 3.2: Voltage Profile for Real and Combined Participation factors

3.7.2.2 Voltage Profiles for DFIG installations

The voltage profiles for DFIG installations are shown in Figure 3.2. It is can be observed that DFIG installed on Bus 18 has bigger impacts on system voltage profile than DFIG installed on Bus 19.

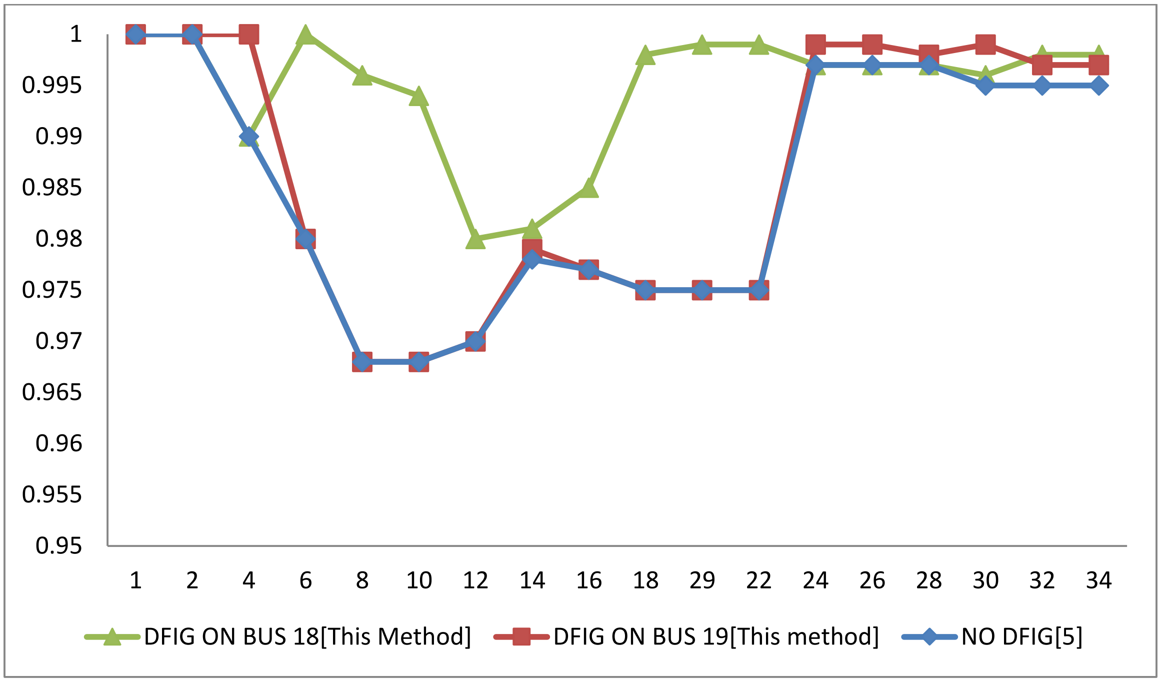


Figure 3.3: Voltage Profile for DFIG installations and without DFIG

3.7.2.3 A Comparison of voltage profiles

Also the DSB model which Involves DFIG units, with a control strategies for the reactive power so as to compensate the total slack do provide an alternative way to control the voltage profile as shown in Fig 3.3 .

The following key is used to interpret the results in figure 3.3

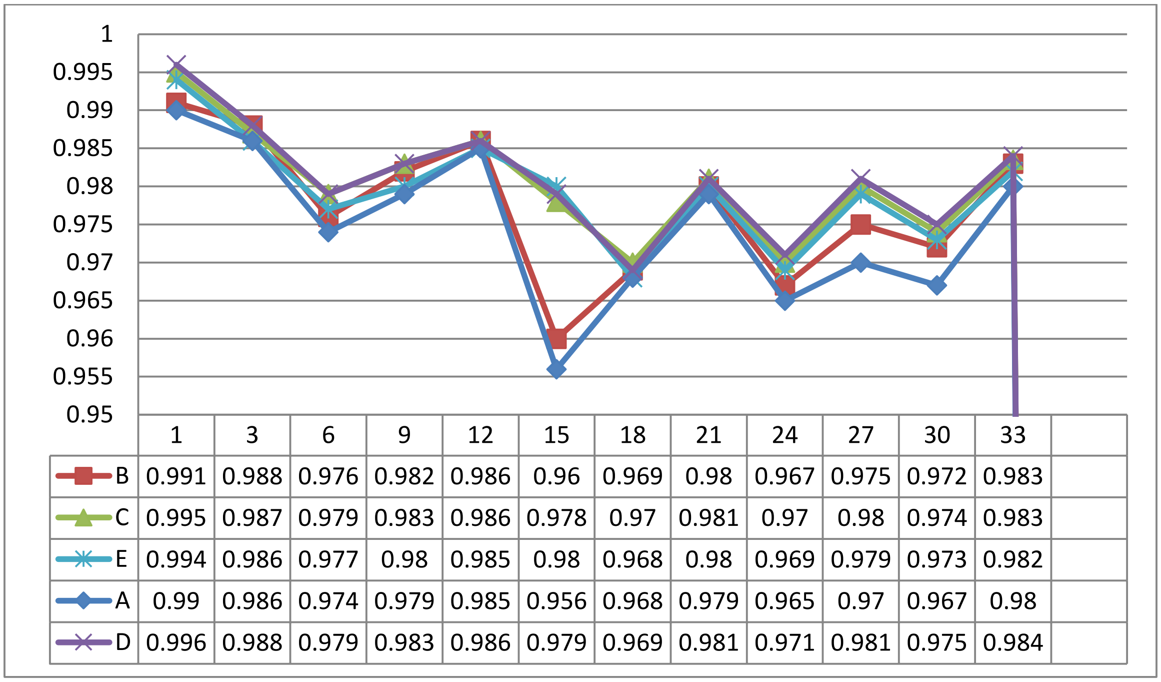
A-Single slack Bus Model [5, 7, 20]

B-Distributed Slack bus model based on DFIG capacity [36]

C-Distributed Slack bus model based on average sensitivity [This method]

D-Distributed Slack bus model based on maximum sensitivity [[This method]

E-Distributed Slack bus model based on DFIG domain [17, 21]



	1	3	6	9	12	15	18	21	24	27	30	33
■ B	0.991	0.988	0.976	0.982	0.986	0.96	0.969	0.98	0.967	0.975	0.972	0.983
▲ C	0.995	0.987	0.979	0.983	0.986	0.978	0.97	0.981	0.97	0.98	0.974	0.983
✱ E	0.994	0.986	0.977	0.98	0.985	0.98	0.968	0.98	0.969	0.979	0.973	0.982
◆ A	0.99	0.986	0.974	0.979	0.985	0.956	0.968	0.979	0.965	0.97	0.967	0.98
× D	0.996	0.988	0.979	0.983	0.986	0.979	0.969	0.981	0.971	0.981	0.975	0.984

Fig 3.4: Voltage Profile with the DFIG based DSB

In all the methods ,the inclusion of the DFIG provides a better way of improving the voltage profile .From the Fig 3.1,it is clear that the DSB taking into consideration the DFIG network sensitivity provide a better way of improving the voltage profile.

3.7 Chapter Conclusion

Slack bus modeling for distribution power flow analysis has been studied and investigated, and the following work has been contributed. First, the distribution power flow with a distributed slack bus model for DFIGs has been studied. Second, scalar participation factors to distribute uncertain real and reactive power system losses for three phase power flow calculations have been formulated using network sensitive combined participation factors. Also two methods to calculate network-based participation factors have been presented; sensitivity-based method and generator domain based method. Lastly a GA based NR solver implemented the distributed slack model with iterative combined participation factors.

The distribution power flow with a single slack bus model was revisited, and a distributed slack bus model was developed for distribution systems with DFIGs. The combined participation factors based on generator network sensitivity, which are explicitly relative to network parameters and load distributions, demonstrate their ability to capture network characteristics and to scale loss contributions of sources surpasses other combined participation factors. Therefore, the DFIG based distributed slack model with network sensitive combined participation factors is recommended for the allocation of real and reactive power losses to various buses.

The studies also conclude that simultaneous distribution of real and reactive slack positively impacts the operation of the ADN by reducing the real power losses, and improving the voltage profile, thus increasing the system overall efficiency.

Chapter 4

DFIG PLACEMENT AND SIZING

In this chapter, the DFIG placement and sizing problem is solved using an hybrid of GA and PSO (HGAPSO) and the results compared with those obtained by doing the placement using load flow and ordinary PSO.An overview of DG placement and sizing is given .

4.1 DG Placement and Sizing

S .Tong, 2006 [18-21] carried out a study on DG placement and sizing. Rau and Wan have used gradient and second order method to minimize loss ,line loading and reactive power requirements in the Distribution network .Willis investigated loss minimization using analytical based 2/3 rule ,assuming a constant power source and a uniformly distributed load.

Hybrid and Constraint Based Multi Objective Programming(HCBMOP) and GA method was proposed by Celli et al to minimize the cost of network upgrading ,power losses and energy required by customer. He later used the method to minimize the cost of network upgrading ,cost of energy losses and DG network acceptability index with the DG fully considered as a valid planning alternative.GA and Multiple Attribute Making Decision (MAMD) approach has been used on a PQ model DG to investigate its technical attributes such as reactive power flows, voltage variation and active loss as well as the economic attributes which include line congestion ,capital cost and emission.

An Heuristic Iterative Search method was also used to minimize the cost of investment and operation of DGs,loss and energy required by customers, which was later applied to minimize DG investment and operation losses and energy purchased from the main grid.

Anti- Colony Optimization (ACO) was applied on a time varying load to minimize investment cost, operation cost and energy buying from transmission grid. Further Particle Swarm Optimization was used on a multi- load level to minimize the cost of active losses, investment and operation cost of DG and emission cost.

The other methods used in the DG placement and sizing so far include analytical approach simulated annealing optimal power flow ,sensitivity analysis, fast sequential quadratic programming and NSGA II and max-min approach .

All these methods are limited in that they have not taken into consideration the reactive power losses which can no longer be ignored due to their increased importance in maintaining the voltage profile. Again such methods have not taken care of the intermittent renewable which today are forming a significant part of the active distribution network.

4.2 DFIG Placement and Sizing

With wind taken into consideration , a GA with decision making approach was used by **Carpinelli et al,2001,[37]** to minimize the cost of power losses and network upgrading for a general wind generator with a peak load and constant load growth.

Ochoa el al,2008,[38] used multi objective optimization with NSGA for a wind turbine generator with a time varying load to maximize the integration of DG and energy export ;minimizing losses and short circuit level.

These two methods have not considered the placement of the DFIG with an objective of optimizing the real and reactive losses. For the first time, the placement and sizing of the commercial DFIG is considered in this chapter using a hybrid of GA and PSO (HGAPSO) and its effects on the real power losses and the reactive power losses and the voltage profile studied.

Juanuwattanakul et al, 2012, [39] proposed an effective method for placement of DFIG units in multiphase distribution networks based on system voltage profile using PSO. The approach consists of utilizing the positive sequence voltage ratio $V_{collapse}/V_{no\text{-}load}$ to identify the weakest three-phase bus for the installation of DFIG units. DFIG ratings are determined by evaluating their impacts on voltage profile, grid losses and maximum loading factor while considering the voltage limits at all buses. The impacts of DIFG on voltage profile, active power loss and voltage stability margin are highlighted. The PSO approach developed in this work is used for comparison with HGAPSO method developed in this chapter.

4.3 The DFIG Capability Limit Curves

The model of a DFIG used in this thesis consists of a pitch controlled wind turbine and an induction generator[36,40].The stator of the DFIG is directly connected to the grid ,while the rotor is connected to the converter consisting of two back to back pulse width modulated (PWM) inveters,which allow direct control of the rotor currents.

Direct control of the rotor currents allows for the variable speed operation and reactive power control thus the DFIG can operate at a higher efficiency over a wide range of wind speeds and thus help in providing voltage support for the power grid.

The characteristics make the DFIG ideal for use as a wind generator, whose equivalent circuit is as shown in the Figure 4.1 where

R_s	stator winding resistance
R_r	Rotor winding resistance
R_m	Core resistance
X_s	stator leakage reactance
X_r	Rotor winding reactance
X_m	Magnetisation reactance

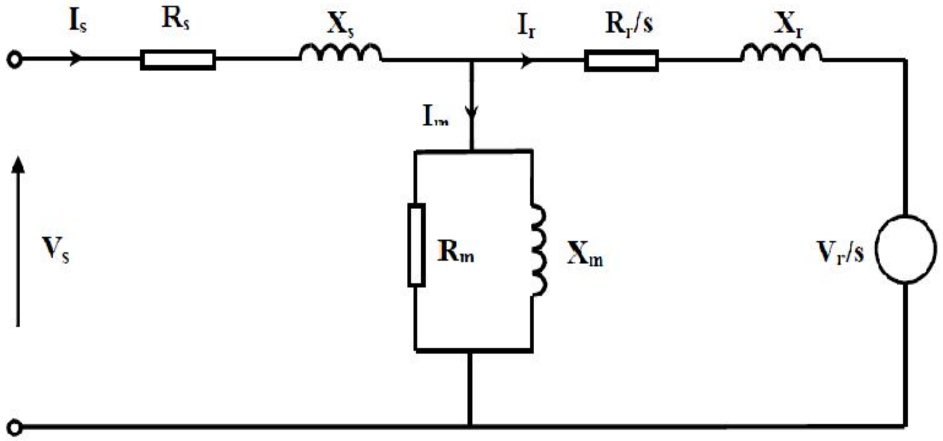


Fig 4.1: Equivalent circuit of a DFIG [36, 40]

The stator active and reactive power can be expressed in terms of the stator and rotor currents as in the equations 4.2 and 4.3[36, 40],

$$P_s^2 + Q_s^{\,2} = (3V_s I_r)^2 \tag{4.2}$$

$$P_s^2 + \left(Q_s + 3\frac{V_s^2}{X_s}\right)^2 = \left(3\frac{X_m}{X_s}V_s I_r\right)^2 . \tag{4.3}$$

Where

P_s is the real stator power

Q_s is the reactive stator power

In the PQ plane, the equation (4.1) represents the circumference centered at the origin [0, 0] with the radius equal to the stator speed apparent power. Equation (4.2) represents a circumference centered at $[-3V_S^2/X_{S,}0]$ and radius equal to $[3(X_m V_S I_r)/X_{S,}]$.Therefore given the maximum rotor and stator allowable currents limits ,$I_{r\,max}$ and $I_{S\,max}$, the DFIG capability limits can be obtained.The composed DFIG capability limits curve is shown in Figure 4.2 where U_S is used instead of V_S .Taking the steady state stability of the DFIG into account, represented by the vertical line at the $[-3V_S^2/X_{S,},0]$ cordinate,it is obvious that the DFIG real and reactive power capability mainly depends on the maximum allowable rotor current.

From the Figure 4.2, the DFIG can operate at any point in the intersecting area within the given limits. When the available active power is far from its maximum, the amount of reactive power is high. The large reactive power control capabilities of the DFIG make it possible to use DFIG as the continuous reactive power support to support system voltage control.

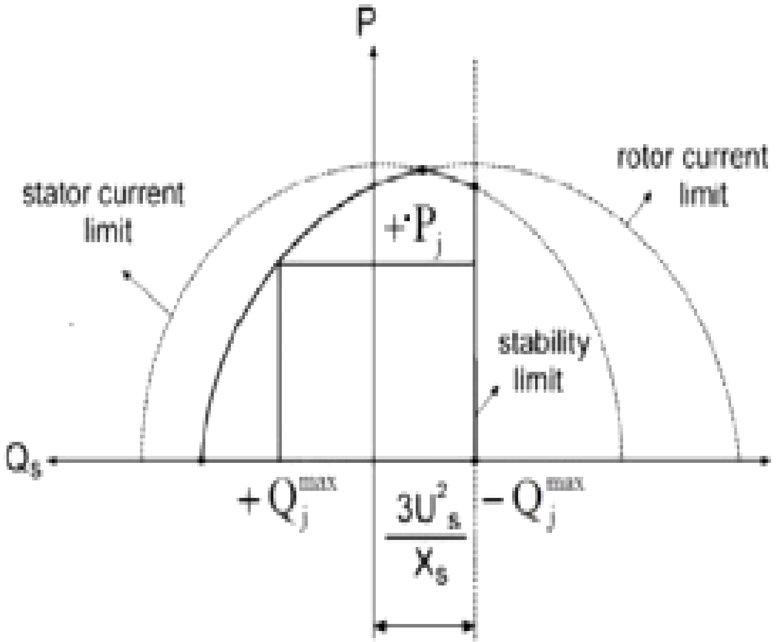


Figure 4. 2: DFIG Capability limits curve [40]

4.4 Problem Formulation

The real power loss in the distribution system is very significant from the system operation point of view. The difference between the generated power and the power demand gives the power loss.

That is:

$$\sum_{i=1}^{n} P_{DFIGi} = \sum_{i=1}^{n} P_{Di} + \sum_{i=1}^{n} P_{L} \qquad (4.3)$$

Where

$P_L = \sum_{i=1}^{n} P_{loss}$ Is the total real power loss

$\sum_{i=1}^{n} P_{DFIGi}$ Is the generated power

$\sum_{i=1}^{n} P_{Di}$ Is the power demand

The objective of the placement technique is to minimize the total real power loss. Mathematically, the objective function can be written as:

$$\min p_L = \sum_{i=1}^{n} P_{loss} \qquad (4.4)$$

with

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} K_i (P_i P_j + Q_i Q_j) + K_t (Q_i P_j - P_i Q_j).$$

where

$$K_i = \frac{R_{ij}\cos(\delta_i - \delta_j)}{V_i V_j}$$

$$K_t = \frac{R_{ij}\sin(\delta_i - \delta_j)}{V_i V_j}$$

Where

K_i is the real power participation factor,

$K_t$is the reactive power participation factor

$P_i\,P_j$, and $Q_{\ i}Q_j$ are the net real and reactive power injections in bus " i" and "j" respectively

R_{ij} is the resistance between bus " i" and "j",

V_iV_j and $\delta_i\delta_j$ are the voltage and angle at bus " i" and "j" respectively.

In the objective function, the network parameters are absorbed in the loss equation by the real and reactive participation factors formulated in chapter 3.

The objective function is solved subject to the following constraint of DFIG domains and the power distribution system parameters:

(i)Power balance

$$\sum_{i=1}^{n} P_{DGi} = \sum_{i=1}^{n} P_{Di} + P_L \tag{4.5}$$

(ii)DFIG active capability limits

$$P_{DGi}^{\min} \leq P_{DG} \leq P_{DGi}^{\max} \tag{4.6}$$

(iii)DFIG reactive capability limits

From

$$P^2_{DFIGi} + (Q_{DFIGi} + 3\frac{V_s^2}{X_s})^2 = (3\frac{X_m}{X_s}V_s I_r)^2 \tag{4.7}$$

Since for the DFIG, $X_m \ggg X_s$ the middle term for the product of the reactive power component can be ignored hence,

$$Q^2_{DFIGi} \le (3\frac{X_m}{X_s}V_s I_r)^2 - P^2_{DFIGi} - (3\frac{V_s^2}{X_s})^2 \tag{4.8}$$

$$-Q^2_{DFIGi} \le (3\frac{X_m}{X_s}V_s I_r)^2 - P^2_{DFIGi} + (3\frac{V_s^2}{X_s})^2 . \tag{4.9}$$

Where

P_{DFIGi} is the real power generated by DFIG i

Q_{DFIGi} is the reactive power generated by DFIG i

(v)Voltage constraints at the buses

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{4.10}$$

(vi)Line thermal limit

$$P_{ij} \le P_{ij}^{\max} \tag{4.11}$$

4.5 HGAPSO Method

HGAPSO is made up of two pure optimization methods GA and PSO.The individual methods are discussed and then the hybrid formed is presented.

4.5.1 Particle Swarm Optimization (PSO)

Swarm Intelligence (SI) is an innovative distributed intelligent paradigm for solving optimization problems that originally took its inspiration from the biological examples by swarming, flocking and herding phenomena in vertebrates[12] Particle Swarm Optimization (PSO) incorporates swarming behaviors observed in flocks of birds, schools of fish, or swarms of bees, and even human social behavior, from which the idea is emerged .PSO is a population-based optimization tool, which could be implemented and applied easily to solve various function optimization problems. As an algorithm, the main strength of PSO is its fast convergence, which compares favorably with many global optimization algorithms like Genetic Algorithms (GA) Simulated Annealing (SA) and other global optimization algorithms. For applying PSO successfully, one of the key issues is finding how to map the problem solution into the PSO particle, which directly affects its feasibility and performance [20].

4.5.2 Genetic Algorithm (GA)

Genetic Algorithms are a family of computational models inspired by evolution. These algorithms encode a potential solution to a specific problem on a simple chromosome-like data structure and apply recombination and mutation operators to these structures so as to preserve critical information[12].An implementation of a genetic algorithm begins with a population of (usually random) chromosomes.

One then evaluates these structures and allocates reproductive opportunities in such a way that those chromosomes which represent a better solution to the target problem are given more chances to reproduce than those chromosomes which are poorer solutions. The goodness of a solution is typically defined with respect to the current population.

The genetic algorithm can be viewed as two stage process. It starts with the current population. Selection is applied to the current population to create an intermediate population. Then recombination and mutation are applied to the intermediate population to create the next population. The process of going from the current population to the next population constitutes one generation in the execution construction of the intermediate population is complete and recombination can occur. This can be viewed as creating the next population from the intermediate population. Crossover is applied to randomly paired strings with a probability denoted Pc. A pair of strings is picked with probability Pc for recombination. These strings form two new strings that are inserted into the next population. After recombination, mutation operator is applied. For each bit in the population, is mutated with some low probability Pm. Typically the mutation rate is applied with less than 1% probability. In some cases mutation is interpreted as randomly generating a new bit in which case, only 50% of the time will the mutation actually change the bit value. After the process of selection, recombination and mutation, the next population can be evaluated. The process of evaluation, selection, recombination and mutation forms one generation in the execution of a genetic algorithm.

4.5.3 Hybrid of PSO and GA (HGAPSO)

The drawback of PSO is that the swarm may prematurely converge [12]. The underlying principle behind this problem is that, for the global best PSO, particles converge to a single point, which is on the line between the global best and the personal best positions. This point is not guaranteed for a local optimum .Another reason for this problem is the fast rate of information flow between particles, resulting in the creation of similar particles with a loss in diversity that increases the possibility of being trapped in local optima.

A further drawback is that stochastic approaches have problem-dependent performance. This dependency usually results from the parameter settings in each algorithm. The different parameter settings for a stochastic search algorithm result in high performance variances. In general, no single parameter setting can be applied to all problems. Increasing the inertia weight (w) will increase the speed of the particles resulting in more exploration (global search) and less exploitation (local search) or on the other hand, reducing the inertia weight will decrease the speed of the particles resulting in more exploitation and less exploration. Thus finding the best value for the parameter is not an easy task and it may differ from one problem to another. Therefore, from the above, it can be concluded that the PSO performance is problem-dependent. The problem-dependent performance can be addressed through hybrid mechanism. It combines different approaches to be benefited from the advantages of each approach.

To overcome the limitations of PSO, hybrid algorithms with GA are proposed. The basis behind this is that such a hybrid approach is expected to have merits of PSO with those of GA. One advantage of PSO over GA is its algorithmic simplicity. Another clear difference between PSO and GA is the ability to control convergence. Crossover and mutation rates can subtly affect the convergence of GA, but these cannot be analogous to the level of control achieved through manipulating of the inertia weight. In fact, the decrease of inertia weight dramatically increases the swarm's convergence. The main problem with PSO is that it prematurely converges to stable point, which is not necessarily maximum. To prevent the occurrence, position update of the global best particles is changed. The position update is done through some hybrid mechanism of GA. The idea behind GA is due to its genetic operators crossover and mutation. By applying crossover operation, information can be swapped between two particles to have the ability to fly to the new search area. The purpose of applying mutation to PSO is to increase the diversity of the population and the ability to have the PSO to avoid the local maxima.

There are three different hybrid approaches are proposed. In PSO-GA (Type 1), the gbest particle position does not change its position over some designated time steps, the crossover operation is performed on gbest particle with chromosome of GA. In this model both PSO and GA are run in parallel.

In PSO-GA (Type 2), the stagnated pbest particles are change their positions by mutation operator of GA. Lastly, in PSO-GA (Type 3), the initial population of PSO is assigned by solution of GA. The total numbers of iterations are equally shared by GA and PSO. First half of the iterations are run by GA and the solutions are given as initial population of PSO. Remaining iterations are run by PSO

In this thesis, the PSO-GA type 2 is preferred since we are interested in changing the siting of the DFIGs optimizes the power losses, taking their capacities as a constant.

PSO, which is stochastic in nature and makes use of the memory of each particles as well as the knowledge gained by the swarm as a whole, has been proved to be powerful in solving many optimization problems. The hybrid PSO systems find a better solution without trapping in local maximum, and to achieve faster convergence rate. This is because when the PSO particles stagnate, GA diversifies the particle position even though the solution is worse. In PSO-GA, particle movement uses randomness in its search. Hence, it is a kind of stochastic optimization algorithm that can search a complicated and uncertain area. This makes PSO-GA more flexible and robust. Unlike standard PSO, PSO-GA is more reliable in giving better quality solutions with reasonable computational time, since the hybrid strategy avoids premature convergence of the search process to local optima and provides better exploration of the search process.

4.6 Proposed HGAPSO Algorithm

The HGAPSO based approach for solving the optimal sizing and placement of the DFIG is aimed at minimizing the distribution line real and reactive losses. In this thesis, the reactive power output is obtained by means of the DFIG power curves after the active power output is known. The total active power output is obtained by the equation(4.5).Considering the capability limits of the DFIGs,the maximum of the reactive power that each DFIG can generate or absorb, the HGAPSO based approach for solving the problem to minimizes the losses takes the following steps.

Step 1: Input the line and bus data and the bus voltage limits

Step 2: calculate the loss using distribution load flow based on backward forward sweep

Step 3: Randomly generate an initial population (array) of particles with random initial positions and velocities on dimensions in the solution space.Set the iteration counter $k = 0$

Step 4: For each particle, if the bus voltage is within the limits, perform mutation on the particle position, one by one, keeping the velocity fixed, then perform mutation on the velocity, keeping the position fixed. Other n positions and k velocities are obtained. Calculate the total losses as in equation 1 in each case.

Step 5: For each particle, compare its objective position and velocity with the *individual best* .If the objective value is lower than *Pbest*, set this value as the current Pbest, and record the corresponding particle position.

Step 6:Compare all components of the particle according to their fitness values. Choose the particle associated with the minimum *individual best Pbest* of all the particles and set the value of this Pbest as the current *overall best Gbest*

Step 7: If the iteration number reaches the maximum limit, go to **step 9**.Otherwise set iteration index $k = k + 1$ and go back to step 4

Step 8: Update the velocity and position of the particle

Step 9: If the particle equals to the population size N, print out the optimal solution of the targeted problem, otherwise set the particle to i=1 and go to **step 3.**

Step 10. Assign Combined participation Factors to each particle taking into consideration the DFIG domains chapter 3

The best position includes the optimal locations and sizes of the DFIGs and the corresponding fitness value represents the minimum total real power loss.

The flow chart for the proposed HGAPSO algorithm is as shown in the Fig 4.3

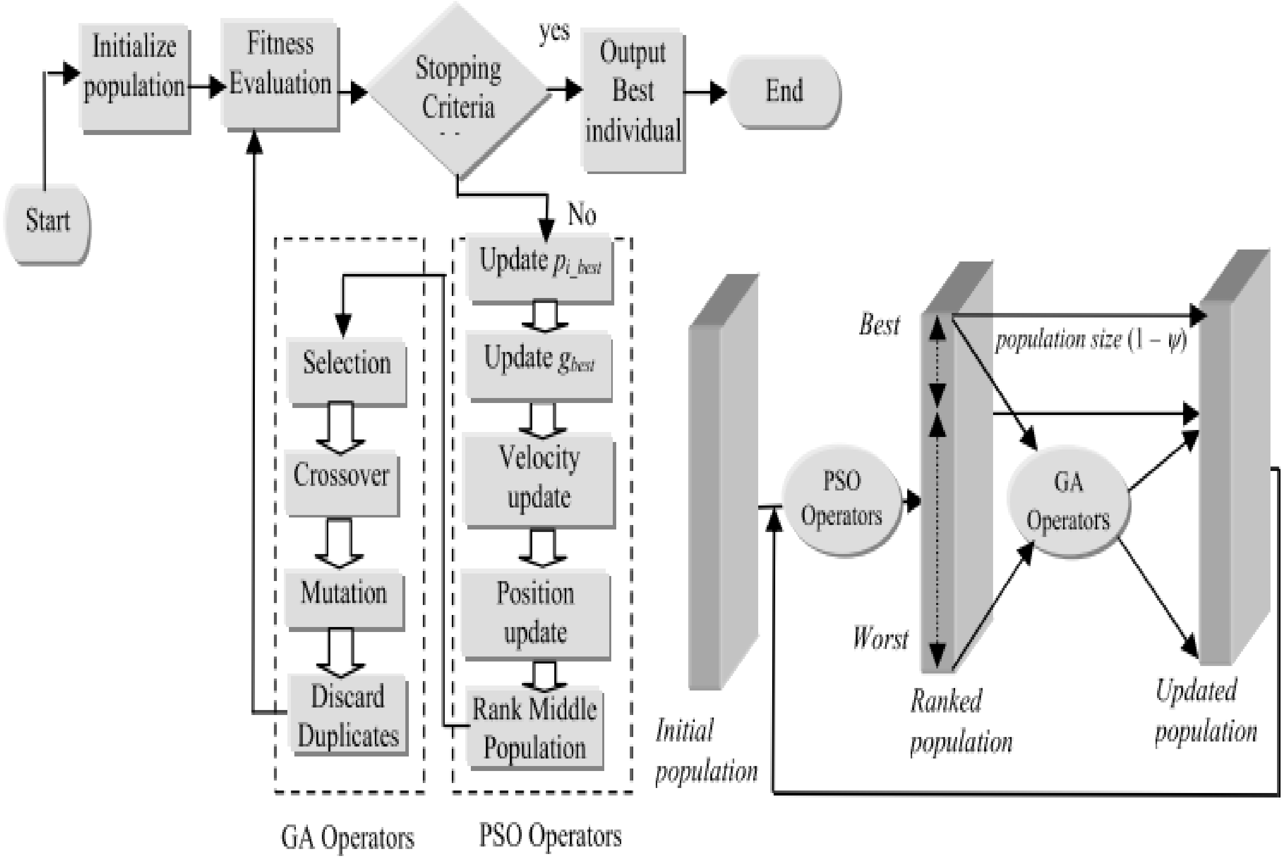


Figure 4.3 Flow chart for HGAPSO Algorithm

4.7 Results and Analysis

The simulation results presented in this section concern the power loss reduction and the improved voltage profile.

4.7.1 Power Loss Reduction

Simulations were run on the IEEE 33Bus Radial distribution Test System [35] the real and reactive power losses obtained through load flow, PSO and HGAPSO are as shown in the Tables 4.1, 4.2 and 4.3

Table 4.1 Case A: 1.5 MW DFIG on Bus 19

$$K = 0.1856 + j0.1098$$

METHOD	P LOSS KW	QLOSS KVAR	LOSS REDUCTION %	
LOAD FLOW[7]	221.4346	150.1784	REAL	REACTIVE
PSO[36]	70.9526	57.2155	67.95	61.90
HGAPSO[This method]	69.5578	56.2116	68.59	62.57

Table 4.2: Case B: 1.5 MW DFIG on Bus 18

$$K = 0.3458 + j0.3189$$

METHOD	P LOSS KW	QLOSS KVAR	LOSS REDUCTION %	
LOAD FLOW[7]	221.4346	150.1784	REAL	REACTIVE
PSO[36]	69.9526	56.3189	68.41	62.50
HGAPSO[This method]	68.4589	54.9676	69.09	63.40

Table 4.3: Case C: 1.5 MW DFIG on Bus 3

$$K = 0.0234 + j0.0187$$

METHOD	P LOSS KW	QLOSS KVAR	LOSS REDUCTION %	
LOAD FLOW[7]	221.4346	150.1784	REAL	REACTIVE
PSO[36]	68.8536	53.8907	68.91	64.12
HGAPSO[This method]	66.5578	50.8765	69.94	66.12

The load flow method determines the total real and reactive power losses accurately in the 33 bus radial distribution system. The basic PSO seems to provide better loss reduction than the load flow but this is not accurate enough since the PSO algorithm may have converged before all the buses are considered.

The HGAPSO on the other hand provides a better loss reduction technique compared to the PSO in that the mutation operator ensures no local /premature convergence occur and thus it can be applied in practical distribution systems. The % real and reactive power loss reduction is better with HGAPSO as compared to the load flow and the PSO.

4.7.2 Bus Voltage Profile

The voltage level of all the buses keep the standards level of voltages (+-5%) with load flow, PSO and HGAPSO as shown in the Fig 4.5 .However, the voltage is more improved by using HGAPSO

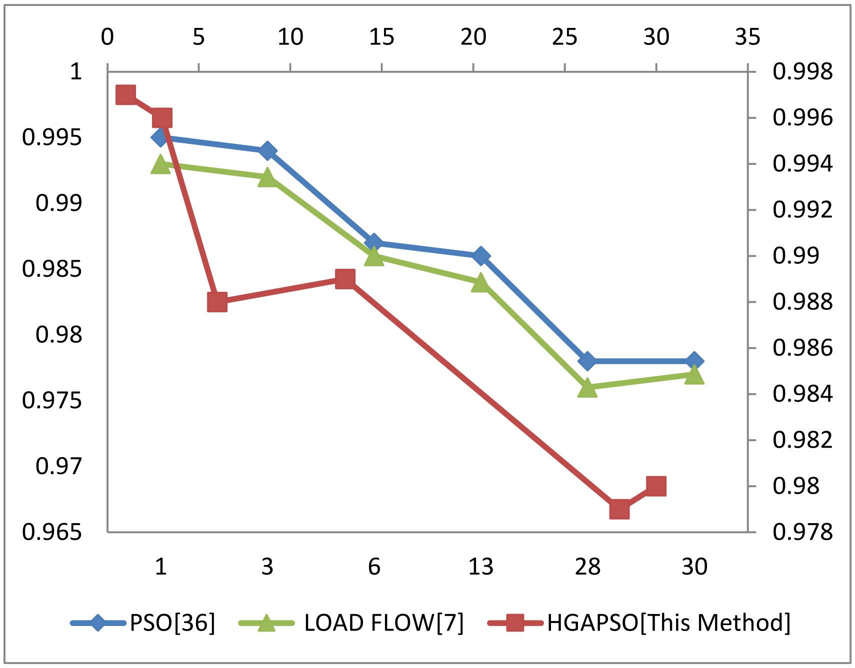


Fig 4.4: Bus Voltages Profile after DFIG Placement using PSO and HGAPSO and load flow

4.8 Chapter Conclusion

The DFIG wind turbines are capable of reducing both real and reactive power losses in a power distribution system; however they need to be placed at suitable locations. The PSO algorithm is optimally placing the DFIG with the objective of reducing the total real power losses in the primary distribution systems. The PSO is fast and accurate in determining the sizes and the locations. However this ordinary PSO is prone to local minima and premature convergence hence not applicable in solving real life power system optimization problems.

The HGAPSO algorithm performs the optimisation over a larger search space since it escapes from local minima and increases the diversity of variable values using the mutation operator. The HGAPSO optimises in a better way, the real and reactive power losses at the same time giving an improved voltage profile.

The numerical results shows that the integration of the DFIG wind turbines into the traditional power distribution system is highly effective in reducing real and reactive power losses in the primary distribution System9 buses 18 and 3 in this case) when HGAPSO is used as compared to the ordinary PSO.

In DFIG placement and sizing with the objective of optimizing real and reactive power losses ,the bus to which the DFIG domain Distributed Slack Bus Model assigns a large Combined Participation Factor is considered as the optimal site for the DFIG.In this case the large combined participation factor is assigned to DFIG In bus 3 and 18 ,the primary distribution system .

When well applied to a DFIG, the HGAPSO can be used to reduce the real and reactive power losses by 70% and 67% at the same time giving an improvement of the voltage profile by almost 0.3% from the PSO and by almost 0.6% from the load flow.

From the tabulated results, the best locations corresponding to the optimum size for reducing the total real and reactive power losses is in the primary distribution system.

Chapter 5

ACTIVE DISTRIBUTION NETWORK RECONFIGURATION (ADNR) PROBLEM WITH WIND & UNCERTAIN LOAD

This chapter deals with the active distribution network reconfiguration (ADNR) problem taking into consideration wind based DFIG and uncertain loads. A hybrid of bacterial foraging (BF) and Differential evolution (DE) (HBFDE) is formulated and then applied for a stochastic wind scenario and the results compared with those of a deterministic case. First, an introduction to network configuration is given in the next section.

5.1 Background

The configuration of most electric distribution networks is radial for proper protection coordination. Due to some objectives such as supply all of the loads, reduce power loss, increase system security and enhancement of power quality, the configuration of these networks may be changed with automatic or manual switching operations. Distribution network reconfiguration also relieves the overloading of network components. This change is performed by opening **sectionalizing** (normally closed) and closing **tie** (normally open) switches of the network. These switching operations are performed in such a way that all of the loads are energized and the radiality of the network is preserved.

From the impact of DG on power distribution networks, the distribution system reconfiguration is found to have more line losses and reduced terminal voltage as compared to transmission network. For optimizing power loss, the new reconfiguration is used as the feeder reconfiguration systematic method to operate the distribution system at minimum cost and with improved system reliability and security. By opening or closing the feeder switches, load currents can be transferred from feeder to feeder thus helping to study the effect of DG on the distribution networks with reference to network reconfiguration problems. The combination of feeder reconfiguration and DG placement process not only reduce the power loss but also improve the voltage profile. DGs are not only employed to provide real and /or reactive power compensation in distribution systems but also to reduce the power losses and to maintain the voltage profile within the acceptable limits. In this thesis the wind based DFIG has been be considered.

The numerous advantages of the DFIG in terms of their low or zero emission and their much smaller size than conventional central power plants have created more incentives than before to use these kinds of generators with free energy source. Therefore, it is necessary to study the impact of DFIGs units on the distribution networks especially on the ADNR [41]-[42].

5.2 Network Reconfiguration Review

The problem of NR is not a new one. Many studies have undertaken the challenge of loss minimization in the area of the network reconfiguration. One of the first researches on this area had been introduced by **Merlin and Back, 1975, [43].** They solved the problem by the branch and bound method. But the introduced method has two drawbacks. Firstly, the convergence of the solution was not guaranteed, and secondly it required a huge amount of calculations for a real network.

R.J. Sarfi et al ,1994 [44], proposed a simple innovative method for calculating loss through the network reconfiguration, which is based on some simplifications in order to calculate the change of loss in load transfer from one feeder to another. Later **Awaji and Galiana, 2012[45]**

improved the method proposed in [44] with a few corrections. The main drawbacks of the method are that there is no guarantee to reach the global solution and the final solution depends on the initial status of the tie and sectionalizing switches.

Due to the evolution of the central grid into a smart one the studies and approaches to NR have changed significantly. Many recent researchers have used evolutionary algorithms to solve ADNR problem in [46, 47], a problem for loss reduction and load balancing as an artificial bee colony (ABC) problem was modeled. **Qiwang et al, 2009, [48]** introduced a power-flow-minimum heuristic algorithm for ADNR problem. In [49], a model based automated strategy was considered the ADNR problem taking the smart grid into consideration. **J. Torres-Jimenez et al, 2010 [50]** proposed a GA and Spanning trees multi-objective approach to solve the ADNR problem [50]. In [51], an algorithm was considered for efficient and automatic NR based on the service restoration and load balancing in a real-time operation. The method was based on differential evolution (DE)**. Chiou et al, 2005, [52]** presented a variable scaling hybrid differential evolution (VSHDE) to solve the ADNR. In his work, minimizing the power loss was considered as the objective function. **Nuno and Susana, 2011 [53]** proposed a method for network reconfiguration to minimize power loss by using the improved MIHDE.In [54], a PSO based algorithm for multi-objective ADNR with fault restoration is proposed. **Wu et al, 1989, [55]** proposed a hybrid algorithm based on GA and PSO for ADNR problem while **Yu et al, 2009, [56]** proposed an improved genetic algorithm with infeasible solution disposing for the ADNR problem.

In all mentioned work, the ADNR problem has been solved without considering the DFIG and the stochastic wind scenario. In general the challenges facing the integration of Wind energy into the grid have been ignored.

5.3 ADNR with Wind Based DFIG

The most recent studies on the ADNR problem with wind has been done by considering general wind turbines. To achieve the reconfiguration of distribution network with wind turbine, **Shuang et al, 2012 [57],** raised a probability-based scenario analysis to form typical scenarios of wind turbine with consideration of statistical characteristics of wind energy output. By generating the switch-state graph of distribution system, NR was simplified to the optimization problem of network switch-state combination. For model solution, a genetic algorithm (GA) and the way of "breaking circle" was employed to seek optimal network reconfiguration scheme with wind turbine under mono-scenario and the multiscenario.

Zhou et al, 2011 [58] proposed a chance constrained programming formulation for distribution reconfiguration with WTG that aims at minimum power loss and increasing voltage quality. A scenario analysis method was applied to describe the random output of WTG through the scenario probability and scenario output. A multiple objective PSO (MOPSO) was employed to solve the multi-objective discrete nonlinear optimization problem. The dedicated particle encoding with the mesh information of the distribution network can effectively avoid producing a large amount of invalid solutions. With MOPSO, it was possible to obtain the optimum solution set of each objective while helping the operator to choose the most appropriate plan for reconfiguration.

Yuqing et al, 2010, [59] presented a novel scenario distribution network reconfiguration model in which the scenario analysis method was applied to describe the random output of the WTG and its influence through the scenario selection and scenario voltage. Multiple WTGs and wind farms connected with a network was also considered in this model. An efficient GA was presented for the scenario distribution network reconfiguration model. Through the non-feasible coding rule in the initial population strategy, cross strategy and eugenic strategy, individuals in the evolution always form the feasible solutions which can meet the requirement of the actual distribution network. Physical optimization based on scenario voltage in the process of evolution reduces the optimization time and the dependence of the initial population. All these studies are based on general WTGs and are therefore not suitable for the commercial DFIG.In Addition the hybrid optimization methods are the state of the art means for a real time and real world power system for they enhance the strengths of the methods involved and discard their weaknesses.

Jingjing Zhao et al, 2009, [60] proposed a joint optimization algorithm of combining reactive power control of wind farm with DFIG and network reconfiguration. In the proposed joint optimization algorithm, an improved hybrid particle swarm optimization with wavelet mutation algorithm (HPSOWM) was developed for voltage profile improvement which utilized reactive power output of wind farm as the control variable. In each particle updating instance at each iteration of reactive power output optimization algorithm, a binary particle swarm optimization algorithm (BPSO) is utilized to find the optimal network structure. This problem will be revisited in this thesis by using an HBFDE algorithm

In the distribution system, due to many candidate switching combinations and also presence of DFIG units, the ADNR problem is modeled as a MINLP problem. Various methods such as LP, MIP, QP, can be used to solve this problem. However, in many cases, the classical methods fail to provide the global optimum solution and only reach local solution.

In recent years, the BF and DE algorithms have been proposed as two powerful optimization evolutionary algorithms in the field of optimization [61]-[62]. Although in many cases, BF eventually determines the desired solution, its convergence rate is slow and its local search is weak. In other side, DE algorithm has a good performance in the local search area but its global search is weak and its performance depends on the proper selection of the initial population. In this thesis, a hybrid method is employed to combine the BF and DE algorithms (HBFDE) based on the evolutionary natures of them. This will take the advantage of the compensatory property of both of them and avoid their negative points. Most important advantage of proposed HBFDE algorithm is high accuracy in finding the optimal switching combination of the distribution system to minimize the network loss.

In addition, the decision maker must be able to balance the consumption and generation of energy at both short and long time intervals. Due to intermittent nature of wind and loads, this is difficult for the network operator to balance the consumption and production of energy when the wind turbines are feeding the electrical network [63]-[65]. This is the main reason why a good prediction has a significant role in the handling of the DFIG and loads in electrical networks. Hence, in this thesis, the system uncertainty including the DFIGs and loads are modelled in a stochastic approach based on scenarios. The scenarios are generated using the **roulette wheel mechanism** which models the stochastic behaviours of the wind speed and loads uncertainty. Moreover, an aggregation method is used to decrease the computation burden and extract one scenario among all generated scenario so that the uncertainty of all scenarios are considered in aggregated scenario based on their probability. Finally, the HBFDE algorithm is used to optimize the problem for deterministic and stochastic (aggregated) scenarios.

5.4 ADNR Problem Formulation with Wind

The ADNR problem considering the DFIG is a mixed integer nonlinear optimization problem. (MINOP). In this problem, there are many different objective functions including loss minimization, balancing the load on transformers, balancing the load on feeders, maximum loading of feeders and minimizing the deviation of voltages from nominal value. In this thesis, power loss minimization is considered as the objective of ADNR problem with regard to DFIG, while the other objectives are considered as constraints. The minimization of total real power loss is calculated as follows [63]:

$$f(\mathrm{X}) = \sum_{i=1}^{N_{br}} R_i \times |I_i|^2 \tag{5.1}$$

$$\mathrm{X}_i = [Tie_1, Tie_2, ..., Tie_{N_{tie}}, Sw_1, Sw_2, ..., Sw_{N_{\mathrm{tie}}}, pf_1, pf_2, ..., pf_{N_{WTG}}]_{1\times(2N_{tie}+N_{WTG})}$$

Where ,

R_i resistance of the *ith* branch

I_i actual current of the *ith* branch

N_{tie} number of tie switches

N_{WTG} number of WTG units, in this case DFIG

The vector X has three sections: Tie_i, that represents the situation of tie switches in *i*th loop and get ‘0’ and ‘1’ values corresponding to open and close states, respectively. Indeed, if the Tie_i is 0, it means that the tie switch of *i*th loop must remain unchanged (open), also if it is ‘1’ , it means that tie switch of *i*th loop must be closed .The Sw_i that is one of the sectionalizing switches in *i*th loop, replace the tie switch of that loop. The third part of vector X is the power factor of *i*th DFIG.

The constraints of the proposed problem are expressed as follows [63, 64]:

- **Distribution line limits**,

$$\left|P_{ij}^{Line}\right| < P_{ij,\max}^{Line} \tag{5.2}$$

where

$\left|P_{ij}^{Line}\right|$ power flowing over distribution lines

This constraint defines the power security of the system

- **Distribution power flow equations**,

$$\begin{aligned} P_i &= \sum_{i=1}^{N_{bus}} V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) \\ Q_i &= \sum_{i=1}^{N_{bus}} V_i V_j Y_{ij} \sin(\theta_{ij} - \delta_i + \delta_j) \end{aligned} \tag{5.3}$$

Where

P_i net injected active power components at the ith bus.

Q_i net injected reactive power components at the ith bus.

V_i amplitude of voltage at the ith bus

δ_i angle of voltage at the ith bus

- **The radiality of the network,**

$$N_{FL} = N_{br} - N_{bus} + 1 \tag{5.4}$$

Where

N_{FL} number of main loops

N_{bus} number of buses

N_{br} number of branches

In this thesis, the main closed loops of the system are used to check the radial structure of the network

- **Limit on the currents of the transformers**,

$$\left|I_{t,i}\right| \leq I_{t,i}^{\max} \qquad i = 1,2,\ldots,N_t \tag{5.5}$$

Where

$|I_{t,i}|$ current amplitude of the ith transformer

N_t number of transformers

- **The current limit of the feeders,**

$$|I_{f,i}| \le I_{f,i}^{\max} \qquad i = 1,2,\ldots,N_f \tag{5.6}$$

Where

$|I_{f,i}|$ current amplitude of the ith feeder

N_f number of feeders

- **Active power constraints of the DFIG,**

$$p_{\min,w,i} \le p_{w,i} \le p_{\max,w,i} \tag{5.7}$$

Where

$p_{w,i}$ Generated active power of ith DFIG.

- **Bus voltage amplitudes ,**

$$V_{\min} \leq V_i \leq V_{\max} \tag{5.8}$$

- **Power factor constraints of the DFIG,**

$$pf_{\min,i} \leq pf_i \leq pf_{\max,i} \tag{5.9}$$

5.5 The Stochastic Model of DFIG and Loads

In this case, there is need to balance the consumption and production of energy in a system considering DFIG. Hence we must make a good prediction of wind speed and loads. In this thesis, to make a good prediction of uncertainty parameters, the wind and loads uncertainty are considered based on the wind and loads forecast error [64, 65]. So, the probability distribution function (PDF) of the wind and loads forecast error should be constructed .In this thesis a typical PDF has been considered. The continuous distribution function of the wind forecast error along with its discretization is shown in Fig.5.1 according to which seven intervals are centered on the zero mean and each of intervals are one wind speed forecast error standard deviation, as presented in [66]. Finally, a roulette wheel mechanism [67] is implemented to generate scenarios for the proposed time. In the roulette wheel mechanism, scenarios are selected on the basis of different wind and loads forecast levels and their probabilities obtained from the PDF.

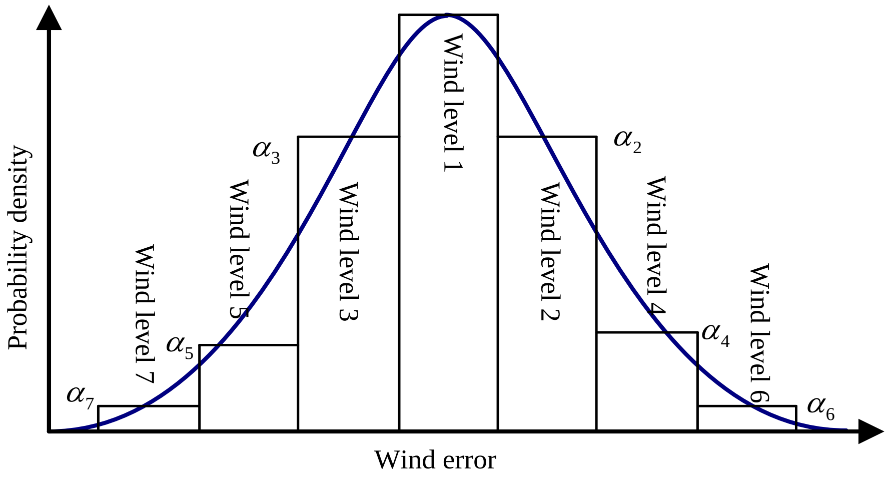


Fig 5.1: Discretization of PDF of wind forecast error

For this purpose, at first, the probabilities of different wind and loads forecast levels are normalized such that their summation becomes equal to unity. Then, by roulette wheel mechanism a scenario is obtained. In this regards, as shown in Fig. 5.2, the range of 0-1 is occupied by the normalized probabilities. After that, random numbers are generated between 0 and 1. Each random number falls in the normalized probability range in the roulette wheel .The selected interval is associated with a binary digit equal to 1, and other interval becomes zero.

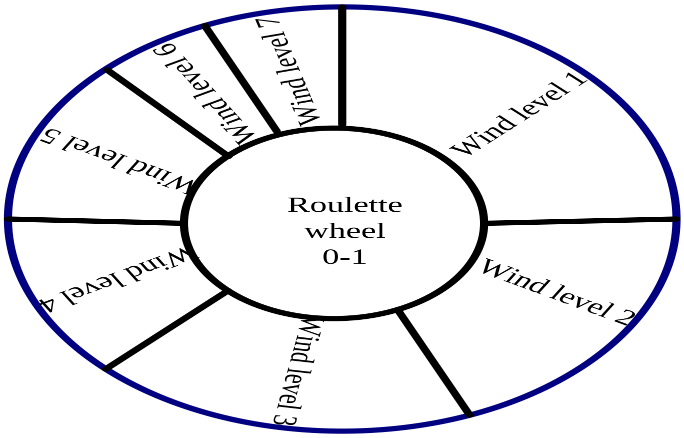


Fig 5.2: Roulette Wheel Selection

After obtaining the wind and load forecast level for all DFIGs and loads, a scenario corresponding to all DFIGs and loads is produced. A scenario is a vector of binary parameters that identify the wind and loads intervals: This procedure is repeated until the desired number of scenarios is generated by the relation [64]

$$scenario_n = [W_{1,n}^{WTG_1}, \dots, W_{7,n}^{WTG_1}, \dots, W_{1,n}^{WTGn1}, \dots, W_{7,n}^{WTGn1}, W_{1,n}^{load1}, \dots, W_{7,n}^{load1}, \dots, W_{1,n}^{loadn}, \dots, W_{7,n}^{loadn}]_{1\times(7(N_{WTG}+N_{load}))} \quad (5.10a)$$

The probability of all scenarios is then calculated by equation 5.10b [64]

$$p_{Senario_n} = \frac{\prod_{j=1}^{N_{WTG}} \sum_{i=1}^{7} w_{n,i,j}^{WTG} . \alpha_{n,i,j} . \prod_{m=1}^{N_{load}} \sum_{r=1}^{7} w_{n,r,m}^{load} . \alpha_{n,r,m}}{\sum_{k=1}^{N_{sen}} \left(\prod_{j=1}^{N_{WTG}} \sum_{i=1}^{7} w_{n,i,j}^{WTG} . \alpha_{n,i,j} . \prod_{m=1}^{N_{load}} \sum_{r=1}^{7} w_{n,r,m}^{load} . \alpha_{n,r,m} \right)}$$

$$n = 1, 2, \dots N_{sen} \quad (5.10)$$

Where

$W_{i,n}^{WTG_j}$ binary parameter indicating whether the ith wind interval of ith WTG is selected in the ith scenario.

N_{sen} Number of scenario

$P_{scenario_n}$ Probability of the nth scenario

α is the coefficient of power of WTG j in the nth scenario of the wind forecast error, standard deviation which is a measure of uncertainty of wind loading.

Finally, obtained wind speed is converted to the active power of DFIGs according to the equation [68]:

$$P_w = \begin{cases} 0 & v_w \le v_1 \, , \, v_w \ge v_3 \\ \phi(v_w) & v_1 \le v_w \le v_2 \\ p_n & v_2 \le v_w \le v_3 \end{cases} \tag{5.11}$$

Where,

v_1, v_2 and v_3 are, cut in, rated and cut-out wind speeds respectively (m/s)

P_w the output power from a wind turbine

$\Phi(V_w)$Power generated between the cut in and rated speed which is a function of the wind speed

P_n power generated between rated and cut out speeds

V_w The useful wind speed (m/s)

5.6 The HBFDE Algorithm

HBFDE algorithm consists of two pure optimization methods, BF and DE.In this section the pure methods and the proposed hybrid is presented. We begin with an overview of the pure methods.

5.6.1 Bacterial Foraging (BF) Algorithm

The Bacterial Foraging algorithm (BF) has been implemented in the global optimization field in the recent years. BF algorithm is based on the foraging behaviour of the *E. coli* bacteria. Each bacterium by its selection behaviour tries to eliminate the poor foraging strategy and modifies the successful foraging strategy. As the other evolutionary algorithms, this algorithm is designed to solve non-gradient optimization problems with non-differentiable and complex objective functions such as DNR problem. In BF algorithm, each possible solution is considered as bacteria. There are three main steps in the original BF algorithm, namely; chemotaxis, reproduction and elimination or dispersal [61].

The **initial population** of bacteria must be produced in their search space according to the equation,

$$BF\_Population = \begin{bmatrix} \mathrm{X}_1 \\ . \\ . \\ . \\ \mathrm{X}_{N_{BF}} \end{bmatrix}_{(N_{BF})\times(2N_{tie}+N_{WTG})} \qquad (5.12)$$

$$\begin{aligned} &for, \\ &\mathrm{X}_i = [Tie_1, Tie_2, ..., Tie_{N_{tie}}, Sw_1, Sw_2, ..., Sw_{N_{tie}} \\ &\qquad , pf_1, pf_2, ..., pf_{N_{WTG}}]_{1\times(2N_{tie}+N_{WTG})} \qquad , i = 1, 2, ..., N_{BF} \end{aligned}$$

The **chemotaxis** step is composed of a set of consequence swimming following by tumble. At first, based on the rotation of the flagella, the bacterium selects the direction that it should move (tumbling). Then, if the new position of bacterium is better than previous, the bacteria will begin to move in the same previous direction (swimming). A unit length in a random direction represents a tumble; $\phi(j)$, this random direction specifies the direction of the movement after a tumble. The constant run-length unit, $C(i, j)$, determines the size of the step taken in the random direction. In the proposed algorithm, the location of the *i*th bacterium at the *j*th chemotactic step, *k*th reproduction step and *l*th elimination/dispersal event is represented by $\theta^i(j,k,l)$,and the objective function is shown by $J(i, j,k,l)$. After a tumble the location of *i*th bacteria is shown by the equation,

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i, j)\phi(j) \tag{5.13}$$

If the obtained objective function at $\theta^i(j+1,k,l)$ is better (lower) than $J(i, j+1,k,l)$, another step of size $C(i, j)$ in the same direction is taken. This swimming operation is repeated as long as a lower objective function is obtained until a maximum present number of steps are reached.

The objective function of each bacterium in the population is affected by **swarming**, that is performed by the cell-to-cell signalling released by the bacteria groups to form swarm patterns. This procedure is expressed as follows [62]:

$$\begin{aligned} &J_{cc}(\theta, P(j,k,l)) = \sum_{i=1}^{s} J_{cc}^{i}(\theta, \theta^i(j,k,l)) = \\ &\sum_{i=1}^{s}[-d_{attract}\exp(-w_{attract}\sum_{m=1}^{p}(\theta_m - \theta_m^i))] + \sum_{i=1}^{s}[h_{repellant}\exp(-w_{repellant}\sum_{m=1}^{p}(\theta_m - \theta_m^i)^2)] \end{aligned} \tag{5.14}$$

Where, $d_{attract}$, $w_{attract}$, $h_{repelllant}$ and $w_{repellant}$ are coefficients representing the characteristics of the attractant and repellent signals released by the cell and θ_m^i is the *m*th component of *i*th bacteria position θ^i .

Also, the position of each member of the population of the S bacteria is show by $p(j,k,l)$ and defined as:

$$p(j,k,l) = \left\{ \theta^i(j,k,l) \middle| i = 1, 2, \ldots s \right\} \tag{5.15}$$

Where

S is the size of the bacteria population.

$J_{cc}(\theta, P(j,k,l))$ represents the cell-to-cell signaling effect, is added to the $J(i,j,k,l)$.

After N_c steps of chemotactic, the **reproduction** process is performed. In this step, the population is halved so that the least healthy half dies and each bacterium in the other healthiest one splits into two bacteria that take the same position.

$$S_r = \frac{S}{2}$$

An **elimination/dispersal** process is performed after taking a maximum number of chemotactic steps, N_{re}. In this operation each bacterium could be moved to the new position of the search space

5.6.2 Differential Evolutionary (DE) Algorithm

The Differential Evolutionary (DE) algorithm was proposed by **Ji-PyngChiou et al [52]** and futher studied and implemented by **D.Pal et al ,[51]** .This algorithm is a very simple and straightforward optimization strategy .The main concept of DE is conducted by means of four main operations: 1-initialization, 2-mutation, 3- crossover, 4- selection.

In the **initialization** step, N_{DE} vertex points are randomly generated and the fitness of the objective function is evaluated. The generated population is sorted based on the objective function values given by the matrix,

$$DE\_Population = \begin{bmatrix} X_1 \\ . \\ . \\ . \\ X_{N_{DE}} \end{bmatrix}_{(N_{DE})\times(2N_{tie}+N_{WTG})} \tag{5.16}$$

$$X_i = [Tie_1, Tie_2, ..., Tie_{N_{tie}}, Sw_1, Sw_2, ..., Sw_{N_{tie}}, pf_1, pf_2, ..., pf_{N_{WTG}}]_{1\times(2N_{tie}+N_{WTG})} \quad , i = 1, 2, ..., N_{DE}$$

In the **mutation** step, a donor vector Xm_i^{j+1} is created by adding the weighted difference between the two vectors to the third vector as in the equation,

$$Xm_i^{j+1} = X_{r3,i} + \beta(X_{r1,i} - X_{r2,i}) \tag{5.17}$$

Where

Indexes $r1, r2, r3 \in [1, N]$ are selected randomly.

It is noted that random indexes have to be different from each other and from the running index. The β is a constant value in the range of 0 to 2 and controls the amplification of the difference vector of randomly chosen individuals and j is number of iteration. The β factor is determined based on performance of the optimization routine in previous experiments.

In the **crossover**, the new individuals are generated using the following scheme in crossover procedure:

$$\mathbf{u}_i^{j+1} = \begin{cases} \mathbf{X}_i^{j+1} & if \;\; r < CR \\ \mathbf{X}_i^{j} & if \; r > CR \end{cases} \tag{5.18}$$

Where,

r is a random number generator

$r \in [0,1]$ and u_i^{j+1} represents trial individuals

$CR \in [0,1]$ is a constant value

In the **selection** step, the equation in (5.19), is used for the selection with the modification,

$$\mathrm{X}_i^{j+1} = \begin{cases} \mathrm{u}_i^{j+1} & if \;\; f(\mathrm{u}_i^{j+1}) < f(\mathrm{X}_i^{j}) \\ \mathrm{X}_i^{j} & otherwise \end{cases} \tag{5.19}$$

Where

$f(\mathrm{u}_i^{j+1})$ and $f(\mathrm{X}_i^{j})$ are the objective function value of u_i^{j+1} and X_i^{j} , respectively

5.6.3 The HBFDE Algorithm

The combination of BF and DE algorithm with each other and other evolutionary algorithms has been considered by other researchers in recent years.

In [42] and [69], BF and DE has been combined to perform economic load dispatch with non-convex loads and improve the performance of algorithms by increasing the effect of swarming. In [52], a variable scaling hybrid DE algorithm has been proposed to dominate the problem of the selection of a mutation operator. But, this thesis aims at the integration of BF and DE algorithms, to combine their advantages and avoid their negative points. For example, DE algorithm is a very efficient local search procedure, but it is not always available since it is very sensitive to the choice of the initial condition and there is no guarantee to obtain the global optimization. Also, the accuracy of the BF algorithm is not very high and its local search is weak. But, by combining these algorithms, the new algorithm namely, HBFDE algorithm has a better convergence rate in comparison to original BF and DE algorithms.The proposed algorithm works for all Wind Turbine Generators (WTG)

5.7 The ADNR Algorithm with Wind and Load Uncertainty

The algorithm consists of two major sections which are outlined in the sections 5.7.1 and 5.7.2.First the DFIG scenarios are generated and then the HBFDE algorithm is formulated.

5.7.1 The algorithm for the DFIG scenario generation

Step 1: Set i as the initial number of trials; i=i+1

Step 2: Import the basic information; that is the bus and load data.

Step 3: Generate 1000 scenarios for the DFIGs speed.

Step 4: Determine the aggregate of the 1000 generated scenarios using equation (5.10).

Step 5: Use equation (5.11) to determine the DFIG output.

5.7.2 The HBFDE Algorithm Mechanism

Step 6: Generate the initial population.

Step7: Let J be the number of HBFDE iterations, J=J+1.

Step 8: Evaluate the objective function for initial population; that is the power loss.

Step 9: Sort the initial population based on augmented objective function value.

Step 10: Devide the sorted population to BF and DE algorithms**.** The population size is set at *3N*, when solving an *N*-dimensional problem. The initial *3N* solutions are randomly generated and sorted by their fitness, and the top $N=N_{DE}$ solutions fed into the DE method to improve their positions. The other $2N=N_{BF}$ solutions are updated by the BF method. In the BF algorithm *N* neighborhood of bacterium is proposed to expand the local search area. The neighbourhoods best bacterium are selected by first evenly dividing the *2N* bacterium into *N* neighbourhoods and designating the bacterium with the better fitness value in each neighbourhood as the neighbourhood's representative. After first iteration of BF and DE, the first combination is completed. In the second combination, the *3N* updated solutions are sorted again for repeating the entire run. This process is performed after taking a maximum number of combinations.

Step 11: Combine the updated population from **step 10** to generate the HBFDE population

Step 12: Compare the HBFDE iterations J and the initial number of trials i. If $J<J_{max}$ then update the HBFDE iterations to J=J+1 and go back to **Step 7** .Otherwise go to **Step 13.**

Step 13. If $i>i_{max}$ then output results, otherwise go back to Step **1.**

The flow chart for the proposed algorithm is shown in Fig 5.3.

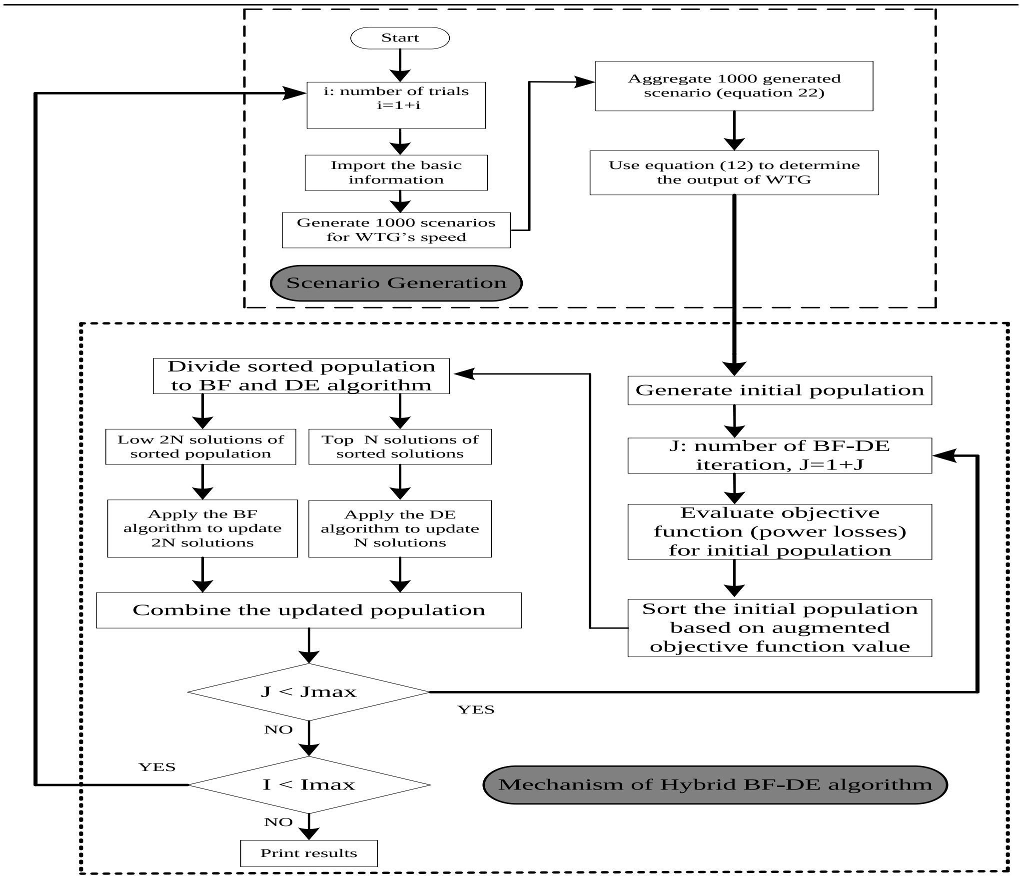


Fig 5.3: Flow Chart for the ADNR Algorithm with wind and load uncertainty.

5.8 Simulation Results and Analysis

The simulation results in this section include the test network before and after reconfiguration, a comparison of the performance of BF,DE and HBFDE,the ADNR problem with wind and uncertain loading ,the voltage profiles and a comparative approach with other methods.

5.8.1 The Test Network before and after reconfiguration

In this thesis to evaluate the feasibility of the proposed approach, we use IEEE 33-bus Radial Distribution Network [55, 70], which is a practical distribution network. The schematic of this network is shown in Fig 5.3a). The distribution network for reconfiguration consists of 33buses and 5 tie lines; the total loads are 5084.26 KW and 2457.32 KVAR. The normally open switches are 33, 34, 35, 36, and 37 represented by the dotted lines and normally closed switches 1 to 32 are represented by the solid lines. For this base case, the initial losses are 221.71 kW.The network after reconfiguration is shown in Fig.5.4 bin this thesis, reconfiguration means closing the normally open switches.

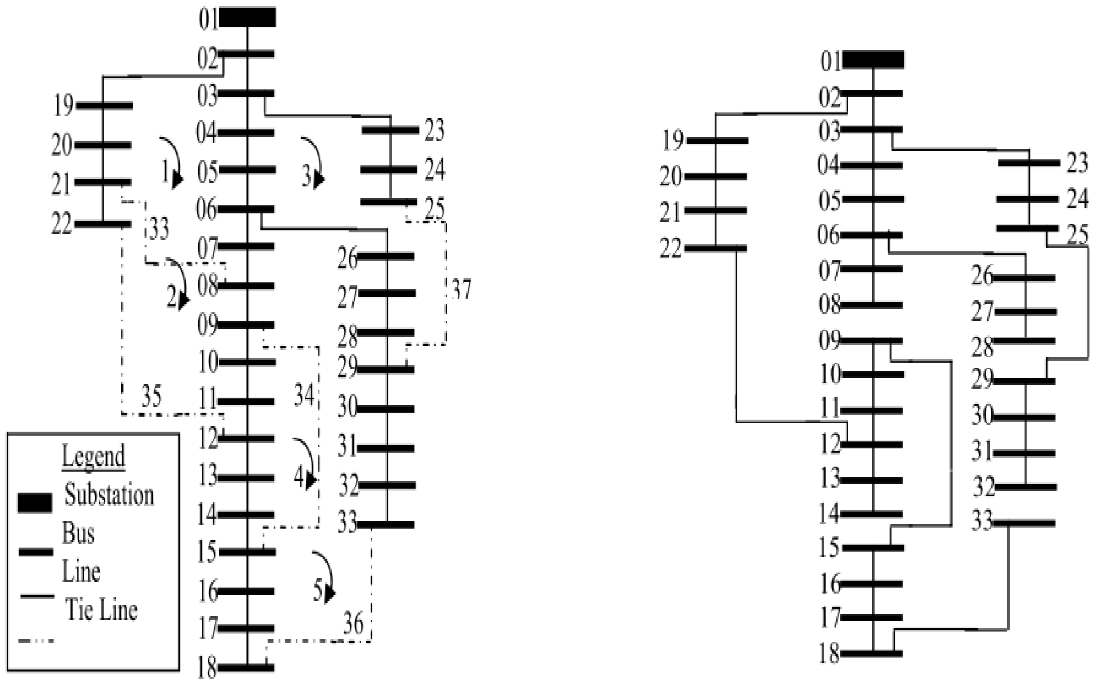


Figure 5.4a)

Figure 5.4b)

Fig. 5.3. 33-Bus IEEE, Radial distribution network a) in the initial reconfiguration b) after reconfiguration with DFIG

5.8.2 A Comparison of BF DE and HBFDE without DFIG

In Table 5.1 a comparison between, HBFDE, BF and DE algorithms for 10 trials is given for ADNR problem without DFIG units. According to this table, the hybrid HBFDE algorithm is more effective than original BF and DE algorithms in that the standard deviation of proposed HBFDE algorithm is less than of BF and DE algorithms. Indeed, the HBFDE algorithm could obtain optimum solution in 9 trials of 10 trials and only in one trial the obtained results are different. The CPU time is average.

Table.5.1: Comparison of average solutions of 10 trials without considering DFIGs.

Algorithm	**Initial population**	**Number of iterations**	**Best solution**	**Worst solution**	**Average**	**CPU Time(s)**
BF[64,65]	100	500	195.398	198.96	197.179	~29
DE[50]	100	500	195.398	198.90	197.649	~24
HBFDE[This method)	100 N_{BF}=60 N_{DE}=40	External loop=10 BF loop=30 DE loop=20	135.498	136.99	135.78	~26

Where

N_{DE} Number of DE population

N_{BF} Number of BF population

5.8.3 ADNR problem with Wind

The ADNR problem considering DFIG and uncertain loads has not been studied so far. Hence, in the Table 5.1 to demonstrate the performance of proposed HBFDE algorithm, the total active power loss of the proposed distribution system optimized without considering DFIG units is shown. According to this table, the obtained results by HBFDE algorithm are better than others in terms of loss reduction, CPU time and load flow iterations.

To obtain the minimum power losses corresponding to stochastic situation, 1000 realizations of DFIGs and loads have been developed .In this case, it can be possible to solve the problem for each scenario separately, but it is questionable which scenario must be followed by decision maker. For this mean, all 1000 generated scenarios is aggregated using equation (5.20) to extract a scenario which includes the uncertainty in all scenarios based on their occurrence probability.

$$Aggregated\ Scenario = \sum_{s=1}^{N_s} \{P_{scenario_s}(\xi^s)\} \tag{5.20}$$

Where

ξ^i the ith scenario

After implementation of the equation (5.20), a decision maker can claim that the output control variables can optimum all scenarios while the constraints in all scenarios are satisfied.

In Table 5.3, the obtained aggregated scenario including loads and DFIGs active power is shown to illustrate the importance of the uncertainty parameters in DNR problem, by comparing the deterministic and stochastic situations. In this table, to show the impacts of DFIGs in DNR problem, the deterministic situation includes two cases; DNR considering the DFIG and without considering the impact of DFIGs in network. In last columns of Table 5.3 the optimum tie switches corresponding to each scenario is shown.

Table.5.2. the Simulation Results for DFIG in Stochastic Scenario

Loss in the base configuration	222.71kw
Loss in the optimal configuration	155.78
Optimal configuration	33,14,8,32,28
Loss reduction	86.93kw
Loss reduction (%)	39.1%
CPU time	0.42 sec
Number of load flow iterations	26

The optimal radial configuration of the IEEE 33 Bus network after all the switching operations is shown in Figure 5.3b). Table 5.2 shows the simulation results of the base configuration and the optimal configuration. The minimum and the maximum voltages of the two configurations are depicted in Fig.5. 4. The power loss before reconfiguration is 222.71 kW and reconfiguration is 155.78 kW. From the results it is observed that reduction in power loss is 86.93 kW which is approximately 39.1 %. The number of all load flow runs required for the entire process is 26.

Table.5.3. The optimum results of deterministic and stochastic situations

Case		Power losses [kW]	Optimum tie Switches
ADNR considering DFIG	Stochastic[This Method]	135.89	s34,s14,s8,s32,s28
	Deterministic[64,This Method]	138.97	s35,s14,s8,s32,s28
ADNR without DFIG	Deterministic[64]	197.398	s37,s14,s8,s32,s28

By comparing the obtained results in Table 5.1 and Table 5.3, it is clear that there are differences between the results of deterministic and stochastic scenarios. In other side, the probability of the deterministic scenario is about 4.1% (among 1000 produced scenarios). This means that the deterministic solution may happen with the low probability of 4.1%. Consequently, the deterministic scenario cannot be an acceptable solution by itself. On the other hand, using the obtained aggregated scenario, all 1000 scenarios contribute into determining the ADNR results according to their probability values. So, the ADNR results of the stochastic framework with DFIG are more realistic than the deterministic one with DFIG. In other word, the most important advantage of stochastic scenario is that individual scenario problems become simple to interpret and with aggregation the 1000 scenarios the underlying problem structure is preserved. Hence the ADNR problem with wind and uncertain loading is better solved in the stochastic scenario.

5.8.4 The Voltage Profile

The voltage profiles before and after reconfiguration is shown in from Fig.5.5. It is observed that the minimum voltage before reconfiguration is 0.9131 p.u for deterministic DNR without DFIG and after reconfiguration takingh into consideration DFIG under both deterministic and stochastic scenarios,the minimum voltage is 0.9391 p.u. This shows that the minimum voltage in the network is improved by 2.78 % after the reconfiguration.

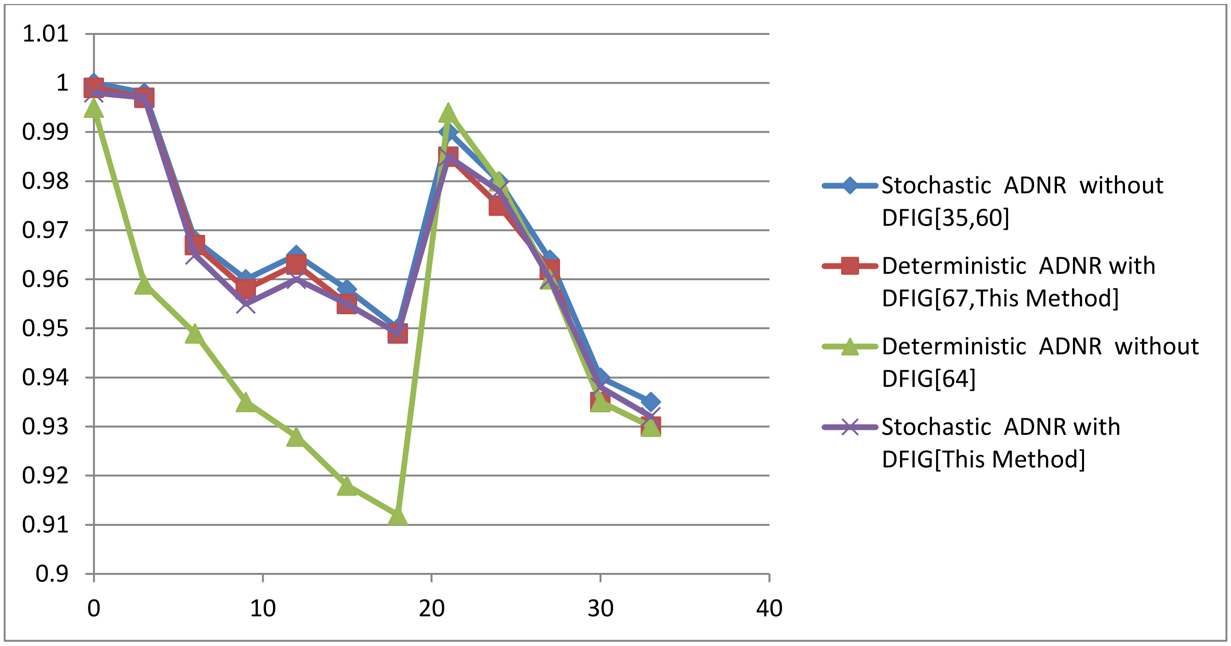


Fig. 5.5. The profile voltages Deterministic and Stochastic Scenarios.

5.8.5 Comparison with Other Methods

The HBFDE method is compared with the methods proposed by **Chiou et al [52]** and **Jingjing Zhao et al [60]** for the same 33-bus test system. For effective comparison, the results of the proposed method along with other methods are shown in Table 5.4.The saving in total loss by the proposed method is higher than all other methods. The number of tie switch operations obtained by the HBFDE and all other methods is 5.The CPU Time for the HBFDE method is the best compared to the other methods.

Table.5.4.A Comparison of results obtained by optimizing active power loss

Method	**Final open switches**	**Total loss savings (%)**	**CPU time**
HBFDE[**This method**]	33,14,8,32,28	33.1	0.42
Jingjing Zhao et al [60]	7,9,14,32,37	32.6	0.87
Chiou et al [52]	7,9,14,32,37	32.6	1.66

5.9 Chapter Conclusion

In this thesis, a hybrid evolutionary algorithm based on the combination of BF and DE algorithms called HBFDE has been proposed to obtain the optimal configuration of radial distribution systems, when the objective function is power loss and holding all the other objectives of ADNR as constraints. An ADNR has been studied considering the wind based DFIG. To reach a more realistic solution than the deterministic situation, a stochastic framework has been considered to model the stochastic behavior of the wind speed and uncertain loads. Additionally, the simulation results have shown the effectiveness of HBFDE algorithm and the stochastic approach which can lead to a more efficient utilization of energy in the distribution systems and permit decision makers to select the possible actions to cope with the wind uncertainty in the modern power system.

Chapter 6

CONTRIBUTIONS AND RECOMMENDATIONS

In this chapter, general thesis conclusions are made, a comparison of the three methods of loss reduction, contributions of this work, the beneficiaries of the work and finally recommendations for future work are made.

6.1 General Conclusions

Three methods of power loss reduction in power system with wind wind based distributed generation has been presented in this work and the following conclusions can be made.

- A distributed slack bus model taking into consideration both the DFIG domains and the network sensitivity using the NR method is the most effective in capturing both real and reactive power losses. Gauss Siedel (GS) method cannot be applied in formulating the distributed slack bus since its convergence is affected by the selection of the slack bus , hence the iterations required to give a solution change with the position of the slack bus[5,7].
- The hybrid methods of power system optimization remain the state of the art methods for the modern power system with intermittent power.HGAPSO and HBFDE methods proved effective in power loss reduction and voltage profile improvement as compared to the pure methods of optimization
- The optimal place for power loss reduction is the primary distribution system. The HGAPSO for DFIG placement and sizing and the DSB with Wind based DFIG Provided Optimal results in the primary distribution.

6.2 Comparison

In this thesis, the distribution test systems used is the IEEE Radial 33 bus systems. The system has 32 sectionalizing branches, 5 tie switches, nominal voltage of 12.66KV and a total system load 3.72 MW and 2.3 MVAR. The original total real power loss and reactive power loss in the system are 221.4346 KW (5.95%) and 150.1784 KNAR (6.53%)

A comparison of the three methods in their effectiveness is as shown in the table 6.1.From the table it is clear that the DBS is effective in distributing the losses and not reducing them in a significant way. Also DIG placement is the best in power loss reduction followed by ANDRÉ.

Table 6.1: Comparison of Loss Reduction.

Type of Loss	**DSB with DFIG**	**DFIG placement and sizing**	**ADNR with Wind and uncertain loads**
Real Losses(KW)	221.4238	69.5578	86.93
% Real Losses	**99.99**	**31.41**	**60.9**
Reactive losses(KVAR)	150.1770	56.2116	123.338
%Reactive Losses	**99.99**	**37.43**	**59.7**

However the three methods result to an improvement of the voltage profile by 2.96% with the DFIG based DSB and ADNR with wind being better than the DFIG placement and sizing.

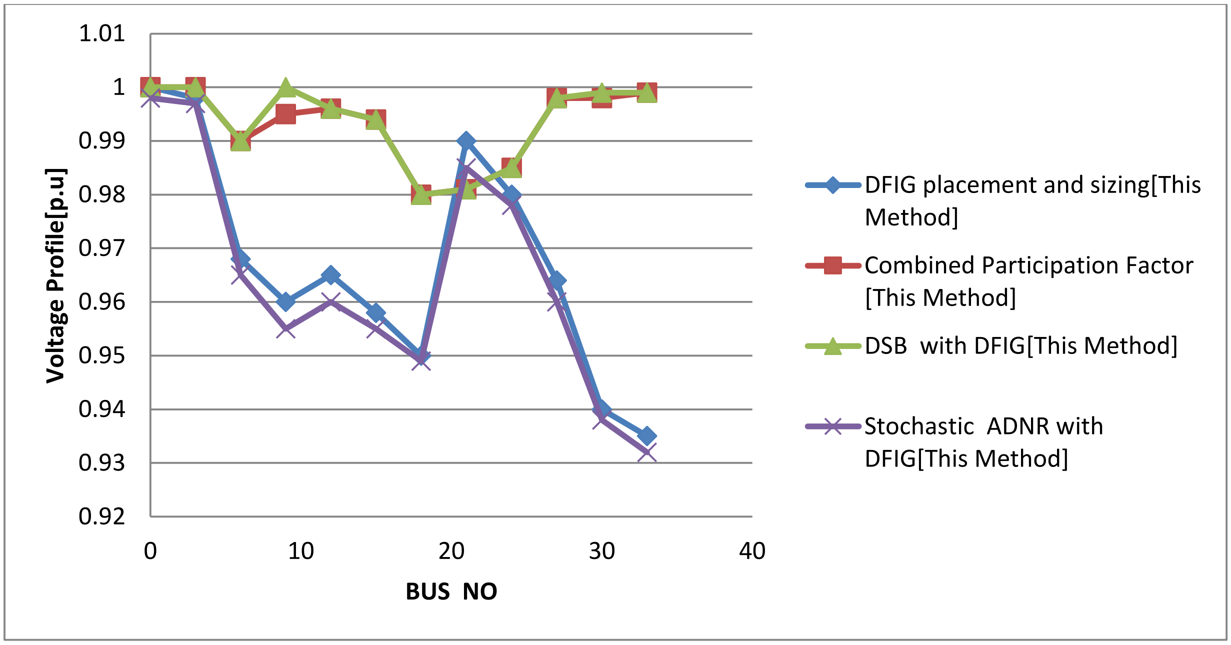


Fig 6.1:A comparison of voltage profile improvement.

6.3 Contributions

The technical challenges facing the integration of wind energy into the power grid are of great concern to the modern power systems designer .Some of these hurdles have been addressed and the following contributions are made:

- Combined participation factors have been formulated, taking into consideration both real and reactive power losses. These factors have been found more effective in the design of the distributed slack bus model as compared to the real power participation factors that existed in the past literature.
- A network sensitive distributed slack bus model based on DFIG was designed so as to distribute real and reactive slacks in the distribution system. A comparison was done with the single slack bus model, DFIG distributed slack bus model based on DFIG domains and the DFIG distributed slack bus model based on DFIG capacity.

- DFIG placement and sizing was done using HGAPSO and comparative study made using pure PSO.In both the optimal place for the DFIG is the primary distribution system ,however the HGAPSO offers an a better voltage profile and can also be applied on a practical distribution system, that is, the ADN.
- The Active distribution network reconfiguration(ADNR) problem has been solved using an HBFDE Algorithm taking into consideration the wind based DFIG and the uncertain loading effect using a stochastic scenario .Such a strategy was found to reduce real and reactive power losses and giving an improvement to the voltage profile.

6.4 Beneficiaries of this Research Work

The results and findings of this research will be found useful by the following:

- **Power system designers**. It will facilitate distribution system expansion reconfiguration with wind based DFIGs and uncertain loading.

- **Utility Companies integrating wind power into the grid.** It will serve as a blue print to the solution of the technical challenges to facing the smart grid implementation, for example minimizing power losses and improving voltage stability.

- **Load Flow Analysis**.there will be an improved slack distribution with the implementation DFIG based distributed slack bus model.This DSB will facilitate the distribution of both real and reactive slack.

- **Smart Grid.** This shall include the researchers working towards the decentralization of power generation and utilization of renewable energy especially wind.

6.5 Recommendations for Future Work

The integration of intermittent power into the distribution system is the practice at heart due to the voltage profile maintenance and reduction in power losses. Thus the following aspects and areas of DFIG need to be investigated:

- Design the DFIG domain and the network sensitive participation factor based distributed slack bus models using a hybrid of GA.
- Develop a DFIG based distributed slack bus model for the Economic load dispatch (ELD)
- Study the DFIG under unbalanced radial distribution systems and note the discrepancies.
- Investigate other aspects of reducing real and reactive power loses in DFIG.These include DFIG-Capacitor placement and reconductoring in the presence of DFIG.
- Power loss reduction with wind based distributed generation by considering Distributed PQ and PV buses.

REFERENCES

[1] J.J.Grainger and W.D Stevenson,JR, *Power System Analysis*, McGraw-Hill, Inc., New Delhi, **2003**.

[2] W. El-Khattam, Y. H. Hegazy, M. M. A. Salama, "An Integrated distributed generation optimization model for distribution system planning", *IEEE Trans. Power System*, vol. 20, No.2 , May, **2005**.

[3] IEEE Standard 1547 for Interconnecting Distributed Resources with Electric Power Systems, **2005**.

[4] http://www.gwec.net/global-figures/graphs/**Feb 2014.**

[5] L.P. Singh, "Advanced Power System Analysis & Dynamics" by New Age International, 3rd Edition.

[6] Gopiya et al.”Planning and Operation of Distributed Generation in Distribution Networks” *International Journal of Emerging Technology and Advanced Engineering(IJETAE),*Volume 2, Issue 9, pp 381-388, September **2012**.

[7] I.J. Nagrath & D.P Kothari, "Modern Power System Analysis" by Tata-McGraw Hill, 4th Edition.

[8] H. Yasami, A. Moeini, S.M.R. Rafiei, A. Darabi and A. Bageri. ” Optimal DG planning considering reliability, cost of energy and power loss, *“Scientific research and essays*, pp 1963-1967, Dec **2011**.

[9] Chiradeja, P. “Benefits of Distributed Generation: A line loss reduction analysis, *“Transmission and Distribution Conference and Exhibition: Asia and Pacific*, pp1-5,May **2005.**

[10] S.Muller, M.Deicke and Rik W. De Doncker, "Doubly Fed Induction Generator Systems for Wind Turbines*,"* *IEEE Industry Applications Magazine*, pp. 26-33, May/June **2002**.

[11] N. Rugthaicharoencheep, "Distribution System Operation for Power Loss Minimization and Improved Voltage Profile with Distributed Generation and Capacitor Placement" *IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technology, Thailand*, pp 1185-1189,

May **2011.**

[12] K.Y Lee, M.A El-Sharkawi,"Modern Heuristic Optimization Techniques: Theory and Applications to Power Systems"*IEEE Press Book,**2008**.*

[13] J. P´erez-Arriaga, G.C. Verghese and F.C. Schweppe, "Selective modal analysis with applications to electric power systems, Part I: Heuristic introduction*," IEEE Trans.Power Apparatus and Systems*, Vol. 101, pp. 3117-3125,**1982**.

[14] G.C. Verghese, I.J. P´erez-Arriaga andF.C. Schweppe, "Measuring state variable participation for selective modal analysis," *IFAC Symposium on Digital Control,* New Delhi, India, January **1982.**

[15] G.C. Verghese, I.J. P´erez-Arriaga and F.C. Schweppe, "Selective modal analysis with applications to electric power systems, Part II: The dynamic stability problem," *IEEE Trans. Power Apparatus and Systems,* Vol. 101, pp. 3126-3134, **1982**.

[16] E.H. Abed et al, "Technical Research Report on Participation Factors for Linear Systems *"Institute for Systems Research,* T.R 99-41, June **1999**.

[17] Pushpendra Singh, L S Titare and L D Arya " Preventive Corrective Rescheduling for Reactive Power Reserve Maximization using Generation Participation Factors*" International Journal of ChemTech Research,* Vol.5, No.2, pp 1009-1015, April-June **2013**.

[18] K.M.S.TongandM.Kleinberg, “A distributed slack bus model and its impact on distribution system application techniques,” *in Proc. IEEE Int.Symp.CircuitsSyst. (ISCAS)*, ,vol.5, pp.4743–4746,May **2005.**

[19] S.TongandK.Miu, “A network-based distributed slack bus model for DGs in unbalanced power how studies, *IEEETrans.PowerSyst*” vol.20, no. 2, pp. 835–842, May **2005**.

[20] K. M. S. Tong, “Participation factor studies for distributed slack bus Models in three-phase distribution power flow analysis,”*inProc.IEEE PESTransm.Distrib.Conf.Exhib*.,2005/2006, pp.92–96,May**2006**.

[21] S. Tong and K. Miu, “Slack bus modeling and cost analysis of distributed generator installations,” *J. Energy Eng*., vol. 133, no. 3, pp.111–120, **2007**.

[22] A.H .Mantawy, and M.S.AL-Ghamdi,”A new reactive power optimization Algorithm”, *IEEE Bologna power technology conference*, June 23rd -26th 2003, Bologna, **2003** Italy.

[23] M.F Kotb,K.M.Shelb,M.EL.Khazendar and A.EI Husseiny”Genetic Algorithm for optimum siting and sizing of Distributed Generation “*Proceedings of the 14th International Middle East Power Systems Conference(MEPCON’10)*,Cairo university ,Egypt,Dec .pp 19-21 ,**2010**.

[24] A. Rabiee “MVAR Management Using Generator Participation Factors for Improving Voltage StabilityMargin”, *Journal of Applied Sciences*, 9: pp 2123 2129, **2009.**

[25] M.I .El-Sayed, EI.Othman, and A.S.EL-Khouly,”Improvement of voltage stability in interconnected power systems using a neural network”, *A journal of American Science,* Vol 8(1), pp 295-301, June **2012**.

[26] D.Bica and P.Maior,”Static Voltage Stability Analysis by participation Factors Computing”, *Scientific Bulletin of the Petru Major University of Targu Mures*, Vol .2 pp 19, **2006**.ISSN 1841-9267.

[27] C.F.Moyano, R.Salgado, L.V.Barboza,”Calculating Participation Factors In the maximum loadability”, *IEEE Bologna Power Tech.Conference*,Bologna Italy, June 23rd -26th **2003** .

[28] HabibollahRaoufi, Mohsen Kalantar, “Reactive power rescheduling with generator ranking for voltage stability improvement” Energy *Conversion and Management*, Volume 50, Issue 4,pp. 1129-1135. April **2009.**

[29] F. Dong, B. Chowdhury, M. Crow, L. Acar, “Improving Voltage Stability by Reactive Power Reserve Management,” *IEEE Transactions on Power System*s, vol. 20, no. 1, pp. 338-345, February **2005**.

[30] Chayakulkheeree, Keerati,”Distributed Slack Bus Power Flow Part I: Mathematical Model and Framework” *The 30th Electrical Engineering Conference*, 25-Oct-**2007**.

[31] Chayakulkheeree, K., "Application of distributed slack bus power flow to competitive environments," *Power Engineering Conference, 2007. AUPEC 2007. Australasian Universities*, vol., no., pp. 9-12 Dec. **2007**.

[32] Kamh, M.Z.; Iravani, R.; , "A Sequence Frame-Based Distributed Slack Bus Model for Energy Management of Active Distribution Networks," *IEEE Transactions on Smart Grid*, vol.3, no.2, pp.828-836, June **2012.**

[33] Naren Bharatwaj ,Abhijit Abhyankar and P Bijwe , “Iterative DCOPF Model Using Distributed Slack Bus” *Indian Institute of Technology* Delhi, June **2012.**

[34] Power Systems: Power System Modeling and Scripting By Federico Milano, Springer, pp 61-100, **2010**.

[35] “Radial test feeders,”*IEEE Distribution System Analysis Subcommittee*:http://ewh.ieee.org/soc/pes/dsacom/testfeeders.html/June **2013.**

[36] D. Santos-Martin ,S. Arnaltes,J.L. Rodriguez Amenedo“Reactive power capability of doubly fed asynchronous generators” *Electric Power Systems Research*,Volume 78, Issue 11, , pp 1837–1840, November **2008.**

[37] Carpinelli, G., Celli, G., Pilo, F and A. Russo "Distributed generation siting and sizing under uncertainty", *in Proc. 2001 IEEE Porto Power Tech Conf*,**2001**.

[38] Ochoa, L.F., Padiha-Feltrin, A., et al.: "Time-series-based maximization of distributed wind generation integration", *IEEE Trans. Energy Conversion*, vol. 3, No. 3,pp.968-974,Sept **2008.**

[39] Juanuwattanakul, P.; Masoum, M. A S; Niyomsak, C.; Mohseni, M., "Voltage analysis for placement of DG in multiphase distribution networks," *Power and Energy Society General Meeting, 2012 IEEE* , vol., no., pp. 22-26 July **2012.**

[40] Fernandez, Francisco Jurado,José Ramón Saenz“Aggregated dynamic model for wind farms with doubly fed induction generator wind turbines *“Renewable Energy* ,Vol .33 NO.1,pp.129-140,**2008.**

[41] Maurizio Delfanti, Davide Falabretti, Marco Merlo” Dispersed generation impact on distribution network losses” *Electric Power Systems Research*, Volume 97,pp 10-18. April **2013.**

[42] Satish Kansal, Vishal Kumar, Barjeev Tyagi, Optimal placement of different type of DG sources in distribution networks, *International Journal of Electrical Power & Energy Systems,* Volume 53, pp 752-760,June **2013**.

[43] Merlin, A., and H. Back. "Search for a minimal-loss operating spanning tree configuration in an urban power distribution system." In *Proc. of the Fifth Power System Conference (PSCC), Cambridge*, pp. 1-18. **1975**.

[44] R.J. Sarfi, M.M.A. Salama, A.Y. Chikhani, “A survey of the state of the art in distribution system reconfiguration for system loss reduction”, *Electric Power Systems Research,* Volume 31, Issue 1, pp 61-70. October **1994**.

[45] A. Ajaja, F.D. Galiana, "Distribution network reconfiguration for loss reduction using MILP," ISGT, pp 1-6, 2012 *IEEE PES Innovative Smart Grid Technologies,* **2012**.

[46] Nguyen Tung Linh, Nguyen Quynh Anh, "Application Artificial Bee Colony Algorithm (ABC) for Reconfiguring Distribution Network," ICCMS, vol. 1, pp.102-106, 2010 *Second International Conference on Computer Modeling and Simulation*, **2010**.

[47] Nguyen Tung Linh, Nguyen Quynh Anh, "Application Artificial Bee Colony Algorithm (ABC) for Reconfiguring Distribution Network," iccms, vol. 1, pp.102-106, 2010 Second International Conference on Computer Modeling and Simulation, **2010**.

[48] Qiwang Li, Wei Ding, Jianquan Zhang, Anhui Liu, "A New Reconfiguration Approach for Distribution System with Distributed Generation," ICEET, International Conference on Energy and Environment Technology, vol. 2, pp.23-26, **2009**.

[49] K. J. Russell, R. P. Broadwater, "Model-based automated reconfiguration for fault isolation and restoration," ISGT, pp 1-4, 2012 IEEE PES Innovative Smart Grid Technologies, **2012**.

[50] J. Torres-Jimenez, J. L. Guardado, F. Rivas, S. Maximov, E. Melgoza, "Reconfiguration of Power Distribution Systems Using Genetic Algorithms and Spanning Trees," *CERMA,2010 IEEE Electronics, Robotics and Automotive Mechanics Conference*, pp.779-784, **2010**.

[51] D. Pal, S. Kumar, B. Tudu, K. K. Manual, N. Chakraborty "Efficient and Automatic Reconfiguration and Service Restoration in Radial Distribution System Using Differential Evolution "*Proceedings Advances in Intelligent Systems and Computing* Volume 199, pp 365-372,**2013**.

[52] Ji-PyngChiou; Chung-Fu Chang; Ching-Tzong Su; , "Variable scaling hybrid differential evolution for solving network reconfiguration of distribution systems," *Power Systems, IEEE Transactions on* , vol.20, no.2, pp. 668- 674, May **2005**.

[53] Nuno Tenazinha, Susana Vinga, "A Survey on Methods for Modeling and Analyzing Integrated Biological Networks," *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, vol. 8, no. 4, pp. 943-958, July-Aug. **2011**.

[54] Yi-xiong Yan, Yan Wang, Yong-sheng Shi, "The Research on Fault Restoration Considering Distributed Generation Based Particle Swarm Optimization," APPEEC, pp.1-4, 2011 *Asia-Pacific Power and Energy Engineering Conference*, **2011.**

[55] M. E. Baran and F. F. Wu, "Network reconfiguration in distribution systems for loss reduction and load balancing," *IEEE Trans. Power Del*.vol. 4, no. 2, pp. 1401–1407, Apr. **1989**.

[56] Jianming Yu; Fan Zhang; Feng Ni; Yuanshe Ma; "Improved Genetic Algorithm with Infeasible Solution Disposing of Distribution Network Reconfiguration," *Intelligent Systems, 2009. GCIS '09. WRI Global Congress on*, vol.2, no., pp.48-52, 19-21 May **2009**.

[57] Shuang Ma; Hao Zhang; Gang Xu, "Distribution Network Reconfiguration with Wind Turbine Based on Breaking Circle," *Engineering and Technology (S-CET), 2012 Spring Congress on*, vol., no., pp.1-4, 27-30May **2012**.

[58] Zhou Suwen; Chen Xingying; Liu Jian; Dong Xinzhou; Liao Yingchen, "Distribution network reconfiguration considering the random character of wind power generation," *Advanced Power System Automation and Protection (APAP), 2011 International Conference on* , vol.2, no., pp.1195,1200,16-20,Oct.**2011**.

[59] HE Yuqing et al," Scenario Model an Algorithm for the Reconfiguration of Distribution Network With Wind Power Generators" *College of Mechatronics & Control Engineering, Shenzhen University*, October **2010.**

[60] Jingjing Zhao et al" Joint optimization algorithm for network reconfiguration and reactive power control of wind farm in distribution system" *WSEAS Transactions on Circuits and Systems* Volume8Issue2, pp 268-279, February **2009.**

[61] Liu, Y., and K. M. Passino. "Biomimicry of social foraging bacteria for distributed optimization: models, principles, and emergent behaviors." *Journal of Optimization Theory and Applications* 115.3 (2002) pp 603-628.

[62] Biswas, Arijit, et al. "Synergy of PSO and bacterial foraging optimization—a comparative study on numerical benchmarks." *Innovations in Hybrid Intelligent Systems*. Springer Berlin Heidelberg,pp 255-263, **2007.**

[63] Huajie Ding, Zechun Hu, Yonghua Song" Stochastic optimization of the daily operation of wind farm and pumped-hydro-storage plant" *Renewable Energy*, Volume 48, pp 571-578, December **2012**.

[64] Al-Awami, A.T.; El-Sharkawi, M.A., "Statistical characterization of wind power output for a given wind power forecast," *North American Power Symposium (NAPS), 2009*, vol., no., pp. 4-6 Oct. **2009**.

[65] H. Q. Zhou, Z. P. Song, J. P. Wang, Y. Xue, "A Review on Dynamic Equivalent Methods for Large Scale Wind Farms," APPEEC, pp.1-7, 2011 *Asia-Pacific Power and Energy Engineering Conference*, **2011**.

[66] S. Dutta, R. Sharma, "Optimal storage sizing for integrating wind and load forecast uncertainties," ISGT, pp.1-7, 2012 *IEEE PES Innovative Smart Grid Technologies*, **2012**.

[67] Golestani, S.; Raoofat, M.; Farjah, E., "An improved integer coded genetic algorithm for security constrained unit commitment problem," *Power and Energy Conference, 2008. PECon 2008. IEEE 2nd International*, vol., no., pp.1251-1255, Dec. **2008**.

[68] Yao, D.L.; Choi, S.S.; Tseng, K.J.; Lie, T.T., "Determination of Short-Term Power Dispatch Schedule for a Wind Farm Incorporated With Dual-Battery Energy Storage Scheme," *Sustainable Energy, IEEE Transactions on* , vol.3, no.1, pp.74,84, Jan. **2012.**

[69] Pandi, V. Ravikumar, Arijit Biswas, Sambarta Dasgupta, and B. K. Panigrahi. "A hybrid bacterial foraging and differential evolution algorithm for congestion management." *European Transactions on Electrical Power* 20, no. 7, pp 862-871, **2010.**

[70] Bi-chang Zou, Qing-wu Gong, Xun Li, Dao-jun Chen, "Reconfiguration in Distribution Systems Based on Refined Genetic Algorithm for Improving Voltage Quality," APPEEC, pp.1-4, 2011 *Asia-Pacific Power and Energy Engineering Conference*, **2011**.

[71] Power Systems: Power System Modelling and Scripting By Federico Milano, Springer, pp 61-100, **2010**.

[72] “Radial test feeders,” *IEEE Distribution System Analysis Subcommittee:*http://ewh.ieee.org/soc/pes/dsacom/testfeeders.html/ June **2013**.

[73] D. Santos-Martin, S. Arnaltes, J.L. Rodriguez- Amenedo, “Reactive power capability of doubly fed asynchronous generators,” Electric Power Systems Research, vol.78, pp.1837-1840, **2008**

[74] Carpinelli, G., Celli, G., Pilo, F and A.Russo "Distributed generation siting and sizing under uncertainty", *IEEE Porto Power Tech Conf in Proc.* ***2001***.

[75] Ochoa, L.F., Padiha-Feltrin, A., et al.: "Time-series-based maximization of distributed wind generation integration", *IEEE Trans. Energy Conversion*, vol. 3, No. 3, pp.968-974, **2008.**

[76] Juanuwattanakul, P.; Masoum, M. A S; Niyomsak, C.; Mohseni, M., "Voltage analysis for placement of DG in multiphase distribution networks," *Power and Energy Society General Meeting, 2012 IEEE* , vol., no., pp. 22-26 July **2012**.

[77] Fernandez, Francisco Jurado,José Ramón Saenz“Aggregated dynamic model for wind farms with doubly fed induction generator wind turbines *“Renewable Energy* ,Vol .33,pp.129-140,**2008**.

[78] Maurizio Delfanti, Davide Falabretti, Marco Merlo” Dispersed generation impact on distribution network losses” *Electric Power Systems Research*, Volume 97,pp 10-18, April **2013.**

[79] Satish Kansal, Vishal Kumar, Barjeev Tyagi, Optimal placement of different type of DG sources in distribution networks, *International Journal of Electrical Power & Energy Systems*, Volume 53 , pp 752-760, June **2013.**

[80] Merlin, A., and H. Back. "Search for a minimal-loss operating spanning tree configuration in an urban power distribution system." In *Proc. of the Fifth Power System Conference (PSCC), Cambridge*, pp. 1-18. **1975**.

[81] R.J. Sarfi, M.M.A. Salama, A.Y. Chikhani, "A survey of the state of the art in distribution system reconfiguration for system loss reduction", *Electric Power Systems Research*, Volume 31, Issue 1, pp 61-70,October **1994.**

[82] A. Ajaja, F.D. Galiana, "Distribution network reconfiguration for loss reduction using MILP," ISGT, pp.1-6, *2012 IEEE PES Innovative Smart Grid Technologies,* **2012**.

[83] Nguyen Tung Linh, Nguyen Quynh Anh, "Application Artificial Bee Colony Algorithm (ABC) for Reconfiguring Distribution Network," ICCMS, vol. 1, pp.102-106, 2010 *Second International Conference on Computer Modeling and Simulation*, **2010**.

[84] Nguyen Tung Linh, Nguyen Quynh Anh, "Application Artificial Bee Colony Algorithm (ABC) for Reconfiguring Distribution Network," ICCMS, vol. 1, pp.102-106, 2010 Second International Conference on Computer Modeling and Simulation, **2010**.

[85] Qiwang Li, Wei Ding, Jianquan Zhang, Anhui Liu, "A New Reconfiguration Approach for Distribution System with Distributed Generation," *ICEET*, vol. 2, pp.23-26, 2009 International Conference on Energy and Environment Technology, **2009**.

[86] K. J. Russell, R. P. Broadwater, "Model-based automated reconfiguration for fault isolation and restoration," ISGT, pp.1-4, 2012 *IEEE PES Innovative Smart Grid Technologies*, **2012**.

[87] J. Torres-Jimenez, J. L. Guardado, F. Rivas, S. Maximov, E. Melgoza, "Reconfiguration of Power Distribution Systems Using Genetic Algorithms and Spanning

Trees," cerma, pp.779-784, 2010 *IEEE Electronics, Robotics and Automotive Mechanics Conference*, **2010.**

[88] D. Pal, S. Kumar, B. Tudu, K. K. Mandal, N. Chakraborty “Efficient and Automatic Reconfiguration and Service Restoration in Radial Distribution System Using Differential Evolution “*Proceedings Advances in Intelligent Systems and Computing* Volume 199, pp 365-372, **2013.**

[89] Ji-PyngChiou; Chung-Fu Chang; Ching-Tzong Su; , "Variable scaling hybrid differential evolution for solving network reconfiguration of distribution systems," *Power Systems, IEEE Transactions on* , vol.20, no.2, pp. 668- 674, May **2005**.

[90] Nuno Tenazinha, Susana Vinga, "A Survey on Methods for Modeling and Analyzing Integrated Biological Networks," *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, vol. 8, no. 4, pp. 943-958, July-Aug. **2011**.

[91] Yi-xiong Yan, Yan Wang, Yong-sheng Shi, "The Research on Fault Restoration Considering Distributed Generation Based Particle Swarm Optimization," appeec, pp.1-4, 2011 *Asia-Pacific Power and Energy Engineering Conference*, **2011.**

[92] M. E. Baran and F. F. Wu, “Network reconfiguration in distribution systems for loss reduction and load balancing,” *IEEE Trans. Power Del*.vol. 4, no. 2, pp. 1401–1407, Apr. **1989**.

[93] Jianming Yu; Fan Zhang; Feng Ni; Yuanshe Ma; "Improved Genetic Algorithm with Infeasible Solution Disposing of Distribution Network Reconfiguration," *Intelligent Systems, 2009. GCIS '09. WRI Global Congress on*, pp.48-52, May **2009**.

[94] Shuang Ma; Hao Zhang; Gang Xu, "Distribution Network Reconfiguration with Wind Turbine Based on Breaking Circle," *Engineering and Technology (S-CET), 2012 Spring Congress on*, pp. 27-30 May **2012**.

[95] Zhou Suwen; Chen Xingying; Liu Jian; Dong Xinzhou; Liao Yingchen, "Distribution network reconfiguration considering the random character of wind power generation," *Advanced Power System Automation and Protection (APAP), 2011 International Conference on* , vol.2, no., pp.1195-1200, Oct.**2011**.

[96] HE Yuqing et al," Scenario Model an Algorithm for the Reconfiguration of Distribution Network With Wind Power Generators" *College of Mechatronics & Control Engineering*, Shenzhen University,**2013**.

[97] Jingjing Zhao et al" Joint optimization algorithm for network reconfiguration and reactive power control of wind farm in distribution system" *WSEAS Transactions on Circuits and Systems* Volume8Issue2, pp 268-279, February **2009**.

[98] Liu, Y., and K. M. Passino. "Biomimicry of social foraging bacteria for distributed optimization: models, principles, and emergent behaviors." *Journal of Optimization Theory and Applications* vol 115.no 3 pp 603-628, **2002**.

[99] Biswas, Arijit, et al. "Synergy of PSO and bacterial foraging optimization—a comparative study on numerical benchmarks." *Innovations in Hybrid Intelligent Systems*. Springer Berlin Heidelberg, Pp 255-263, **2007**.

[100] Huajie Ding, Zechun Hu, Yonghua Song" Stochastic optimization of the daily operation of wind farm and pumped-hydro-storage plant" *Renewable Energy*, Volume 48, pp 571-578, December **2012**.

[101] Al-Awami, A.T.; El-Sharkawi, M.A., "Statistical characterization of wind power output for a given wind power forecast," *North American Power Symposium (NAPS), 2009*, vol., no., pp.4-6 Oct. **2009**.

[102] H. Q. Zhou, Z. P. Song, J. P. Wang, Y. Xue, "A Review on Dynamic Equivalent Methods for Large Scale Wind Farms," appeec, pp.1-7, 2011 *Asia-Pacific Power and Energy Engineering Conference*, **2011**.

[103] S. Dutta, R. Sharma, "Optimal storage sizing for integrating wind and load forecast uncertainties," ISGT, pp.1-7, 2012 *IEEE PES Innovative Smart Grid Technologies*, **2012**.

[104] Golestani, S.; Raoofat, M.; Farjah, E., "An improved integer coded genetic algorithm for security constrained unit commitment problem," *Power and Energy Conference, 2008. PECon 2008. IEEE 2nd International*, vol., no., pp.1251-1255, Dec. **2008**.

[105] Yao, D.L.; Choi, S.S.; Tseng, K.J.; Lie, T.T., "Determination of Short-Term Power Dispatch Schedule for a Wind Farm Incorporated with Dual-Battery Energy Storage Scheme," *Sustainable Energy, IEEE Transactions on*, vol.3, no.1, pp.74-84, Jan. **2012**.

[106] Pandi, V. Ravikumar, Arijit Biswas, Sambarta Dasgupta, and B. K. Panigrahi. "A hybrid bacterial foraging and differential evolution algorithm for congestion management." *European Transactions on Electrical Power* vol 20, no. 7,pp 862-871, **2010**.

[107] Bi-chang Zou, Qing-wu Gong, Xun Li, Dao-jun Chen, "Reconfiguration in Distribution Systems Based on Refined Genetic Algorithm for Improving Voltage Quality," APPEEC, pp.1-4, 2011 *Asia-Pacific Power and Energy Engineering Conference*, **2011**.

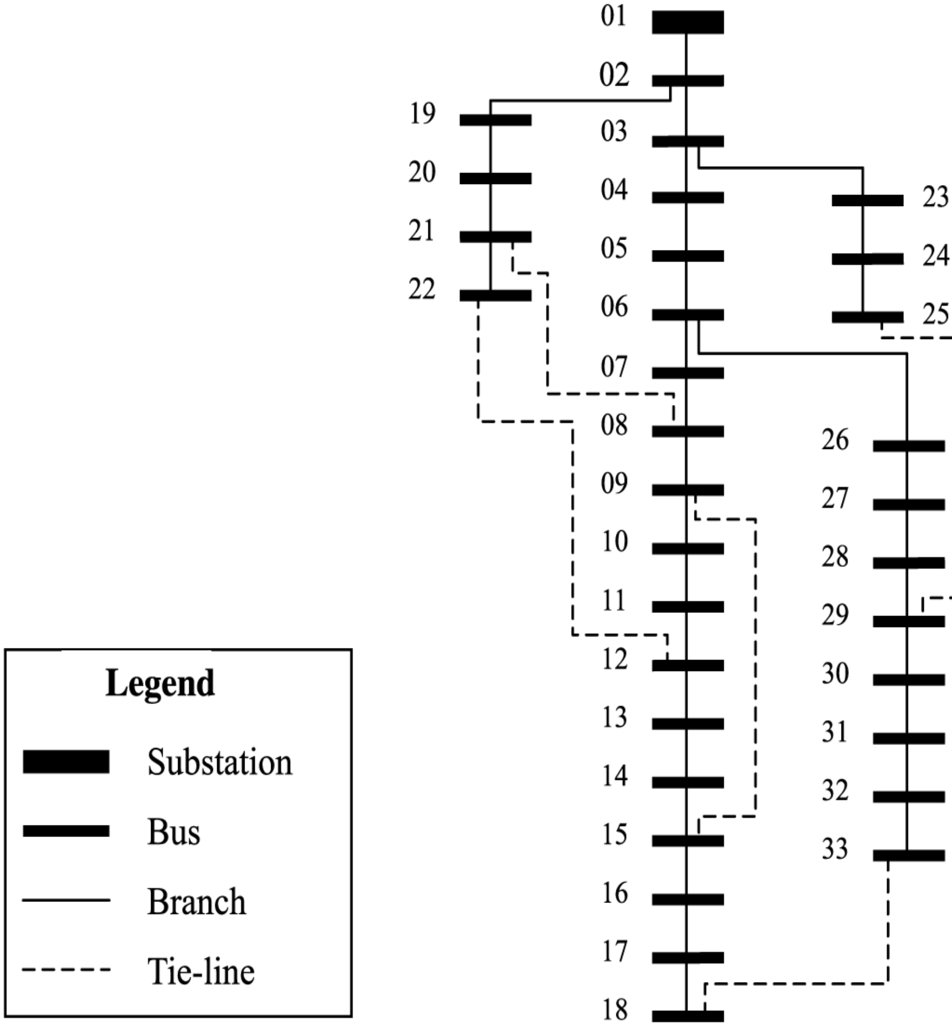
RESEARCH PAPERS OUT OF THE PRESENT WORK PUBLISHED IN INTERNATIONAL JOURNAL

1. **Mr.Peter Musau Moses** and Dr.Nicodemus Abungu Odero ”Distributed Slack Bus Model for a Wind Based Distributed Generation using Combined Participation Factors” *International Journal of Emerging Technology and Advanced Engineering(IJETAE),*Volume 2, Issue 10, October 2012,PP 459-469.
2. **Mr.Peter Musau Moses** and Dr. Nicodemus Abungu Odero “Solving The Active Distribution Network Reconfiguration (ADNR) Problem Taking Into Consideration A Stochastic Wind Scenario And Load Uncertainty By Using HBFDE Method” *International Journal of Emerging Technology and Advanced Engineering(IJETAE),*Volume 3, Issue 7, July 2013,PP 26-36.
3. **Mr.Peter Musau Moses**, Dr. Nicodemus Abungu Odero and Prof. J. Mwangi Mbuthia“Power Loss Reduction in the Active Distribution Network by Doubly Fed Induction Generator (DFIG) Placement and Sizing Using Ordinary Particle Swarm Optimization (PSO) and an hybrid of Genetic Algorithm (GA) and PSO (HGAPSO)”*International Journal of Emerging Technology and Advanced Engineering (IJETAE),* Volume 3, Issue 7, July 2013, PP 37-46.
4. **Mr.Peter Musau Moses**, Dr. Nicodemus Abungu Odero “Reducing Real and Reactive Power Losses in the Power Distribution System by DFIG Placement and Sizing Using Ordinary PSO and HGAPSO: A Comparison” *International Journal of Emerging Technology and Advanced Engineering (IJETAE),* (Accepted).

APPENDIX A

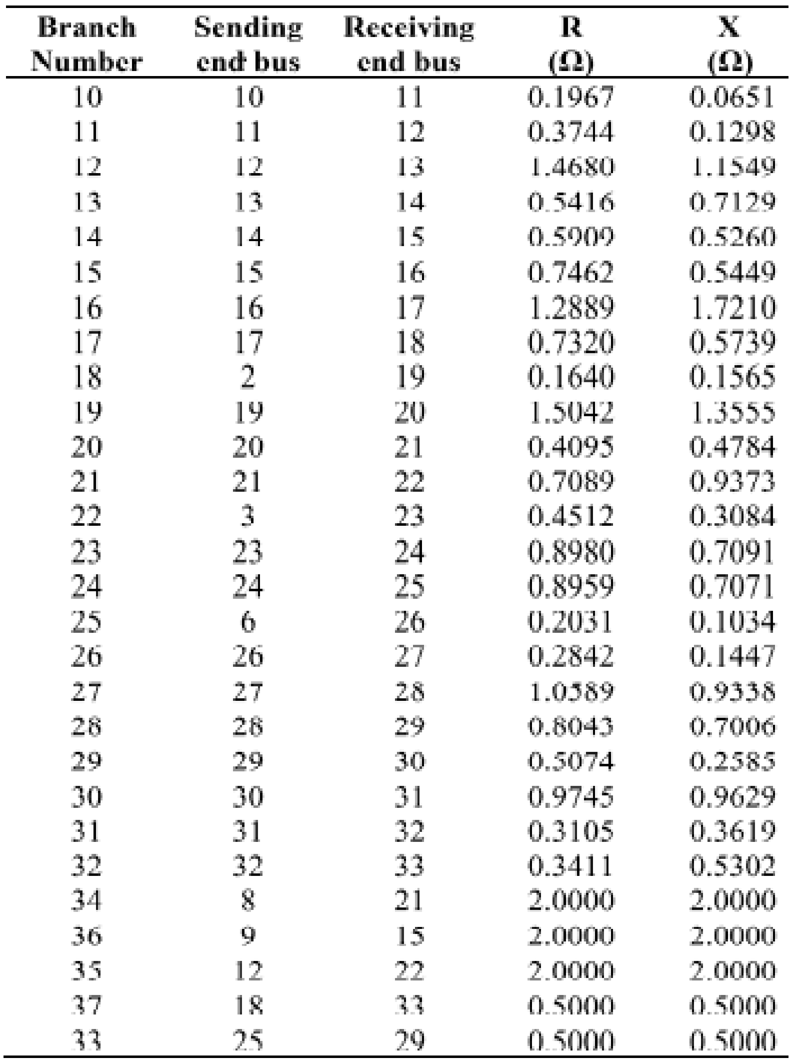
APPENDIX A.1

IEEE 33 BUS RADIAL DISTRIBUTION NETWORK SYSTEMS



APPENDIX A.2

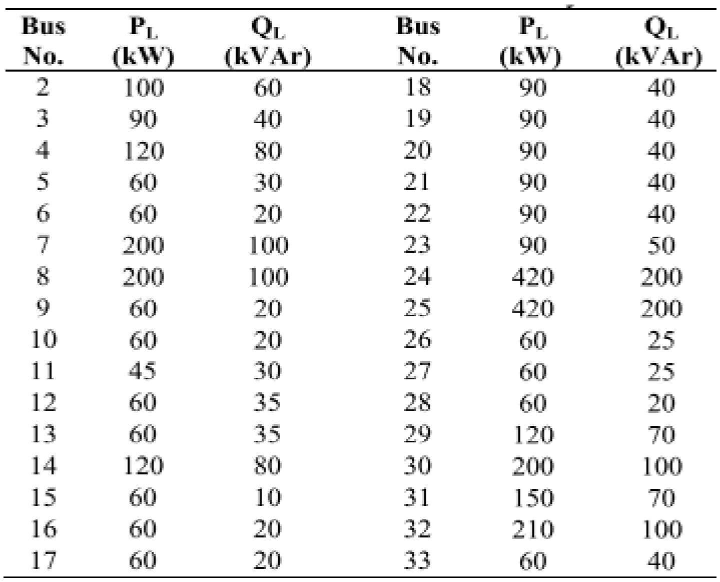
33 BUS RADIAL DISTRIBUTION NETWORK SYSTEM/BUS DATA



Branch Number	Sending end bus	Receiving end bus	R (Ω)	X (Ω)
10	10	11	0.1967	0.0651
11	11	12	0.3744	0.1298
12	12	13	1.4680	1.1549
13	13	14	0.5416	0.7129
14	14	15	0.5909	0.5260
15	15	16	0.7462	0.5449
16	16	17	1.2889	1.7210
17	17	18	0.7320	0.5739
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3555
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3084
23	23	24	0.8980	0.7091
24	24	25	0.8959	0.7071
25	6	26	0.2031	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0589	0.9338
28	28	29	0.8043	0.7006
29	29	30	0.5074	0.2585
30	30	31	0.9745	0.9629
31	31	32	0.3105	0.3619
32	32	33	0.3411	0.5302
34	8	21	2.0000	2.0000
36	9	15	2.0000	2.0000
35	12	22	2.0000	2.0000
37	18	33	0.5000	0.5000
33	25	29	0.5000	0.5000

APPENDIX A.3

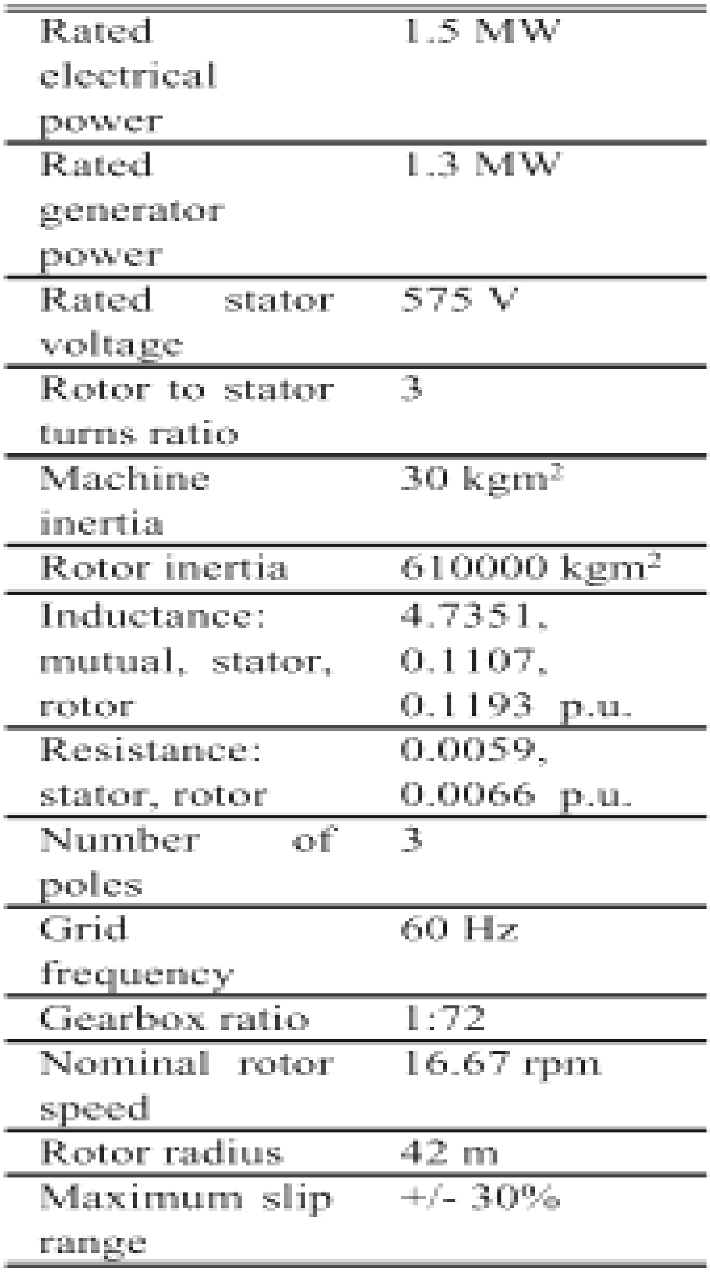
33 BUS RADIAL DISTRIBUTION NETWORK LOAD DATA.



Bus No.	P_L (kW)	Q_L (kVAr)	Bus No.	P_L (kW)	Q_L (kVAr)
2	100	60	18	90	40
3	90	40	19	90	40
4	120	80	20	90	40
5	60	30	21	90	40
6	60	20	22	90	40
7	200	100	23	90	50
8	200	100	24	420	200
9	60	20	25	420	200
10	60	20	26	60	25
11	45	30	27	60	25
12	60	35	28	60	20
13	60	35	29	120	70
14	120	80	30	200	100
15	60	10	31	150	70
16	60	20	32	210	100
17	60	20	33	60	40

APPENDIX B

DFIG PARAMETERS



Rated electrical power	1.5 MW
Rated generator power	1.3 MW
Rated stator voltage	575 V
Rotor to stator turns ratio	3
Machine inertia	30 kgm^2
Rotor inertia	610000 kgm^2
Inductance: mutual, stator, rotor	4.7351, 0.1107, 0.1193 p.u.
Resistance: stator, rotor	0.0059, 0.0066 p.u.
Number of poles	3
Grid frequency	60 Hz
Gearbox ratio	1:72
Nominal rotor speed	16.67 rpm
Rotor radius	42 m
Maximum slip range	+/- 30%