



## **CANDIDATE'S DECLARATION**

I hereby declare that the thesis "**Particle Swarm Optimization Based Reactive Power Optimization of Utility Grid With Wind Generation**" is my own work conducted under the guidance of **Baseem Khan (PhD)**, Department of Electrical Engineering, Hawassa University Institute of Technology, Hawassa (SNNPRS), Ethiopia.

I further declare that to the best of my knowledge the thesis does not contain any part of work that has been submitted for the award of any degree either in this university or any other university without proper citation.

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## ABSTRACT

*Reactive power is critical to the operation of the power systems on both safety and economic aspects. Irrational distribution of the reactive power would severely disturb the power quality of the power systems and increases the transmission loss. Reactive Power Optimization (RPO) is defined as the minimization of active power loss by controlling a number of variables. Reactive power optimization problem is a nonlinear optimization problem and has both equality and inequality constraints. In this thesis, the Particle Swarm Optimization (PSO) algorithm and Mat-power toolbox are used to solve the reactive power optimization problem for generation/distribution system with wind generation (WG) plant. The proposed method minimizes the active power loss in a practical power system as well as determines the optimal placement of a new installed WG (Wind Generation). The practical 21-bus, power distribution network of Southern Region is used to evaluate the performance.*

**Keywords:** *Particle Swarm Optimization Algorithm, Control Variables, Wind Generation, Reactive Power Optimization, Mat-power and Active power Loss Minimization*

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## NOMENCLATURE

<b>P</b>	<b>Active power</b>
<b>Q</b>	<b>Reactive power</b>
<b>Pd</b>	<b>Active Power Demand/load</b>
<b>Qd</b>	<b>Reactive Power Demand/load</b>
<b>Gs</b>	<b>Shunt Conductance</b>
<b>Bs</b>	<b>Shunt Susceptance</b>

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<b>V<sub>m</sub></b>	<b>Magnitude of the Voltage</b>
<b>V<sub>a</sub></b>	<b>Phase angle of the voltage</b>
<b>V<sub>min</sub></b>	<b>Minimum Voltage limit</b>
<b>V<sub>max</sub></b>	<b>Maximum Voltage limit</b>
<b>Q<sub>min</sub></b>	<b>Minimum reactive power output</b>
<b>Q<sub>max</sub></b>	<b>Maximum reactive power output</b>
<b>Q<sub>shunt</sub></b>	<b>Shunt VAR compensation</b>
<b>V<sub>g</sub></b>	<b>Generator bus Voltage</b>
<b>P<sub>min</sub></b>	<b>Minimum active power output</b>
<b>P<sub>max</sub></b>	<b>Maximum active power output</b>
<b>F<sub>bus</sub></b>	<b>From Bus number</b>
<b>T<sub>bus</sub></b>	<b>To Bus number</b>
<b>R</b>	<b>Resistance of a distribution line</b>
<b>X</b>	<b>Reactance of a distribution line</b>
<b>B</b>	<b>Susceptance of a distribution line</b>
<b>Q<sub>g</sub></b>	<b>Reactive power generation</b>
<b>P<sub>g</sub></b>	<b>Active power generation</b>
<b>rateA</b>	<b>long term rating of the branch</b>
<b>rateB</b>	<b>Short term rating of the branch</b>
<b>rateC</b>	<b>Emergency rating of the branch</b>
<b>ratio</b>	<b>Tap ratio of the transformer</b>
<b>angle</b>	<b>phase shift angle of the transformer</b>
<b>MW</b>	<b>Mega Watt</b>
<b>MVar</b>	<b>Mega Volt Amper reactive</b>
<b>Pu</b>	<b>per unit</b>

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<b>Deg</b>	<b>degree</b>
<b>Q<sub>c</sub></b>	<b>Reactive power injection</b>
<b>T</b>	<b>Transformer tap ratio</b>

## **ACRONYMS**

<b>WG</b>	<b>Wind Generation</b>
<b>DG</b>	<b>Distributed Generation</b>
<b>GA</b>	<b>Genetic Algorithm</b>
<b>OPF</b>	<b>Optimal Power Flow</b>
<b>PSAT</b>	<b>Power System Analysis Toolbox</b>
<b>PSO</b>	<b>Particle Swarm Optimization</b>
<b>EEU</b>	<b>Ethiopian Electric Utility</b>
<b>ORPC</b>	<b>Optimal Reactive Power Control</b>
<b>MATLAB</b>	<b>Matrix Laboratory</b>
<b>RPO</b>	<b>Reactive Power Optimization</b>



**CERTIFICATE**

This is to certify that the work entitled “**Particle Swarm Optimization Based Reactive Power Optimization of Utility Grid With Wind Generation**” submitted by **Hailu Tibebe Mengistu (PGEgw/010/07)** Department of Electrical Engineering, Hawassa University Institute of Technology, Hawassa, Ethiopia is a record of a bona fide research carried out by him under my supervision and guidance. The thesis work in my opinion, has reached the requisite fulfilling the requirement of Master of Science Degree. The results contained in the thesis have not been submitted in part or full to any other University or Institute for the award of any degree.

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## **CHAPTER ONE**

### **1. INTRODUCTION**

#### **1.1. Background And Motivation**

Over the last few years, the interest in reactive power compensation has been growing, mainly because of the way in which energy supplier charge a customer for reactive power. The aim is to minimize reactive power flow in supplying and distribution systems, eliminate or minimize the charge for reactive power as well as aspire to active energy limitation, in result, reducing charge for electrical energy. In fact, the energy providers want their customers to compensate reactive power.

Modern electric utilities challenge the problem of load growth along with a severe limitation on investment resources which strictly limits upgradation to the transmission and distribution system infrastructure. One way for increasing system performance is investment in reactive resources. The goal of any power system is to deliver electricity to its customers in a cost-effective and reliable way. Unless this power system is planned and maintained reliable, it causes opposing economic effect due to interruption costs and power outages on both utility and its customers. The reactive power optimization (RPO) is a sub problem of the optimal power flow calculation and has a significant influence on secure and economic operation of power systems. The controllable system quantities are the capacity of a new wind generator, controlled voltage magnitude, reactive power injection from reactive power sources and transformer tapping. The main objective of this paper is to minimize the active power loss by optimizing the control variables within their limits and to find the optimal placement of a new WG in distribution system. Integrating of WG into distribution network reduces power loss because some portion of the required current form upstream is substantially reduce which result

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lower loss through line resistance. Further reduction of loss can be achieved by intelligently managing reactive power from the installed WG [1].

This paper presents an efficient algorithm suitable for system loss minimization simultaneously satisfying the network performance constraints and the constraints on the control variables. Reactive power optimization system can improve the power quality as well as reduce the active power loss [3]. In our country Ethiopia, there is a lot of total blackout have been occur on each year. These blackouts brought social disruptions and hundreds of millions of birrs in loss. One of the main reasons causing this total blackout is due to the reactive power shortage. Reactive power plays a prominent role in minimizing the active power loss of the power systems. Reactive power optimization system can also significantly reduce the power factor angle of each bus, thus cutting the overall energy losses. Each year, a large amount of electricity is wasted on the transmission or distribution lines around the world [2]. This active power loss not only causes energy waste and produces extra carbon emission, but also increases the generation cost. Along with the development of the economic, the scale of the power grid also keeps growing. In Ethiopia, still, the construction and upgrading of the power grid did not keep match with the growth of the loads at the same time a lot of industrial parks are installing around the country, then a severe shortage of the reactive power would be occur. In the early days, the reactive power optimization technique is to improve the power factor at each end user by installing reactive power compensators. This method, of course, can reduce the total power loss. For this thesis the simplest and most economical method to solve active power loss problem is reactive power optimization method using Particle swarm optimization.

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## 1.2. Statement of the Problem

Southern region is experiencing frequent power interruptions and total blackout in recent times. One of the reasons of this problem, which is also acknowledged by Ethiopian Electric Utility, is that the shortage of reactive power generation and built to handle the current load demands. The solution for this problem can be coordinated reactive power optimization system and upgrading of the distribution system. It is expected that the results, conclusions and recommendations of this thesis are helpful for finding the solution of this problem.

## 1.3. Objectives of the Thesis

The main objective of this thesis is to study the particle swarm optimization based reactive power optimization in southern region 21-bus power network system for active power loss minimization. The general and specific objectives of the thesis are described in the problem formulation of the thesis in detail.

## 1.4. Methodology

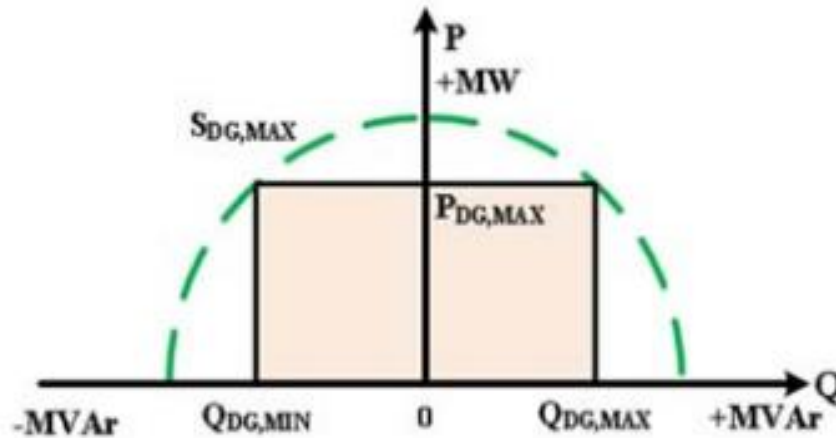
Several conventional optimization algorithms [4] have been proposed to solve the RPO problem such as linear programming, quadratic programming, and interior point method. Main problem associated with these conventional techniques is easily falling in local optimum solution. As the RPO is nonlinear, evolutionary computation methods such as genetic algorithm (GA) [5], evolutionary programming (EP) and particle swarm optimization (PSO) [6] algorithms are best suitable to solve it. In this work, an application of particle swarm optimization (PSO) and MATPOWER toolbox [7] is used to solve reactive power optimization problem integrating with a new WG. The PSO algorithm is a global search method which explores search space to get the global optimum. The PSO is a stochastic, population-based

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computer algorithm modelled on swarm intelligence. PSO finds the global minimum of a multidimensional function with best optimum. MATPOWER is an open source MATLAB toolbox focused on solving the power flow problems. Optimization method is needed to quickly find the active power loss minimization for the objective function, satisfying all of the system constraints. In this thesis a particle swarm optimization algorithm is used. PSO method have been used many times before this thesis and have the advantages in terms of less computation times, ease of use and applicability. The detail of methodology of the thesis is described in the research methodology section.

### **1.5. Reactive Power Supply Capability of Wind Generation**

WG connected to electrical grid through power electronic converter can be set to inject reactive power by changing its operating power factor or increasing its reactive current output. How much reactive power can be supplied by WG unit depends on its active power set point. The diagram illustrating reactive power capability is shown in Figure 1.2. If WG active power is set close to its rated apparent power rating, capacitive or inductive reactive power range that can be supplied is small. Reactive supply capability of WG can be increased by reducing its active power generation. If active power set point is reduced, more reactive supply is guaranteed [11]. When the real power output is 0 MW, the wind generator can still deliver as much as 1.2 MVar or absorb -1.0 MVar reactive power. Since 2007, some commercial wind turbines have already been equipped with this kind of full reactive power capability, which can produce full reactive power regardless of the wind conditions. While the reactive power capacity of the early products is usually related to their real-time real power outputs.

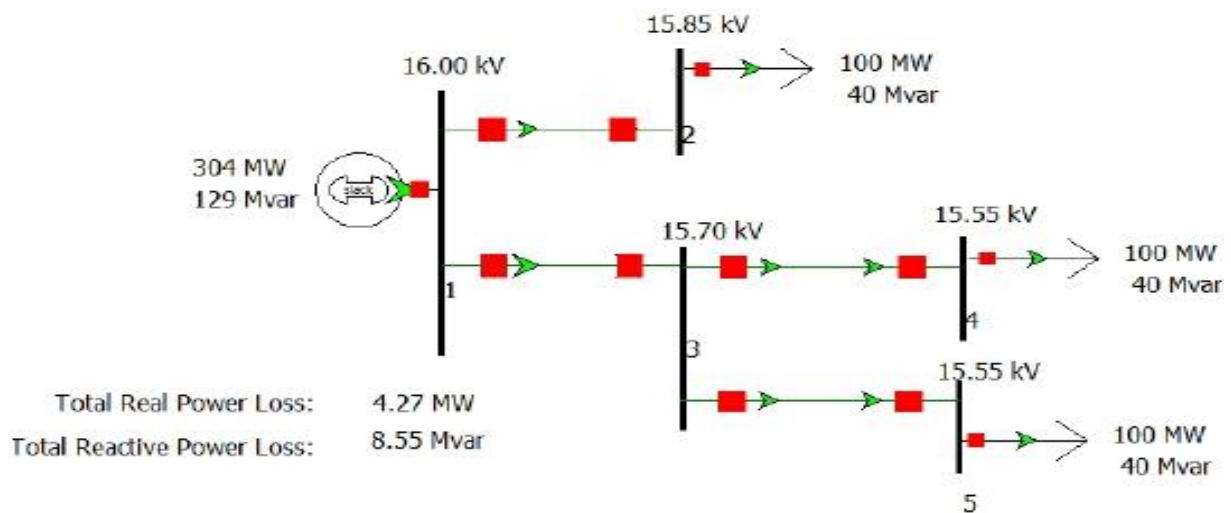


*Figure 1.1 Apparent, active and reactive power from WG point*

Even though the amount of reactive power that can be supplied by WG is limited and is not enough to supply the entire reactive power requirement, this corrective action in consequence can minimize the power losses inside the distribution network. As WG unit will be integrated into distribution network depending on the location, reactive power amount required from WG unit will be varied in different operating conditions. In finding optimal reactive power, optimization algorithm such as particle swarm optimization is required [12]. Not all Distributed Generation (DG) technology is suitable to control reactive power continuously. For an example, DG from intermittent resources such as Photovoltaic is not reliable because the required services probably cannot be delivered when it is needed. The technologies of synchronous generator-based DG, micro turbine generation system and fuel cell can fit this requirement. These technologies are available commercially and capable to provide active power and other services such as reactive current injection when required.

## 1.6. Reactive Power Compensation Methods

Simply as an example, there are many reactive power compensation methods. Fig.1.2 shows a simple 5-bus system without using any reactive power compensators. This system is developed in PowerWorld Simulator 17[13]. The active and reactive power output of the generators are 304MW and 129MVar, respectively. Meanwhile there is no capacitor in this system, the generator will take the entire burden of both active power and reactive power loads. After Running the simulation, can get a 4.27MW active power loss and 8.55 MVar reactive power loss.



*Figure 1.2. Five Bus System without Power Factor Correction*

The easiest means to compensate the reactive power is to connect the capacitors in parallel with the loads. This method can be further divided into single power factor correction, group power factor correction, and bulk power factor correction [14].

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## 1.6.1. Single Power Factor Correction

In single power factor correction system, each load has a shunt capacitor. The capacitor and the load it attends to share the same switch, so no extra control devices are required in this system. When the capacitors inject reactive power, both transmission loss and voltage drop will decrease. In this case, the active power loss is 3.84 MW and the Reactive power loss is 7.67 MVar.

The drawback of this method is that the shunt capacitors are not fully applied all the time. Since the load and its shunt capacitor use the same switch, the capacitor will not compensate reactive power if the load is turned off.

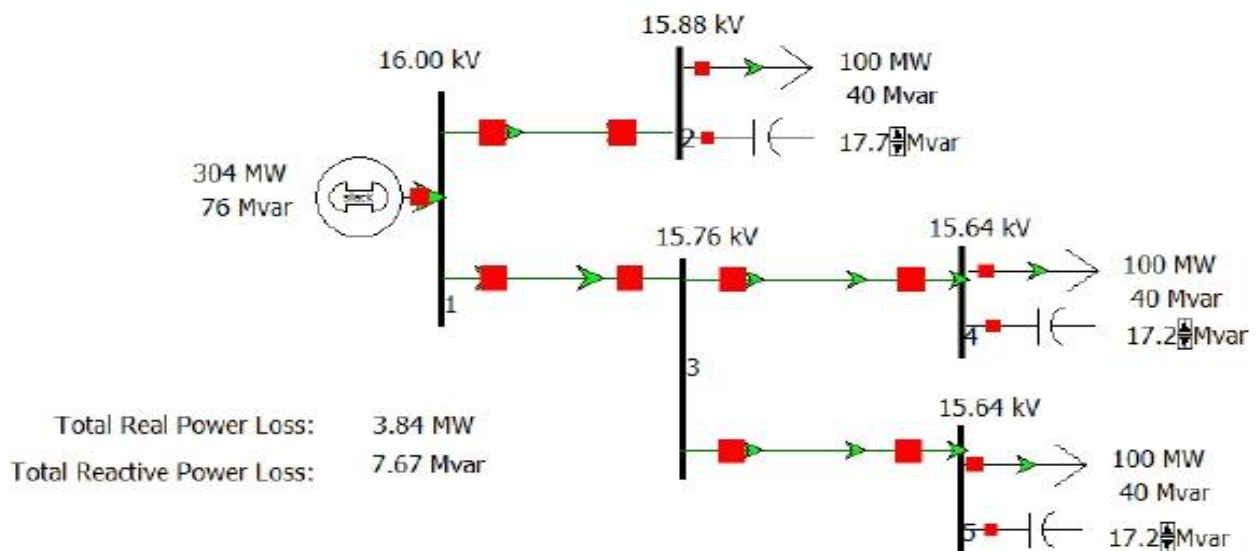


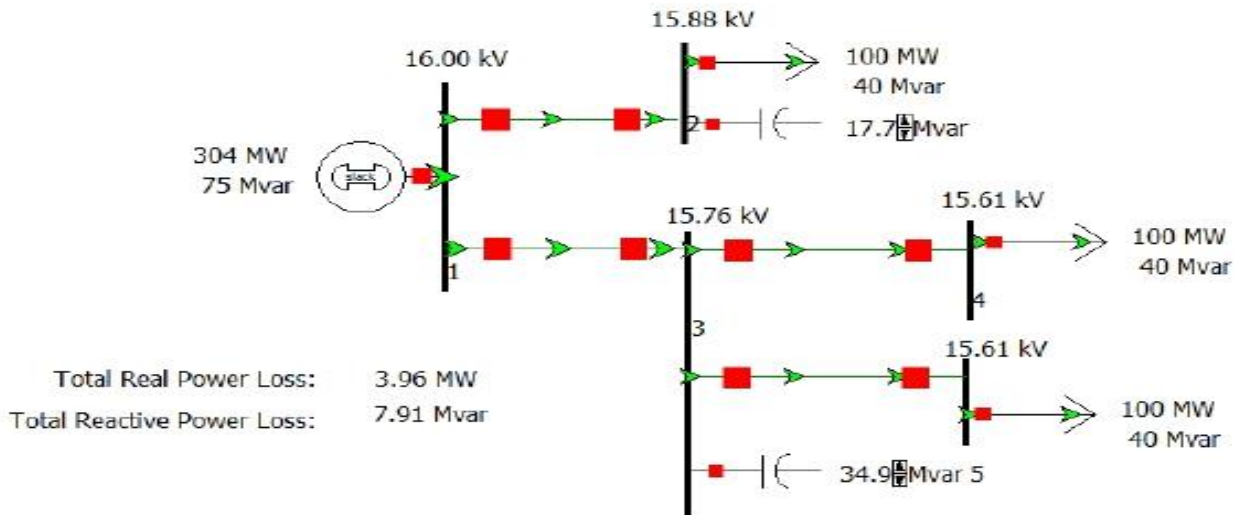
Figure 1.3. Single Power Factor Correction

## 1.6.2. Group Power Factor Correction

To overcome the defect of single power factor correction technique, a more effective way named group power factor correction was proposed. The PowerWorld Model for group power factor correction technique is shown in Fig.1.4. In this system, instead of just compensating only one load, one capacitor could handle a group of loads. Also, the reactive power injection are controlled by a Microprocessor based on the real time reactive power demand. In the

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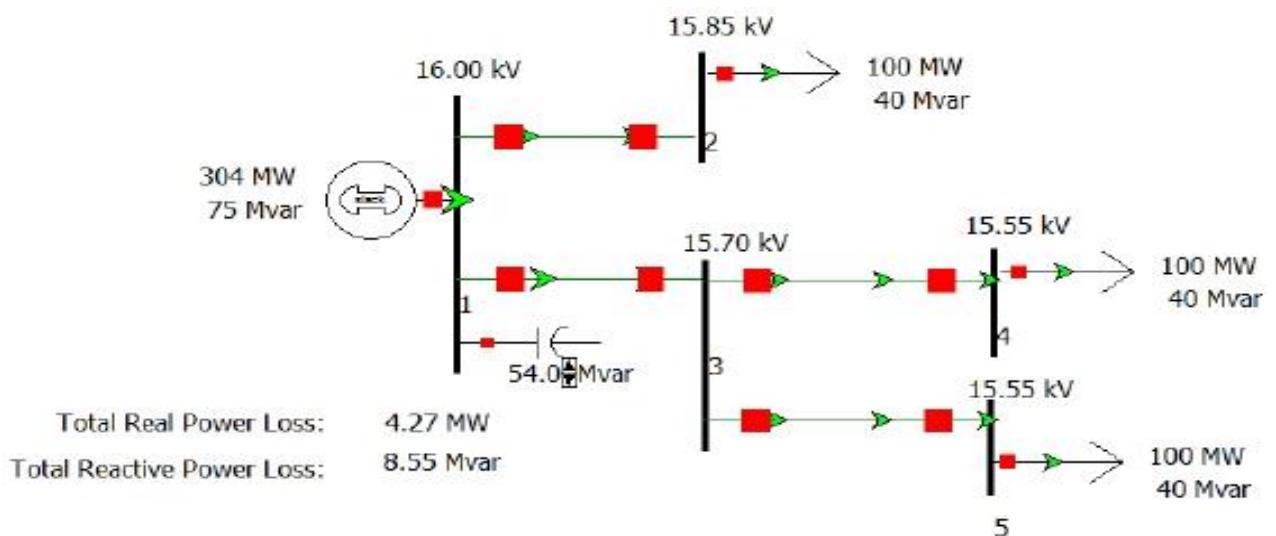
PowerWorld model, the active power loss is 3.96 MW and the reactive power loss is 7.91 MVar, which are somewhat higher than those in single power factor correction method. However, the efficiency of the shunt capacitors is greatly improved.



*Figure 1.4. Group Power Factor Correction*

### 1.6.3. Bulk Power Factor Correction

The third power factor correction method is called bulk power factor correction, as shown in Fig.1.5. The shunt capacitor bank is in charge/custody of the whole system, and it is directly connected to the PV bus. Since most of the loads in the electric power systems are inductive loads, they will consume large amounts of reactive power.



*Figure 1.5 Bulk Power Factor Correction*

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The reactive power has to be obtained from somewhere in the network. If all the reactive power is produced from one place, then the active power loss will be huge. This conclusion is demonstrated in Fig.1.5, both active power loss and reactive power loss is greater than the above two 1.6.1 and 1.6.2 sections. Therefore, on this example the principle of reactive power optimization is compensating reactive power at where the loads consume.

### **1.7. Organization of the Thesis**

The remaining of this paper is organized as follows: In Chapter 2, the problem is formulated with objective functions, equality and inequality constraints. In chapter 3, MATPOWER code utilizing PSO algorithm is provided to solve reactive power optimization problem of distribution network with WG is discussed in detail. In chapter 4, result and discussion for the practical southern region 21-bus power network is challenged in this paper. Conclusions and recommendations are made in the last chapter.

### **1.8. Literature Reviews**

In 2013, L. Shengqi et al. [1] presented reactive power optimization problem in distribution system with wind power and PV generators. Reactive power optimization mathematical model including the active power loss, reactive power compensation capacity and static voltage margin is constructed. In May 1992, Chebbo et al. [2] presented the cause of the 1977 New York blackout has been proved to be the reactive-power problem. The 1987 Tokyo blackout was believed to be due to a reactive-power shortage and a voltage collapse at the summer peak load. These events have confirmed the importance of reactive power planning and dispatching in maintaining the security of modern power systems. Appropriate control of system voltage profiles can enhance system security and may also reduce system losses. In May 1985, Lee et

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al. [3] presented on a unified method for optimal real and reactive power dispatch for the economic operation of power systems. The optimization problem is solved using the conventional Gradient projection method which is used for the first time in the power system study allows the use of functional constraints without the need of penalty function or Lagrange multiplier. In August 2014, T. Sharma et al. [4] presents a brief literature survey of reactive power dispatch and also discusses a comparative study of conventional and evolutionary computation techniques applied for reactive power dispatch. In a power system optimal reactive power dispatch is supported to improve the voltage profile, to reduce losses, to improve voltage stability, to reduce cost etc. In August 2015, K. Naima et al. [5] presents the methodology adopted for controlling the reactive power in western Algerian power system. This Algerian system is in phase of extension because of the strong increase of the request of electricity (+ 5 in 7 % a year), With a population increasing by 1.2 % a year, and which changes these consumer habits using a large number of modern electrical equipment's. The objective is to study this system and to try to solve these problems by the optimization of the reactive powers through Flexible AC Transmission System devices and metaheuristics methods of optimization. In February 2014, Y. Amrane et al. [6] proposes a particle swarm optimization method for solving optimal reactive power dispatch (ORPD) problem. The proposed PSO have been applied for the ORPD problem with different objectives such as minimization of active power losses and improving the voltage profile satisfying various constraints of power flow equation, generator voltage limits, switchable capacitor banks, transformer tap changer limits, and transmission line limits. In 2014, Kittavit Buayai et al. [7] presents the applied MATPOWER techniques for optimization solving in power system research. MATPOWER has been powerful developed for power flow and optimal power flow solving. These two mains of MATPOWER are importance for electrical energy management in terms of loss reduction in power systems and system performance improvement. In power flow solving of

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MATPOWER process can be applied for conveniently solving in heuristic optimizations. In Feb 2011, Zimmerman et al. [8] MATPOWER is an open-source MATLAB based power system simulation package that provides a high-level set of power flow, optimal power flow (OPF), and other tools targeted toward researchers, educators, and students. The OPF architecture is designed to be extensible, making it easy to add user-defined variables, costs, and constraints to the standard OPF problem. This paper presented on the details of the network modeling and problem formulations used by MATPOWER, including its extensible OPF architecture. In May 2012, Ackermann [9] presented an overview of the lessons learned in integrating wind power into power systems and provides an outlook of the relevant issues and solutions to allow even higher wind power penetration levels. This includes the development of standard wind turbine simulation models. In 2010, M. Zamri Che Wanik et al. [11] presented an intelligent approach for managing reactive power from a group of distributed generators (DG) connected to low voltage (LV) bus. The objective is to minimize active power losses and keep the voltage profiles in the network within specified limit. Optimization results shows that this approach manages to reduce power losses and at the same time keeping the voltages within required limit. In 2010, U. Leeton et al. [12] presented the solution of reactive power flow optimization for electric power distribution systems integrating with distributed generating (Distributed Generator: DG) plants which can support daily load demand. To reduce the total energy losses of the entire system, transformer tap and reactive power injection from available reactive power source are required. The setting of variables based on a particular load demand is to minimize losses by using particle swarm optimization in solving optimal power flow problems. In June 2010, Kepka [14] presented on to design automatic detuned capacitor bank for reactive power compensation company with rated power of 200KVAR, rated voltage of 400V and detuning factor  $p=7\%$ . One out of few assumptions was to find supplier who offers low prices and average quality as well as the one, who offers very good quality of the power

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factor correction equipment in order to meet the requirements of Elektrotim company customers. In 2013, Y. Li et al. [15] presented on Optimal Reactive Power Flow (ORPF) is a branch problem in the gradual development of the optimal power flow problem. Differential Evolution (DE) has been proved to be a promising evolutionary algorithm for solving the ORPF problem, but it requires a relatively large population size to avoid premature convergence, which will increase the algorithm convergence time. On the other hand, Artificial Bee Colony (ABC) algorithm has been proved to have good global search ability. Integrating the respective advantages of DE and ABC, a hybrid ABC assisted DE algorithm, denoted as DE-ABC, is proposed in this study to overcome DE's disadvantage of requiring large population size and strengthen the global search ability. In 1995, Kennedy et al. [16] presented a concept for the optimization of nonlinear functions using particle swarm methodology. In 2016, Lohia et al. [17] presented a method for optimal placement and sizing of the capacitors in radial distribution feeder using Genetic algorithm (GA) with an objective of loss reduction and voltage profile improvement. In 2009, Venkatara [18] presented on the Technology/Engineering /Mechanical Provides all the tools needed to begin solving optimization problems using MATLAB. The Second Edition of Applied Optimization with MATLAB Programming enables readers to harness all the features of MATLAB to solve optimization problems using a variety of linear and nonlinear design optimization techniques. In 2007, Cai et al. [19] presented a modified particle swarm optimization (MPSO) method to realize optimal reactive power dispatch (ORPD) considering voltage stability improvement. In 2016, Rayudu et al. [20] presented the biological swarm behaviour of a bird flocking or fish schooling for solving the optimal reactive power dispatch (ORPD) problem using PSO algorithm. In 2015, N. K. Patel et al. [22] this paper presents an approach based on particle swarm optimization method to dispatch reactive power optimally in the power system. In deregulated power system environment, reactive power dispatch problem has immense significance for economical operation and reliability of

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the system as it is strongly related to network loss and system voltage profile. In 2015, S. Pandya et al. [23] Optimal reactive power dispatch is one of the major and important optimization problems in electrical power system operation and control. This is nothing but multi objectives, nonlinear, minimization problem of power system optimization. The particle swarm optimization (PSO) is one of the best populations based intelligent technique of optimization. The basic PSO algorithm is used for optimal reactive power dispatch. In June 2011, Mauro Sebastián Innocente et al. [24] In the original Particle Swarm Optimization (PSO) formulation, convergence of a particle towards its attractors is not guaranteed. A velocity constraint is successful in controlling the explosion, but not in improving the fine-grain search. Clerc and Kennedy studied this system, and proposed constriction methodologies to ensure convergence and to fine tune the search. Thus, they developed different constriction methods according to the correlations among some coefficients incorporated to the system. In 2011, J. C. Bansal et al. [25] Particle Swarm Optimization is a popular heuristic search algorithm which is inspired by the social learning of birds or fishes. It is a swarm intelligence technique for optimization developed by Eberhart and Kennedy in 1995. Inertia weight is an important parameter in PSO, which significantly affects the convergence and exploration exploitation trade-off in PSO process. Since inception of Inertia Weight in PSO, a large number of variations of Inertia Weight strategy have been proposed. In August 2017, Khine Zin Oo et al. [26] presents particle swarm optimization (PSO) algorithm and MATPOWER toolbox are applied to solve the ORPD problem for distribution system with distributed generating (DG) plant. The proposed method minimizes the active power loss in a practical power system as well as determines the optimal placement of a new installed DG. The main idea of this paper is to minimize the active power loss with the approach of reactive power optimization while to adjust the values of control variables and find the optimal placement of the newly installed WG.

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## 1.9. Contribution

1. Designing the southern region 21-Bus power network system using PSAT software by providing all the necessary data.
2. Utilize the Bus data, Generator data and transmission line data of the southern region 21-Bus power network in a MATPOWER toolbox to calculate the power flow and manage the equality constraints in the reactive power optimization problems.
3. Develop the MATLAB coding for southern region 21-Bus power network in order to solve reactive power optimization problem.
4. Use particle swarm optimization algorithm to adjust the values of control variables (voltage magnitudes, tap positions, and shunt capacitance) in the power systems to minimize the active power loss.
5. Place the newly installed wind generation for providing reactive power support.

## **CHAPTER TWO**

### **2. PROBLEM FORMULATION**

At present most of active and reactive power requirement of system loads are generated in the power plants and transmit through utility transmission and distribution network. This leads to higher transmission and distribution losses and is an ineffective way of utilizing transmission and distribution facilities in the network. Further a small-scale reactive power generation at grid substation is little ahead than traditional way but it also added ineffectiveness to the distribution level network. Since the embedded generators are connected to distribution network and most of them are synchronous generators, there is a possibility to utilize these generators for supplying reactive power requirement without much affecting their active power generation to the grid. This could save the capital investment of additional reactive power generating sources such as medium voltage level capacitor bank and be a better way of utilizing existing resources in an optimal way. It is becoming more and more important for power distribution companies to be able to meet efficiently and reliably the demands of their customers. This means that one of their goals is to be able to find an operating state for a large, three-phase, distribution network which minimizes the cost for the power company supplying the power, while satisfying the requirements of the customer.

In the next section states that the general and specific objectives of the research, introduces some mathematical model of active power loss and presents a formulation of the active power loss problem for loss reduction.

# PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

## 2.1. Thesis Objectives

### 2.1.1 General Objective

The main objective of reactive power optimization (RPO) of electric power system is to minimize an active power loss via the optimal adjustment of the power system control variables, while at the same time satisfying various equality and inequality constraints.

### 2.1.2 Specific objective

The specific objectives of the thesis are:

- Collect data from Ethiopian Electric Utility which are needed for transmission/distribution network and other necessary data.
- Determine the optimal place for installing wind generation in the power network.
- Address Particle Swarm Optimization (PSO) for RPO
- Analyse the problem of RPO in the context of Southern Region 21-Bus power network
- Draw appropriate conclusion and recommendation from the result of the study including future scope of the work.

## 2.2. Mathematical Function

The goal of optimal reactive power dispatch [15] is to determine the optimum values of independent variables by optimizing a predefined objective function with respect to the operating bounds of the system.

The optimal reactive power control (ORPC) in a conventional power system is a highly nonlinear, multi-objective, multi-variable and multi-constraint problem where the main objective is to improve the voltage profile by minimizing the power losses and maintaining a secure operation of this power system. The conventional power system referred to here, is the one with non-variable resource such as fossil fuel-power, hydro-power and nuclear plants, which are mainly based on big synchronous generators. These objectives can be achieved by

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

the power system operator by optimally adjusting the facilities such as on-load transformer tap changer, generator excitation, switchable shunt capacitors, switchable inductors, and flexible AC transmission system (FACTS) such as static Var compensator (SVC) and static compensator (STATCOM).

The total active power loss is considered in this work as an objective function. Different constraints as explained earlier are taken into account. The mathematical model of this problem is summarized as follows:

### 2.2.1. Active power loss minimization

The active power loss of the system equals the sum of the real power loss on each branch, and it can be described as:

$$\begin{aligned} \text{Min } f &= \text{Min}(P_{\text{loss}}) \\ f: P_{\text{loss}} &= \sum_{K=1}^N G_{ij} (V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij}) \end{aligned} \quad (4)$$

Where,

$N$  = number of branches,

$G_{ij}$  = the conductance of the branch between bus  $i$  and bus  $j$ ,

$V_i$  = the voltage magnitude of bus  $i$ ,

$V_j$  = the voltage magnitude of bus  $j$ ,

$\theta_{ij}$  = the difference of phase angle between bus  $i$  and bus  $j$

### 2.2.2. System Constraints

To process Reactive power optimization problem there are two RPO constraints named equality and inequality constraints. These constraints are explained in the sections given below.

#### 1) Equality Constraint

Minimization of objective function is subject to follow equality constraints. The equality constraints are the power balance equations, which can be defined by the equations below:

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### i. Real Power Constraint:

$$H1 = P_{gi} - P_{di} - V_i \sum V_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) = 0 \quad (5)$$

$i \in n$ , where set of numbers of buses except the swing/slack bus

### ii. Reactive Power Constraint:

$$H2 = Q_{gi} - Q_{di} - V_i \sum V_j (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij}) = 0 \quad (6)$$

$i \in n$ , where set of numbers of buses except the swing/slack bus

## 2) Inequality Constraint

The inequality constraints are typically technical limitations of the power system devices in the network. The inequality constraints are the ranges of the voltage magnitudes, tap positions of the transformers, and reactive power injection.

### a. Bus Voltage magnitude constraints:

$$V_{Gi-\min} \leq V_{Gi} \leq V_{Gi-\max} \quad (7)$$

### b. Generator bus reactive power constraints:

$$Q_{Gi-\min} \leq Q_{Gi} \leq Q_{Gi-\max} \quad (8)$$

### c. Transformer Tap position constraints:

$$T_{i-\min} \leq T_i \leq T_{i-\max} \quad (9)$$

### d. Reactive power source capacity constraints:

$$Q_{ci-\min} \leq Q_{ci} \leq Q_{ci-\max} \quad (10)$$

Where,

$N$  = number of branches,

$G_{ij}$  = branch conductance between bus  $i$  and bus  $j$ ,

$V_i$  = voltage magnitude of bus  $i$ ,

$V_j$  = voltage magnitude of bus  $j$ ,

$\theta_{ij}$  = phase angle difference between bus  $i$  and bus  $j$

$P_{Gi}$  = active power generation at bus  $i$

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$P_{Di}$  = active power demand at bus i

$Q_{Gi}$  = reactive power generation at bus i

$Q_{Di}$  = reactive power demand at bus i

$Q_{ci}$  = reactive power source i installation

The control variables are self-constrained variables. In this reactive power dispatch problem, the inequality constraints are incorporated as penalty terms into the objective function in (4).

### 2.3. Exterior Penalty Function (EPF) Method

Reactive power optimization problem is a constrained problem. In optimization, the constrained problems are usually converted into unconstrained problems for convenience. One of the commonly used methods to convert the constrained problem is adding exterior penalty function terms to the objective function. Penalty function is used to handle inequality constraints. So, the fitness function for above reactive power dispatch problem is generalized as follows:

$$\text{Minimize } F: f + P(r_h, r_g) \quad (11)$$

Where,

$P(r_h, r_g)$  is the penalty Function

$r_h$  is the penalty multiplier for the equality constraint.

$r_g$  is the penalty multiplier for the inequality constraint.

$F$  is called the fitness function.

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The equality constraint in this thesis will be automatically fulfilled by using MATPOWER 3.2 toolbox, so only inequality constraints need to be concerned. Therefore, the final objective function could be described as:

$$F = P_{loss} + \sum r_{Vi} (V_i - V_i^{lim})^2 + \sum r_{Ti} (T_i - T_i^{lim})^2 + \sum r_{QGi} (Q_{Gi} - Q_{Gi}^{lim})^2 \quad (12)$$

Where,  $r_{Vi}$  is the penalty multiplier for voltage limit,  $r_{Ti}$  is the penalty multiplier for transformer tap setting limit and  $r_{QGi}$  is the penalty multiplier for generated reactive power limit respectively. Penalty multipliers are large positive constants for minimum deviation in these inequality constraints.

Limiting values of  $V_i^{lim}$ ,  $T_i^{lim}$  and  $Q_{Gi}^{lim}$  are defined as follows:

$$V_i^{lim} = \begin{cases} V_i^{max}, & V_i > V_i^{max} \\ V_i^{min}, & V_i < V_i^{min} \end{cases} \quad (13)$$

$$T_i^{lim} = \begin{cases} T_i^{max}, & T_i > T_i^{max} \\ T_i^{min}, & T_i < T_i^{min} \end{cases} \quad (14)$$

$$Q_{Gi}^{lim} = \begin{cases} Q_{Gi}^{max}, & Q_{Gi} > Q_{Gi}^{max} \\ Q_{Gi}^{min}, & Q_{Gi} < Q_{Gi}^{min} \end{cases} \quad (15)$$

In Exterior Penalty Function, if all the control variables are within the limits, the penalty function would be zero. At the reverse, if the control variables go outside of the limits, then the penalty function would be added to the objective function to penalize the violation. In reactive power optimization, if the control variables go above the voltage limit, major damages to the power systems would occur. So, the voltage magnitudes, tap positions, and reactive power injection have to be sensibly examined.

## **CHAPTER THREE**

### **3. RESEARCH METHODOLOGY**

Power system optimization problems are more complication and diversity when additional constraints are considered. The heuristic algorithm optimization is required in finding the optimal settings of control variables including voltage magnitude of a new WG. In this paper, the technique of applied MATPOWER into a particle swarm optimization (PSO) algorithm is contributed to solve RPO problem integrating a WG.

#### **3.1. Particle Swarm Optimization**

##### **3.1.1. Overview of the Particle Swarm Optimization**

Particle Swarm Optimization (PSO) was developed by J.Kennedy and R.Eberhart in 1995 [16][20][22][23]. The idea of PSO comes from a simplified social system like bird flocking or fish schooling. The PSO is inspired by the social behaviour of a flock of migrating birds trying to reach an unknown destination. In PSO, each solution is a bird in the flock and is referred to as a particle. A particle is analogous to a chromosome in GAs [17] [18]. As opposed to GAs, the evolutionary process in the PSO does not create new birds from parent ones. Rather, the birds in the population only evolve their social behaviour and accordingly their movement towards a destination. Each bird looks in a specific direction, and then when communicates together, they identify the bird that is in the best location. Accordingly, each bird speeds towards the best bird using a velocity that depends on its current position. Each bird, then investigates the search space from its new local position, and the process repeats until the flock reaches a desired destination.

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In General, PSO is a fast, simple and efficient population-based optimization method. Each particle updates its position based upon its own best position, global best position among particles and its previous velocity vector according to the following equations:

$$V_i^{k+1} = WV_i^k + C_1r_1(p_{besti} - X_i^k) + C_2r_2(g_{best} - X_i^k) \quad (16)$$

$$X_i^{k+1} = X_i^k + \chi * V_i^{k+1} \quad (17)$$

$$\chi = \frac{2}{c-2+\sqrt{c^2-4c}} \quad (18)$$

Where,

$C=c_1=c_2$ : Positive acceleration constants

$V_i^{k+1}$ : The velocity of  $i^{th}$  particle at  $(k+1)^{th}$  iteration

$W$  : Inertia weight of the particle

$V_i^k$  : The velocity of  $i^{th}$  particle at  $k^{th}$  iteration [-0.003, 0.003]

$r_1, r_2$  : Randomly generated numbers between [0, 1]

$p_{best_i}$  : The best position of the  $i^{th}$  particle obtained based upon its own experience

$g_{best}$  : Global best position of the particle in the population

$x_i^{k+1}$  : The position of  $i^{th}$  particle at  $(k+1)^{th}$  iteration

$x_i^k$  : The position of  $i^{th}$  particle at  $k^{th}$  iteration

$\chi$  : Constriction factor. It may help insure convergence. [24]

The acceleration factors handle the step sizes of the particles in the next iteration. If the acceleration factors are too small, the particles may not have enough velocity to reach the target regions. If the acceleration factors are too big, the particles may fly over the optimal value. Appropriate selection of acceleration factors could avoid trapping into local minimal and reduce the computation time. Inertia weight is an important parameter in PSO, which significantly affects the convergence and exploration exploitation trade-off in PSO process.

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Inertia Weight ( $w$ ) is used to control the velocity [25]. Inertia Weight plays a key role in the process of providing balance between exploration and exploitation process. The Inertia Weight determines the contribution rate of a particle's previous velocity to its velocity at the current time step. A large Inertia Weight facilitates a global search while a small Inertia Weight facilitates a local search.

Suitable selection of inertia weight  $w$  provides good balance between global and local explorations.

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter \quad (19)$$

Where,  $w_{max}$  is the value of inertia weight at the beginning of iterations,  $w_{min}$  is the value of inertia weight at the end of iterations,  $iter$  is the current iteration number and  $iter_{max}$  is the maximum number of iterations.

### The advantages of PSO over conventional optimization techniques are:

- PSO only requires the fitness function (performance index or objective function) information to guide the search in the problem space instead of complex mathematical operations like gradient, Hessian, or matrix inversion. This reduces the computational complexity and relieves some of the restrictions that are usually imposed on the objective function like differentiability, continuity, or convexity
- PSO is a population-based method, which follows stochastic transition rules. This property makes it to be less sensitive to good initial solution, to be less susceptible to get trapped on local minima but also to be efficient in searching a complicated and high dimension space
- It can be easily programmed and modified with basic mathematical and logic operations.

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- It is inexpensive in terms of computation time and memory
- It requires less parameter tuning.
- It works with direct real-valued numbers, which eliminates the need to do binary conversion of a classical canonical genetic algorithm.

### **3.2. MATPOWER**

MATPOWER [21] is a powerful MATLAB programming package for power flow and optimal power flow solving. Mat-power is a package of MATLAB M-files that is developed by Ray D. Zimmerman, Carlos E. Murillo-Sánchez and Deqiang Gan in 1996 to meet the computational requirements of the Power Web project [8]. The biggest advantage of MATPOWER is its easiness to use and modify the original code. MATPOWER process can be applied into particle swarm optimization in terms of loss reduction in power system. The process of MATPOWER comprises of three steps as follows:

- Input file, the power system data such as bus data, branch data and generator data will be read for next steps.
- Calculate the power flow by Newton-Raphson method.
- Display all results.

### **3.3. Simulation with MATLAB Software**

MATLAB (“MATrix LABoratory”) is a tool for numerical computation and visualization. It is widely used in all areas of applied mathematics, in the industry and in education and research at universities. Also, widely used tool in worldwide for simulation. MATLAB stands for MATrix LABoratory and the software is built up around vectors and matrices. This makes the software particularly useful for linear algebra, but MATLAB is also a great tool for solving algebraic and differential equations and for numerical integration. MATLAB has powerful graphic tools and capable of producing results by pictures in both 2D and 3D. It is also a

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programming language, and it is one of the easiest programming languages for writing mathematical programs. MATLAB also has some tool boxes useful for image processing, signal processing, optimization, etc. Simulink is an additional package, that's capable of graphical multi-domain simulation and model-based design for dynamic and embedded systems. Simulink were used to model Electrical Distribution system and coding were done to simulate according to research objectives [19].

### **3.4. Procedures of PSO Algorithm Combined with MATPOWER Toolbox for Reactive Power Optimization**

In the RPO problem, the elements of the solution consist of all control variables, namely, generator bus voltages, the transformer tap setting and the reactive power generation. These variables are representing continuous variables in the PSO population. The fitness function of RPO problem presented in this paper is to minimize the total power loss. For each individual, the equality constraints given by (5) and (6) are satisfied by using MATPOWER toolbox.

Step by step procedures to implement the reactive power optimization problem using PSO combined with MATPOWER toolbox are as follows:

1. Initialization of PSO parameters. Load case information: the system data; generator data, bus data and branch data are saved in MATPOWER case file.
2. Initialize various particles (control variables) values randomly.
3. Find fitness value of fitness function and save  $P_{best}$  and  $G_{best}$  values.
4. Update the velocity and position of each particle using (16) and (17).
5. Call MATPOWER simulation function 'runpf' to run power flow updated particles' positions and velocities.
6. Display simulation results and loss of each particle after power flow calculation using MATPOWER.

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7. Check whether the inequality constraints violates the limit or not at the end of power flow. If the solution exceeds the limits, penalize the violations.
8. Find new fitness value of fitness function using updated particle position and velocity.
9. Compare new fitness value with previous value. If the new fitness value obtained is better than the previous value, update new  $P_{best}$  and  $G_{best}$ .
10. Repeat above procedure from step 4 for max no. of iterations.

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The flow chart of the PSO algorithm combined with MATPOWER toolbox for RPO is illustrated in Figure 3.1.

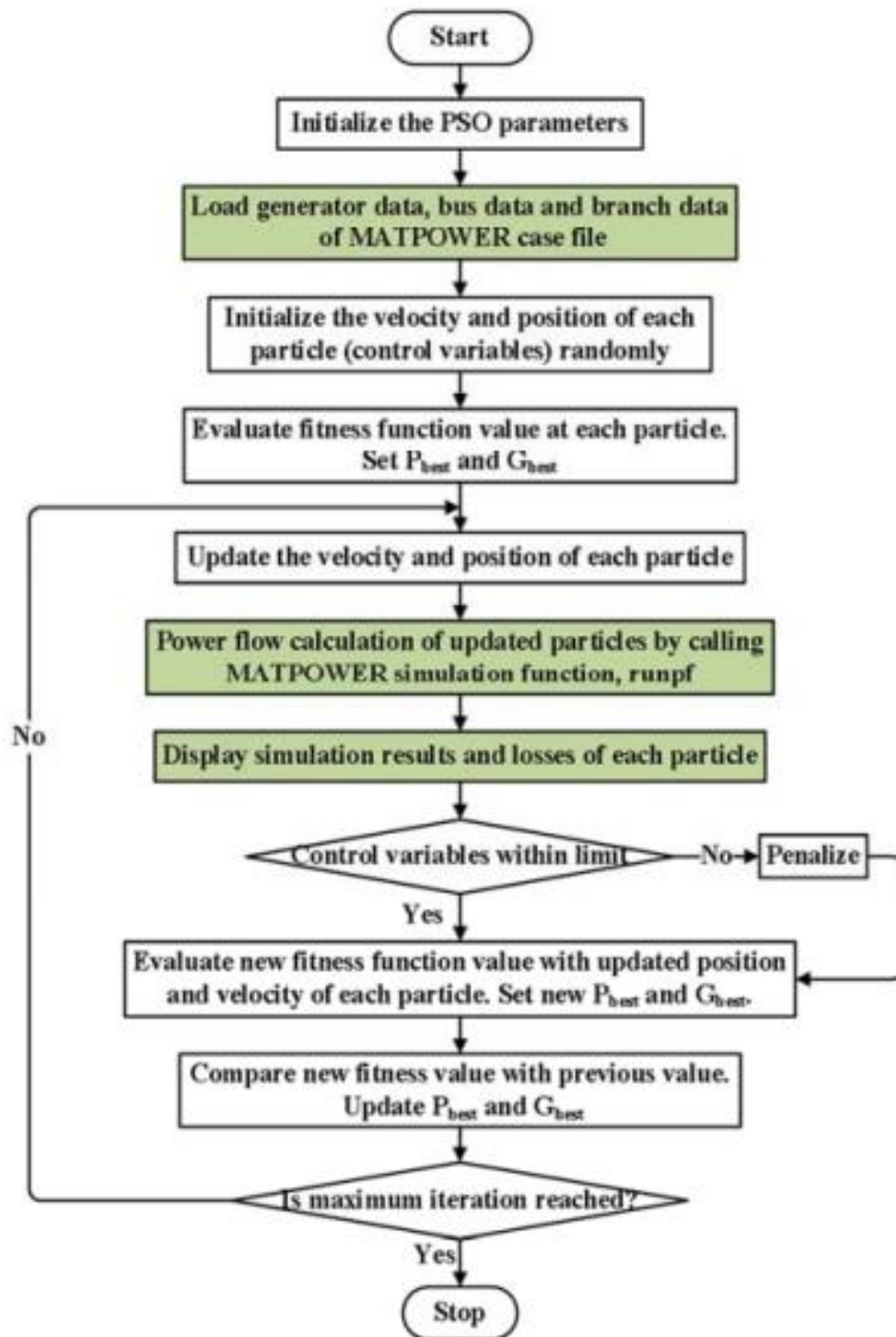


Figure 3.1 Flow chart of PSO algorithm combined with MATPOWER toolbox.

## CHAPTER FOUR

### 4. SIMULATION RESULT AND DISCUSSION

#### 4.1. Case Study: Southern Region 21-Bus Power Network

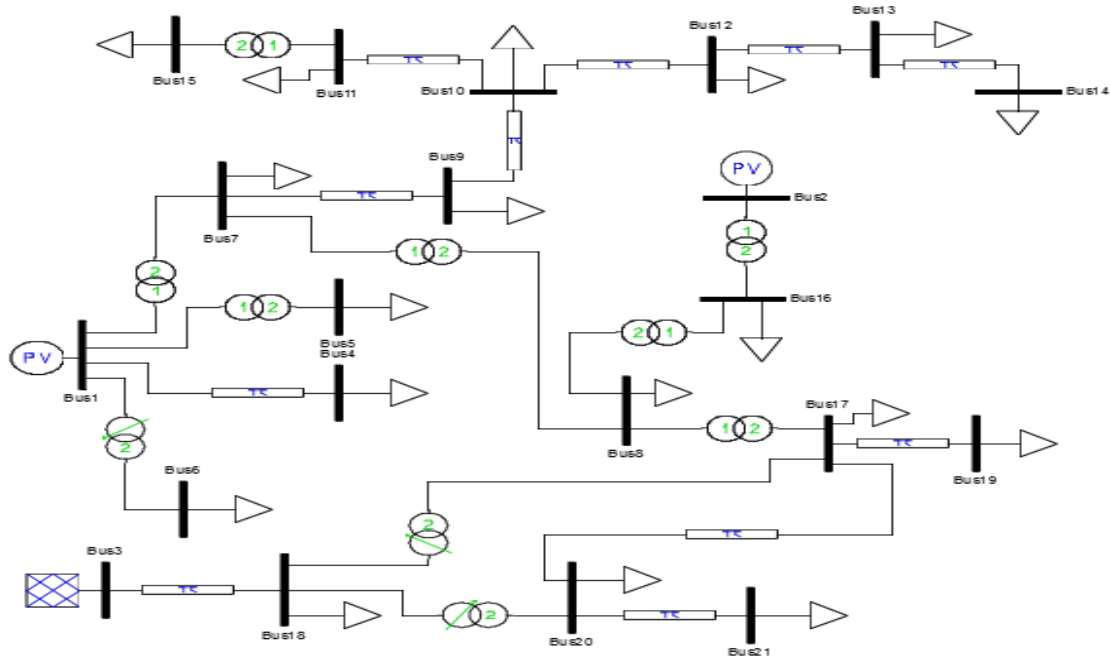
To prove the effectiveness of the proposed PSO based algorithm for reactive power optimization, a practical 21-bus distribution test system is used as shown in Figure 4.1

The voltage levels of the test system are 400KV, 230 kV, 132 kV and 66 kV. The Southern Region 21-Bus network system has three generators at bus numbers 1, 2 and 3. The first PV one is at bus 1; the second PV is at bus 2; the 3<sup>rd</sup> generator is at Bus 3(slack bus). This system includes of 21 transmission lines, three tap-ratio transformers in lines between bus numbers 1-6, 17-18 and 18-20. In addition, bus numbers 4 and 13 has been selected as shunt VAR compensation buses. The lower limits voltage magnitude of all buses is considered as 0.9 pu, while the upper limit is considered as 1.1 pu for the generator buses and 1.05 pu for the load buses. The tap ratio transformer setting has lower limit as 0.95 pu and upper limit as 1.05 pu. The obvious features of the simulation results are also discussed in this section.

*Table 4-1 Variable limits (p.u)*

	Lower Limit	Upper Limit
Reactive Power Generation (Bus 1)	0 MVar	20 MVar
Reactive Power Generation (Bus 2)	0 MVar	15 MVar
Reactive Power Generation (Bus 3)	0 MVar	15 MVar
Voltage Magnitude	0.9	1.1
Tap Setting	0.95	1.05
Shunt VAR Compensation (Bus 4)	0 MVar	20 MVar
Shunt VAR Compensation (Bus 13)	0 MVar	10 MVar
Load Bus	0.95	1.05

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**Figure 4.1 SNNPR 21-Bus Power Network System**

The initial operating conditions for the proposed method are given as follows for 100 MVA base. The total load of the system is 360.20MW and 29MVAR. MATPOWER toolbox is used to calculate the power flow of practical 21-bus distribution system. Before optimization, the total real and reactive power loss of the entire system is 18.543MW and 23.14MVAR, respectively.

### 4.2. Parameters of PSO based RPO

The selection of the PSO parameters for general problems is listed in Table 4.2. Programmers may change some of these parameters based on different problems.

**Table 4-2 PSO Parameters Selection**

Sr. No	Parameters	Value
1	Particle/Population size	50
2	Dimension of the particles	8
3	Acceleration factor	[C1=2, C2=2]
4	Max. number of iterations	200
5	Inertial Weight	[Final Inertia weight = 0.4, Initial Inertia weight = 0.9]
6	Random Number	[0, 1]
7	Optimal Penalty Settings	[r <sub>vi</sub> =25500, r <sub>Ti</sub> =10000, r <sub>Gi</sub> =1000]
8	Constriction Factor	[0.729]

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

The Table 4-3 to 4-5 are information used for this thesis.

**Table 4-3 Bus data**

```

%% bus data
% bus_i type Pd Qd Gs Bs area Vm Va baseKV zone Vmax Vmin
bus = [
  1 2 0 0 0 0 1 1.020 0 230 1 1.1 0.9;
  2 2 0 0 0 0 1 1.040 0 132 1 1.1 0.9;
  3 3 0 0 0 0 1 1.050 0 400 1 1.1 0.9;
  4 1 0.5 20 0 20 1 0.981 0 230 1 1.05 0.95;
  5 1 1 2 0 0 1 1.019 0 132 1 1.05 0.95;
  6 1 10 0 0 0 1 1.034 0 66 1 1.05 0.95;
  7 1 19 1 0 0 1 1.027 0 132 1 1.05 0.95;
  8 1 70 1 0 0 1 1.034 0 230 1 1.05 0.95;
  9 1 33 0 0 0 1 1.025 0 132 1 1.05 0.95;
  10 1 70 0 0 0 1 1.019 0 132 1 1.05 0.95;
  11 1 11 0 0 0 1 1.010 0 66 1 1.05 0.95;
  12 1 8 0 0 0 1 1.016 0 132 1 1.05 0.95;
  13 1 10 0 0 10 1 1.007 0 132 1 1.05 0.95;
  14 1 3.5 2 0 0 1 0.953 0 132 1 1.05 0.95;
  15 1 3 0 0 0 1 1.047 0 66 1 1.05 0.95;
  16 1 8.5 1 0 0 1 1.037 0 132 1 1.05 0.95;
  17 1 75 0 0 0 1 1.037 0 132 1 1.05 0.95;
  18 1 24 0 0 0 1 1.037 0 400 1 1.05 0.95;
  19 1 9.2 0 0 0 1 1.035 0 132 1 1.05 0.95;
  20 1 3 0 0 0 1 1.048 0 132 1 1.05 0.95;
  21 1 1.5 2 0 0 1 1.045 0 132 1 1.05 0.95;
];
    
```

(Source: Take from Mat-power Toolbox)

**Table 4-4 Generator Data**

```

%% generator data
% bus Pg Qg Qmax Qmin Vg mBase status Pmax Pmin
gen = [
  1 80 20 20 0 1.02 100 1 180 0;
  2 75 15 15 0 1.04 100 1 175 0;
  3 40 15 15 0 1.05 100 1 140 0;
];
    
```

(Source: Take from Mat-power Toolbox)

Table 4-5 Branch Data

```

%% branch data
%   fbus   tbus   r   x   b   rateA   rateB   rateC   ratio   angle   status
branch = [
    1   4   0.0215  0.05058  0   0   0   0   0   0   1;
    1   5   0   0.038   0   0   0   0   0   0   1;
    1   6   0   0.01656  0   0   0   0   0.95  0   1;
    1   7   0   0.02712  0   0   0   0   0   0   1;
    2  16   0   0.0092   0   0   0   0   0   0   1;
    3  18   0.0325  0.0132   0   0   0   0   0   0   1;
    7   8   0   0.0144   0   0   0   0   0   0   1;
    7   9   0.0021  0.0049   0   0   0   0   0   0   1;
   16   8   0   0.0090   0   0   0   0   0   0   1;
    8  17   0   0.01404  0   0   0   0   0   0   1;
    9  10   0.0033  0.0079  0.0018  0   0   0   0   0   1;
   10  11   0.1290  0.0030   0   0   0   0   0   0   1;
   10  12   0.0378  0.0090  0.0020  0   0   0   0   0   1;
   11  15   0   0.0259   0   0   0   0   0   0   1;
   12  13   0.0093  0.02166  0.0049  0   0   0   0   0   1;
   13  14   0.0219  0.0516  0.0116  0   0   0   0   0   1;
   17  19   0.0106  0.0247   0   0   0   0   0   0   1;
   18  17   0   0.0573   0   0   0   0   0.975  0   1;
   17  20   0.03546  0.03256  0   0   0   0   0   0   1;
   18  20   0   0.0283   0   0   0   0   0.943  0   1;
   20  21   0.0107  0.0253   0   0   0   0   0   0   1;
];
    
```

(Source: Take from Mat-power Toolbox)

The results are stored in “diary” file. As PSO is a stochastic optimization method, it gives different optimized results in every simulation. Therefore, it considered only one of the best results.

There are two scenarios were considered in this section to show the effectiveness of the proposed method to control reactive power on practical 21-bus transmission/distribution system. The conventional PSO algorithm has been implemented in MATLAB programming language incorporated with MATPOWER package, and numerical tests are carried out on a core i5, 1.17 GHz, 8 GB RAM computer.

1. RPO results before/After optimization
2. RPO results After optimization with WG

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

### 4.3. SNNPR 21-Bus RPO result before Optimization

In the table 4-6 shows that the base case for power flow result before optimization has the total active power generation 379.11MW and total reactive power generation is 20.31MVAR and the total active power load is 360.20MW and the total reactive power load is 29MVAR.

*Table 4-6. SNNPR 21-Bus Data before Optimization*

Bus No	Voltage		Generation		Load	
	V <sub>m</sub> (pu)	V <sub>a</sub> (deg)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1	1.020	-5.529	80.00	-17.21	-	-
2	1.040	-5.151	75.00	76.06	-	-
3	1.050	0.000	224.11	-38.54	-	-
4	1.020	-5.553	-	-	0.50	20.00
5	1.019	-5.550	-	-	1.00	2.00
6	1.074	-5.611	-	-	10.00	0.00
7	1.025	-6.546	-	-	19.00	1.00
8	1.027	-5.841	-	-	70.00	1.00
9	1.023	-6.929	-	-	33.00	0.00
10	1.020	-7.406	-	-	70.00	0.00
11	1.002	-7.429	-	-	11.00	0.00
12	1.013	-7.723	-	-	8.00	0.00
13	1.014	-7.936	-	-	10.00	0.00
14	1.012	-8.02	-	-	3.50	2.00
15	1.002	-7.474	-	-	3.00	0.00
16	1.033	-5.518	-	-	8.50	1.00
17	1.019	-5.124	-	-	75.00	0.00
18	0.986	-2.075	-	-	24.00	0.00
19	1.018	-5.249	-	-	9.20	0.00
20	1.032	-3.394	-	-	3.00	0.00
21	1.031	-3.403	-	-	1.50	2.00
<b>Total:</b>			<b>379.11</b>	<b>20.31</b>	<b>360.20</b>	<b>29.00</b>

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

In the table 4-7 shows the Power Loss result before optimization that indicates the total active power loss 18.910MW and total reactive power loss 24.49MVA<sub>r</sub>.

*Table 4-7. SNNPR 21-Bus Branch Data before Optimization*

BRNCH No	FROM BUS	TO BUS	FROM BUS INJECTION		TO BUS INJECTION		LOSS ( $I^2 * Z$ )	
			P (MW)	Q (MVA <sub>r</sub> )	P (MW)	Q (MVA <sub>r</sub> )	P (MW)	Q (MVA <sub>r</sub> )
1	1	4	0.50	-0.82	-0.50	0.82	0.000	0.00
2	1	5	1.00	2.00	-1.00	-2.00	0.000	0.00
3	1	6	10.00	0.01	-10.00	0.00	0.000	0.01
4	1	7	68.50	-18.41	-68.50	19.72	0.000	1.31
5	2	16	75.00	76.06	-75.00	-75.09	0.000	0.97
6	3	18	224.11	-38.54	-208.87	44.73	15.244	6.19
7	7	8	-90.24	-16.99	90.24	18.14	0.000	1.15
8	7	9	139.74	-8.50	-139.35	9.41	0.391	0.91
9	16	8	66.50	74.09	-66.50	-73.25	0.000	0.84
10	8	17	-93.74	58.86	93.74	-57.23	0.000	1.63
11	9	10	106.35	-9.41	-105.99	10.08	0.359	0.86
12	10	11	14.25	0.01	-14.00	0.00	0.251	0.01
13	10	12	21.74	-10.06	-21.53	9.90	0.208	0.05
14	11	15	3.00	0.00	-3.00	0.00	0.000	0.00
15	12	13	13.53	-9.90	-13.50	9.46	0.025	0.06
16	13	14	3.50	0.81	-3.50	-2.00	0.003	0.01
17	17	19	9.21	0.02	-9.20	0.00	0.009	0.02
18	18	17	104.57	-9.86	-104.57	16.03	0.000	6.18
19	17	20	-73.38	41.17	75.80	-38.95	2.418	2.22
20	18	20	88.93	-9.56	-88.93	11.63	0.000	2.08
21	20	21	1.50	2.00	-1.50	-2.00	0.001	0.00
<b>Total:</b>							<b>18.543</b>	<b>23.14</b>

### 4.4. SNNPR 21-Bus RPO results after Optimization

The MATLAB code for Optimization is attached in Appendix A.

When the optimization process starts, the position of each particle will be continuously updated until reaching the stopping criteria.

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

At the beginning of the optimization process, the positions of the particles are arbitrarily selected. Before optimization the global optimal active and reactive power loss is at about 18.543MW and 23.14MVAR. As the particles continually update their positions towards the best solution, the active power loss keeps decreasing. As shown in the figure 4.2 below, after 90 iterations, no obvious improvement can be observed. Lastly, the active and reactive power loss converges to 16.576MW and 24.37MVAR.

In the table 4-8 show that the power flow result after optimization has the total active power generation 376.78MW and total reactive power generation 26.48MVAR.

*Table 4-8. SNNPR 21-Bus Data after optimization*

Bus No	Voltage		Generation		Load	
	Vm (pu)	Va (deg)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1	1.044	-4.553	80.00	68.80	-	-
2	1.004	-4.167	75.00	-70.28	-	-
3	1.113	0.000	221.78	27.96	-	-
4	1.044	-4.572	-	-	0.50	20.00
5	1.043	-4.574	-	-	1.00	2.00
6	1.051	-4.641	-	-	10.00	0.00
7	1.026	-5.561	-	-	19.00	1.00
8	1.017	-4.860	-	-	70.00	1.00
9	1.023	-5.935	-	-	33.00	0.00
10	1.020	-6.399	-	-	70.00	0.00
11	1.002	-6.423	-	-	11.00	0.00
12	1.013	-6.591	-	-	8.00	0.00
13	1.012	-6.773	-	-	10.00	0.00
14	1.010	-6.857	-	-	3.50	2.00
15	1.002	-6.467	-	-	3.00	0.00
16	1.011	-4.537	-	-	8.50	1.00
17	1.018	-4.150	-	-	75.00	0.00
18	1.045	-1.143	-	-	24.00	0.00
19	1.017	-4.273	-	-	9.20	0.00
20	1.039	-2.413	-	-	3.00	0.00
21	1.039	-2.422	-	-	1.50	2.00
<b>Total:</b>			<b>375.83</b>	<b>22.86</b>	<b>360.20</b>	<b>29.00</b>

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

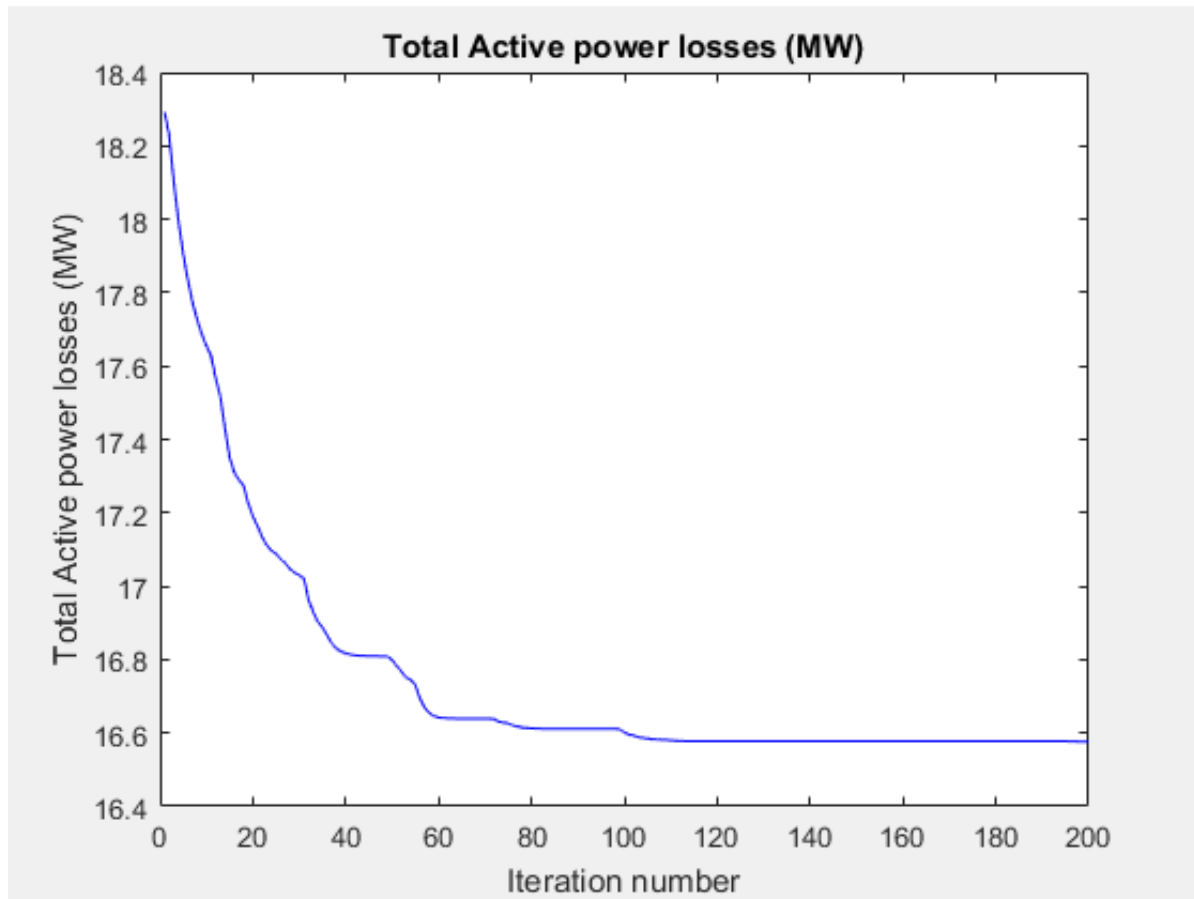
In the table 4-9 shows that the power loss result after optimization indicates the total active power loss 16.576MW and total reactive power loss 24.37MVar.

*Table 4-9. SNNPR 21-Bus power loss after optimization*

BRNCH No	FROM BUS	TO BUS	FROM BUS INJECTION		TO BUS INJECTION		LOSS ( $I^2 * Z$ )	
			P (MW)	Q (MVar)	P (MW)	Q (MVar)	P (MW)	Q (MVar)
1	1	4	0.50	-1.21	-0.50	1.21	0.000	0.00
2	1	5	1.00	2.00	-1.00	-2.00	0.000	0.00
3	1	6	10.00	0.02	-10.00	-0.00	0.000	0.02
4	1	7	68.50	67.99	-68.50	-65.67	0.000	2.32
5	2	16	75.00	-70.28	-75.00	71.25	0.000	0.96
6	3	18	221.78	27.96	-208.67	-22.64	13.104	5.32
7	7	8	-90.19	66.49	90.19	-64.78	0.000	1.72
8	7	9	139.69	-1.82	-139.30	2.73	0.389	0.91
9	16	8	66.50	-72.25	-66.50	73.10	0.000	0.85
10	8	17	-93.69	-9.32	93.69	10.52	0.000	1.20
11	9	10	106.30	-2.73	-105.95	3.39	0.356	0.85
12	10	11	14.25	0.01	-14.00	-0.00	0.252	0.01
13	10	12	21.70	-3.40	-21.52	3.24	0.175	0.04
14	11	15	3.00	0.00	-3.00	0.00	0.000	0.00
15	12	13	13.52	-3.24	-13.50	2.77	0.017	0.04
16	13	14	3.50	0.82	-3.50	-2.00	0.003	0.01
17	17	19	9.21	0.02	-9.20	-0.00	0.009	0.02
18	18	17	99.32	38.14	-99.32	-32.12	0.000	6.02
19	17	20	-78.58	21.58	80.85	-19.50	2.271	2.08
20	18	20	85.35	-15.51	-85.35	17.49	0.000	1.99
21	20	21	1.50	2.00	-1.50	-2.00	0.001	0.00
<b>Total:</b>							<b>16.576</b>	<b>24.37</b>

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

In the figure 4-2 below shows the graphical representation of total active power loss with respect to total number of iterations.



*Figure 4.2 SNNPR 21-Bus Loss Reduction result after optimization*

### 4.5. SNNPR 21-Bus Power Network RPO with WGs

The MATLAB code for the RPO with adding new WGs is attached in Appendix B.

The second scenario is about adding a new WG to the practical 21-bus system and then optimizes the reactive power of the system by using the proposed approach. A direct-derive synchronous generator and wind turbine is selected as the new WG. Its rated power is 2050 kW which can deliver 1.2 MVar and -1.0 MVar reactive powers. The optimal placement of a new WG in 132 kV Bukuluguma (Bus-14) distribution network is determined in this scenario.

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

If a new WG is installed on different buses, it will be required to modify the capacity of the real and reactive power to new parameters.

If the wind turbine is installed on a PV bus (Bus 1&2), then both active and reactive power capacity of the generator need to be changed. In Table 4.10, below the active power output of the generator at bus 1 is amplified from 80 to 82.05 and the range of reactive power output for bus 1 is changed from [0, 20] to [-1, 21.2] and respectively.

*Table 4-10. Generator Data of the Modified System when the WG is installed at bus 1*

```
%% generator data
% bus Pg Qg Qmax Qmin Vg mBase status Pmax Pmin
gen = [
  1 82.05 20 21.2 -1 1.02 100 1 182.05 0;
  2 75 15 15 0 1.04 100 1 175 0;
  3 40 15 15 0 1.05 100 1 140 0;
];
```

In Table 4.11, below the active power output of the generator at bus 2 increased from 75 to 77.05 and the range of reactive power output for bus 2 is changed from [0, 15] to [-1, 16.2]

*Table 4-11 Generator Data of the Modified System when the WG is installed at bus 2*

```
%% generator data
% bus Pg Qg Qmax Qmin Vg mBase status Pmax Pmin
gen = [
  1 80 20 20 0 1.02 100 1 180 0;
  2 77.05 15 16.2 -1 1.04 100 1 177.05 0;
  3 40 15 15 0 1.05 100 1 140 0;
];
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

If the wind turbine is installed on PQ bus (e.g. bus 4), in addition to modifying the capacity of the real and reactive power to new parameters, the voltage magnitude of the new installed WG bus should also be treated as a new control variable, as illustrated in the fig. 4.12 and fig. 4.13. The voltage magnitude of the new installed WG bus is added as a new control variable before executing the MATLAB code. The other study is about adding a new WG to the 21-Bus system and then optimizes the reactive power of the system by using Particle Swarm Optimization.

**Table 4-12 Bus Data of the Modified System when the WG is Installed on Bus 4**

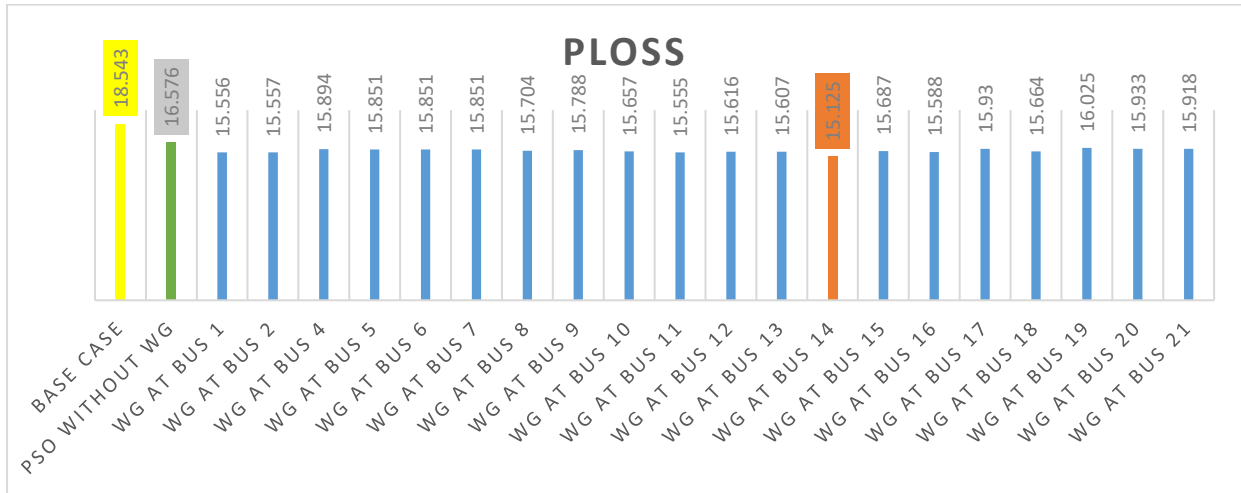
%% bus data													
%	bus_i	type	Pd	Qd	Gs	Bs	area	Vm	Va	baseKV	zone	Vmax	Vmin
bus = [													
	1	2	0	0	0	1	1.020	0	230	1	1.1	0.9;	
	2	2	0	0	0	1	1.040	0	132	1	1.1	0.9;	
	3	3	0	0	0	1	1.050	0	400	1	1.1	0.9;	
	4	2	0.5	20	0	20	1	0.981	0	230	1	1.1	0.9;
	5	1	1	2	0	0	1	1.019	0	132	1	1.05	0.95;
	6	1	10	0	0	0	1	1.034	0	66	1	1.05	0.95;
	7	1	19	1	0	0	1	1.027	0	132	1	1.05	0.95;
	8	1	70	1	0	0	1	1.034	0	230	1	1.05	0.95;
	9	1	33	0	0	0	1	1.025	0	132	1	1.05	0.95;
	10	1	70	0	0	0	1	1.019	0	132	1	1.05	0.95;
	11	1	11	0	0	0	1	1.010	0	66	1	1.05	0.95;
	12	1	8	0	0	0	1	1.016	0	132	1	1.05	0.95;
	13	1	10	0	0	10	1	1.007	0	132	1	1.05	0.95;
	14	1	3.5	2	0	0	1	0.953	0	132	1	1.05	0.95;
	15	1	3	0	0	0	1	1.047	0	66	1	1.05	0.95;
	16	1	8.5	1	0	0	1	1.037	0	132	1	1.05	0.95;
	17	1	75	0	0	0	1	1.037	0	132	1	1.05	0.95;
	18	1	24	0	0	0	1	1.037	0	400	1	1.05	0.95;
	19	2	9.2	0	0	0	1	1.035	0	132	1	1.05	0.95;
	20	1	3	0	0	0	1	1.048	0	132	1	1.05	0.95;
	21	1	1.5	2	0	0	1	1.045	0	132	1	1.05	0.95;
];													

**Table 4-13 Generator Data of the Modified System when the WG is Installed on Bus 4**

%% generator data										
%	bus	Pg	Qg	Qmax	Qmin	Vg	mBase	status	Pmax	Pmin
gen = [										
	1	80	20	20	0	1.020	100	1	180	0;
	2	75	15	15	0	1.040	100	1	175	0;
	3	40	15	15	0	1.050	100	1	140	0;
	4	2.05	0	1.2	-1	0.981	100	1	2.05	0;
];										

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

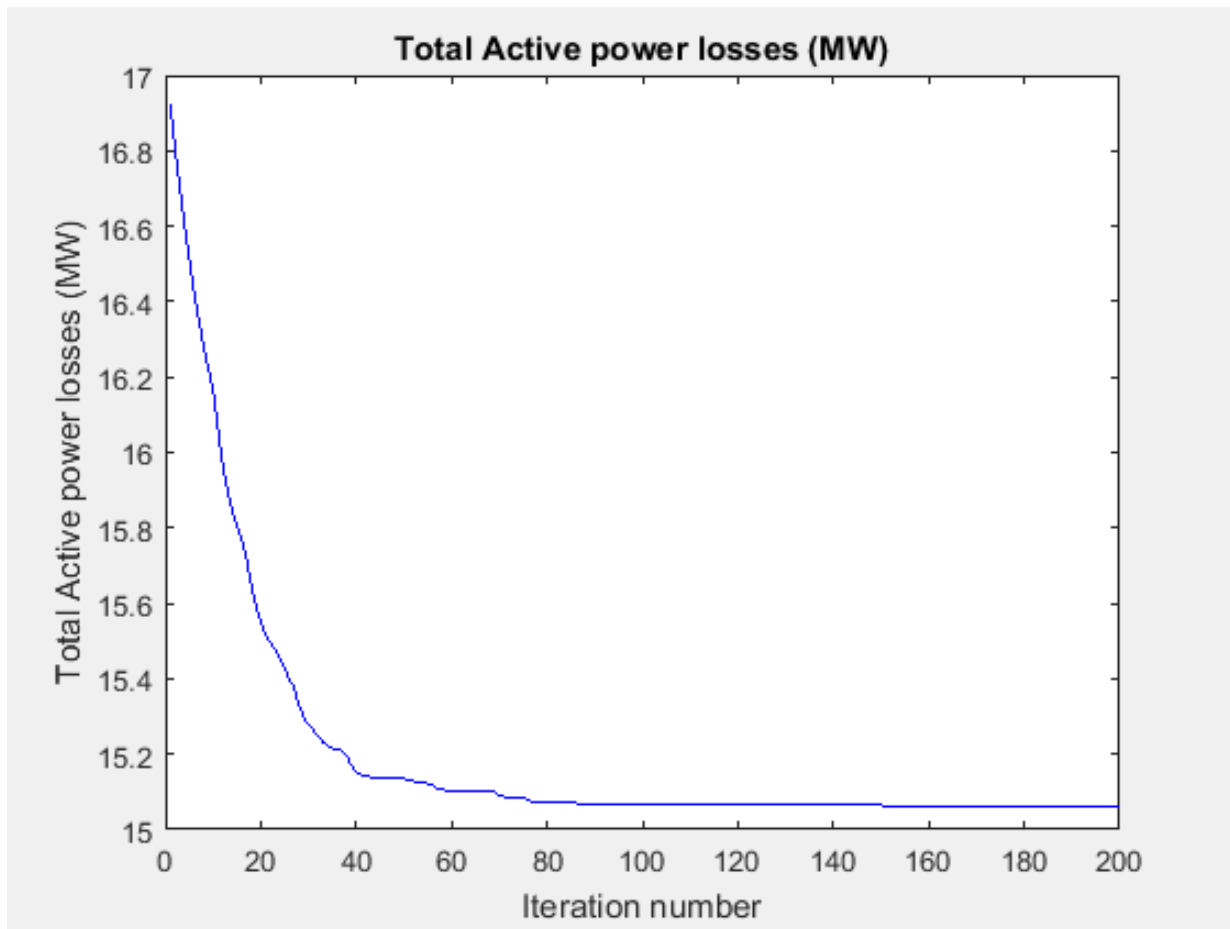
A comparison of the real power loss of base case, optimization without new WG and optimization when WG is installed on various buses of southern region 21-bus distribution network is illustrated in Fig. 4.14.



**Figure 4.3 Comparison of loss reduction**

It can be seen that optimization with a new WG can further reduce the active power loss than optimization using PSO without WG. After integrating a new WG on bus 14, the total active power loss can be reduced to minimum 15.125 MW. The optimal placement of a new WG is on bus 14.

Figure 4.4. shows the optimal loss reduction process of the proposed method when a small wind turbine is installed on bus 14. The initial real power loss of the system is at about 17 MW. The particles start to converge after conducting 90 iterations. Finally, the total power loss of the system is 15.125 MW. The total CPU time is 210sec.



*Figure 4.4 Loss reduction process when new WG is installed on bus 14.*

The results from Table 4.14. show the optimal settings of control variables to get minimum active power loss when a new WG is installed on bus 14. There are 9 control variables which optimize reactive power and the proposed method succeeds in keeping all control variables within their limits. The total active power loss after optimization with a new WG is 15.125 MW.

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

*Table 4-14. Optimal Results of Control Variables with WG*

<b>Bus</b>	<b>Control Variables</b>	<b>Min</b>	<b>Max</b>	<b>With New WG on Bus 14</b>
1	$V_{G1}(p.u)$	0.9	1.1	0.9399
2	$V_{G2}$	0.9	1.1	1.0827
3	$V_{G3}$	0.9	1.1	1.1206
14	$V_{WG}$	0.9	1.1	0.98
1-6	$T_1$	0.95	1.05	0.974
17-18	$T_2$	0.95	1.05	1.0062
18-20	$T_3$	0.95	1.05	1.0019
4	$Q_{C4}(MVar)$	0	20	19.5529
13	$Q_{C13}$	0	10	6.4804
<b>Active Power Loss (MW)</b>				<b>15.125</b>

## **CHAPTER FIVE**

### **5. CONCLUSION, RECOMMENDATION AND FUTURE WORK**

#### **5.1. Conclusion**

By examining the outcomes of the two scenarios, the following conclusion can be obtained:

1. In this thesis, combined technique of particle swarm optimization algorithm with MATPOWER toolbox is applied to solve reactive power optimization problem and to determine the optimal placement of new installed WG in existing system. The performance of the proposed technique has been tested on the 21-bus transmission/distribution system and compared the simulation results without and with WG. It can be observed that reactive power optimization approach for distribution system with a wind generation can further reduce the active power loss than without WG. The benefit of lower active power loss obtained will provide better economic dispatch and secure operation in power system.
2. Before the reactive power optimization, the reactive power in southern region 21-Bus power network is arbitrary distributed. After optimization the result can be meaningfully decrease the active power loss of the system. Results can be attained after conducting 90 iterations (approx.), which replicates the excellent searching ability of Particle Swarm Optimization algorithm for solving nonlinear problems.
3. When a small capacity Wind generation is installed into the system, the active power loss would be further reduced. As the output of the Wind Generation increases, the active power loss of the system could be decreases.

## 5.2. Recommendation

For the purpose of minimizing the active power loss, utility company can either change the structure of the power grid or replace the old wiring with lower impedance lines. But in order to get the maximum profit, electricity grid designers have to take a more general view and calculate the power flow. In Ethiopia mostly, hydroelectric power plants supply to meet our energy demand and there is high electric interruption, which is reported due to decrease in the level of water used for this power generation. Therefore, this thesis recommends for Ethiopian electric utility to apply the concept of Wind Generation integration into transmission or distribution system, which mostly uses small scale renewable energy technologies and solve the problem associated with the increase in energy demand in our country and increase the reliability of our distribution system.

## 5.3. Future Work

- In this study considers only one wind generation system. If more wind generation will be added on each network, it will save more energy loss. If it adds more Wind Generations on the system, the computation time also increase. So, further research needs to simplify power system model to reduce this computational time.
- New Meta heuristic techniques such as Grey wolf optimization; whale optimization etc. can be utilized to further improve the results.
- More system constraints can be included to make the proposed problem more practical and realistic.

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## APPENDIX A

```
function [fxmin, xmin] = ORPD_21bus ()

clc

clear all

warning off all

global Ybus Yf Yt;

%% define named indices into bus, gen, branch matrices

[PQ, PV, REF, NONE, BUS_I, BUS_TYPE, PD, QD, GS, BS, BUS_AREA, VM, ...

    VA, BASE_KV, ZONE, VMAX, VMIN, LAM_P, LAM_Q, MU_VMAX, MU_VMIN] =

idx_bus;

[F_BUS, T_BUS, BR_R, BR_X, BR_B, RATE_A, RATE_B, RATE_C, ....

    TAP, SHIFT, BR_STATUS, PF, QF, PT, QT, MU_SF, MU_ST, ...

    ANGMIN, ANGMAX, MU_ANGMIN, MU_ANGMAX] = idx_brch;

[GEN_BUS, PG, QG, QMAX, QMIN, VG, MBASE, GEN_STATUS, PMAX, PMIN, ...

    MU_PMAX, MU_PMIN, MU_QMAX, MU_QMIN, PC1, PC2, QC1MIN, QC1MAX, ...

    QC2MIN, QC2MAX, RAMP_AGC, RAMP_10, RAMP_30, RAMP_Q, APF] = idx_gen;

[baseMVA, bus, gen, branch, areas, gencost]=case_21; %Input data of 21 bus test system

% Determine the value of weight change

w_start = 0.9; %Initial inertia weight's value

w_end = 0.40; %Final inertia weight

w_varyfor = floor(0.7*100);

w_now = w_start;

inertdec = (w_start-w_end)/w_varyfor; %Inertia weight's change per iteration

iter=0;
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
% Initialize size of Swarm, no. of control variables and Velocity
%size of swarm=50 (user may change it), no. of control variables=vg1, vg2,
%vg3(Generator bus voltage in pu), T1, T2, T3
%(Transformer tap position), QC4, QC13 (Injected reactive power of
%capacitors in MVAR)
Swarm=[unifrnd(0.90,1.10,50,3),unifrnd(0.95,1.05,50,3),unifrnd(0,20,50,2)];
VStep =[unifrnd(0.04,0.04,50,3),unifrnd(0.002,0.002,50,3), unifrnd(4,4,50,2)];
for i=1:50 % no of particles
    global bus gen branch v1 v2 v3
    v1=Swarm(i,1);
    v2=Swarm(i,2);
    v3=Swarm(i,3);
    bus(1,VM)=Swarm(i,1);
    bus(2,VM)=Swarm(i,2);
    bus(3,VM)=Swarm(i,3);
    gen(1,VG)=Swarm(i,1); % gen1
    gen(2,VG)=Swarm(i,2); % gen2
    gen(3,VG)=Swarm(i,3); % gen3
    branch(3,TAP)=Swarm(i,4);% T1, transformer tap
    branch(18,TAP)=Swarm(i,5); % T2
    branch(20,TAP)=Swarm(i,6); % T3
    bus(4,BS)=Swarm(i,7); % QC4, capacitor
    bus(13,BS)=Swarm(i,8); % QC13, capacitor
    global bus gen branch Yf Yt Ybus
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
[Ybus, Yf, Yt] = makeYbus(baseMVA, bus, branch);% construct Ybus

[MVAbase,bus,gen,branch,success,et]=runpf; % run NR load flow

global V

global Ybus

bbb=branch(:,[PF,QF]).^2; % ans. is P(from)^2, Q(from)^2

ccc=bbb';

ddd=(sum(ccc))';

eee=sqrt(ddd); % actual values of apparent powers "From bus injection"

fff=branch(:,[PT,QT]).^2;

ggg=fff';

hhh=(sum(ggg))';

iii=sqrt(hhh); % actual values of apparent powers "To bus injection"

jjj=[];

for count_1=1:21 % jjj will contain actual max. apparent power.("from" bus power is
compared with "to" bus power)

    if eee(count_1)>=iii(count_1)

        jjj(count_1)=eee(count_1);

    else

        jjj(count_1)=iii(count_1);

    end

end

%penalty value calculation for line flow violations

for count_2=1:21 % max power is compared with thermal limit

    if jjj(count_2)>branch(count_2, RATE_A)
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
    kkk(count_2)=10000*((jjj(count_2)-branch((count_2), RATE_A))^2); % if limit
violates,penalty is imposed

else

    kkk(count_2)=0; %if no violation, penalty is zero

end

end

penalty_line=sum(kkk);% summation of all penalty of line flow violations

%penalty value calculation for bus voltage violation

lll=bus(:,VM); % voltage mag. of each bus

for count_3=1:21

    if lll(count_3)>bus(count_3,VMAX)

        penalty_volt(count_3)=10000*(lll(count_3)-bus(count_3,VMAX))^2;

    elseif lll(count_3)<bus(count_3,VMIN)

        penalty_volt(count_3)=10000*(bus(count_3,VMIN)-lll(count_3))^2;

    else

        penalty_volt(count_3)=0;

    end

end

end

penalty_volt=sum(penalty_volt);%summation of penalty for bus voltage violation

%penalty value calculation for reactive power violation of all

%generators(PV buses and slack bus)

mmm=gen(:,QG);% reactive power output of all generators

for count_4=1:3

    if mmm(count_4)>gen(count_4,QMAX)

        penalty_reactive(count_4)=10000*((mmm(count_4)-gen(count_4,QMAX))^2);
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
elseif mmm(count_4)<gen(count_4,QMIN)
    penalty_reactive(count_4)=10000*((gen(count_4,QMIN)-mmm(count_4))^2);
else
    penalty_reactive(count_4) =0;
end
end
end
penalty_reactive=sum(penalty_reactive); %summation of penalty for Q limit violation
%penalty value calculation for P violation of slack generator
nnn=gen(:,PG);
if nnn(1,1)>gen(1, PMAX)
    penalty_slack=1000*((nnn(1,1)-gen(1, PMAX))^2);
elseif nnn(1,1) <gen(1,PMIN)
    penalty_slack=1000*((gen (1, PMIN)-nnn(1,1))^2);
else
    penalty_slack=0;
end
%sum of all penalties, penalty function is used to handle inequality
%constraints
global penalty_function
penalty_function=(penalty_slack)+ (penalty_reactive)+(penalty_volt)+(penalty_line);
%sum of real power losses of all branches
global loss
sum_P_loss=(sum(real(loss)));
global penalty_function
fun_Swarm=(sum_P_loss)+(penalty_function);
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
% Objective function= sum of active power losses of the transmission lines

fSwarm(i,:)=sum_P_loss;

end

% Initializing the Best positions matrix and

% the corresponding function values

PBest = Swarm;

fPBest = fSwarm;

% Finding best particle in initial population

[fGBest, g] = min(fSwarm);

lastbpf = fGBest;

Best = Swarm(g,:); % Used to keep track of the Best particle ever

fBest = fGBest;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%          THE PSO LOOP          %%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

While (iter < 200 )% no of iterations

    global iter

    iter = iter+1;

    if iter>190

        diary on

    end

    % Update the value of the inertia weight w

    if (iter<=w_varyfor) & (iter > 1)
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
w_now = w_now - inertdec; %Change inertia weight

end

% The PLAIN PSO %

% Set GBest

A = repmat(Swarm(g,:), 50, 1); %A = GBest. repmat(X, m, n) repeats the matrix X in m
rows by n columns, 50=no. of particles

% Generate Random Numbers

R1 = rand(50, 8); % 50=No. of particles, 8 dimension of the problem(size of swarm=no. of
variables)

R2 = rand(50, 8);

% Calculate Velocity

VStep = w_now*VStep + 2.0*R1.*(PBest-Swarm) + 2.0*R2.*(A-Swarm);% c1=c2=2

% Apply Vmax Operator for v > Vmax

changeRows = VStep > 0.003;

VStep(find(changeRows)) = 0.003;

% Apply Vmax Operator for v < -Vmax

changeRows = VStep < -0.003;

VStep(find(changeRows)) = -0.003;

% ::UPDATE POSITIONS OF PARTICLES::

Swarm = Swarm + 0.729 * VStep; % Evaluate new Swarm, Chi=0.729

for j=1:50 %no of particles

v1=Swarm(j,1);

v2=Swarm(j,2);

v3=Swarm(j,3);

bus(1,VM)=Swarm(j,1);
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
bus(2,VM)=Swarm(j,2);
bus(3,VM)=Swarm(j,3);
gen(1,VG)=Swarm(j,1); % gen1
gen(2,VG)=Swarm(j,2); % gen2
gen(3,VG)=Swarm(j,3); % gen3
branch(3,TAP)=Swarm(j,4);% T1, transformer tap
branch(18,TAP)=Swarm(j,5); % T2
branch(20,TAP)=Swarm(j,6); % T3
bus(4,BS)=Swarm(j,7); % QC4, capacitor
bus(13,BS)=Swarm(j,8); % QC13, capacitor

[Ybus, Yf, Yt] = makeYbus(baseMVA, bus, branch);

[MVAbase,bus,gen,branch,success,et]=runpf;

global V

bbb=branch(:,[PF,QF]).^2; % ans. is P(from)^2, Q(from)^2
ccc=bbb';
ddd=(sum(ccc))';
eee=sqrt(ddd); %actual values of apparent powers "From bus injection"
fff=branch(:,[PT,QT]).^2;
ggg=fff';
hhh=(sum(ggg))';
iii=sqrt(hhh); %actual values of apparent powers "To bus injection"
jjj=[];

for count_1=1:21 % jjj will contain actual max. apparent power.("from" bus power is
compared with "to" bus power)

    if eee(count_1)>=iii(count_1)
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
    jjj(count_1)=eee(count_1);  
else  
    jjj(count_1)=iii(count_1);  
end  
end  
%penalty value calculation for line flow violations  
for count_2=1:21 % max power is compared with thermal limit  
    if jjj(count_2)>branch(count_2, RATE_A)  
        kkk(count_2)=10000*((jjj(count_2)-branch((count_2), RATE_A))^2); % if limit  
violates,penalty is imposed  
    else  
        kkk(count_2)=0; %if no violation, penalty is zero  
    end  
end  
penalty_line=sum(kkk);% summation of all penalty of line flow violations  
%penalty value calculation for bus voltage violation  
lll=bus(:,VM); % voltage mag. of each bus  
for count_3=1:21  
    if lll(count_3)>bus(count_3,VMAX)  
        penalty_volt(count_3)=10000*(lll(count_3)-bus(count_3,VMAX))^2;  
    elseif lll(count_3)<bus(count_3,VMIN)  
        penalty_volt(count_3)=10000*(bus(count_3,VMIN)-lll(count_3))^2;  
    else  
        penalty_volt(count_3)=0;  
    end  
end
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
end

penalty_volt=sum(penalty_volt);%summation of penalty for bus voltage violation

%penalty value calculation for reactive power violation of all

%generators(PV buses and slack bus)

mmm=gen(:,QG);% reactive power output of all generators

for count_4=1:3

    if mmm(count_4)>gen(count_4,QMAX)

        penalty_reactive(count_4)=10000*((mmm(count_4)-gen(count_4,QMAX))^2);

    elseif mmm(count_4)<gen(count_4,QMIN)

        penalty_reactive(count_4)=10000*((gen(count_4,QMIN)-mmm(count_4))^2);

    else

        penalty_reactive(count_4)=0;

    end

end

penalty_reactive=sum(penalty_reactive);%summation of penalty for Q limit violation

%penalty value calculation for P violation of slack generator

nnn=gen(:,PG);

if nnn(1,1)>gen(1,PMAX)

    penalty_slack=1000*((nnn(1,1)-gen(1,PMAX))^2);

elseif nnn(1,1)<gen(1,PMIN)

    penalty_slack=1000*((gen(1,PMIN)-nnn(1,1))^2);

else

    penalty_slack=0;

end

%sum of all penalties
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
global penalty_function
penalty_function=(penalty_slack)+ (penalty_reactive)+(penalty_volt)+(penalty_line);
%sum of real power losses of all branches
global loss
sum_P_loss=(sum(real(loss)))
global penalty_function
fun_Swarm=(sum_P_loss)+(penalty_function);
fSwarm(j,:)=sum_P_loss;
end

% Updating the best position for each particle
changeRows = fSwarm < fPBest;          % latest fswarm-previous fswarm
fPBest(find(changeRows)) = fSwarm(find(changeRows)); %fitness value
PBBest(find(changeRows), :) = Swarm(find(changeRows), :); %position
lastbpart = PBBest(g, :);

% Updating index g
[fGBest, g] = min(fPBest);

%Update Best. Only if fitness has improved.
if fGBest < lastbpf
    [fBest, b] = min(fPBest);
    fbest(iter) = fBest;
    figure(1);
    plot(fbest, '-b' );
    title('Total Active power losses (MW)');
    xlabel('Iteration number');
    ylabel('Total Active power losses (MW)');
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
fBest;
Best = PBest(b,:);
end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%                               %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[fxmin, b] = min(fPBest)
xmin = PBest(b, :)
diary off
return
```

## APPENDIX B

```
function [fxmin, xmin] = ORPD_21bus ()

clc

clear all

warning off all

global Ybus Yf Yt;

%% define named indices into bus, gen, branch matrices

[PQ, PV, REF, NONE, BUS_I, BUS_TYPE, PD, QD, GS, BS, BUS_AREA, VM, ...
    VA, BASE_KV, ZONE, VMAX, VMIN, LAM_P, LAM_Q, MU_VMAX, MU_VMIN] =
idx_bus;

[F_BUS, T_BUS, BR_R, BR_X, BR_B, RATE_A, RATE_B, RATE_C, ...
    TAP, SHIFT, BR_STATUS, PF, QF, PT, QT, MU_SF, MU_ST, ...
    ANGMIN, ANGMAX, MU_ANGMIN, MU_ANGMAX] = idx_brch;

[GEN_BUS, PG, QG, QMAX, QMIN, VG, MBASE, GEN_STATUS, PMAX, PMIN, ...
    MU_PMAX, MU_PMIN, MU_QMAX, MU_QMIN, PC1, PC2, QC1MIN, QC1MAX, ...
    QC2MIN, QC2MAX, RAMP_AGC, RAMP_10, RAMP_30, RAMP_Q, APF] = idx_gen;

[baseMVA, bus, gen, branch, areas, gencost]=case_21; %Input data of 21 bus test system

% Determine the value of weight change

w_start = 0.9; %Initial inertia weight's value

w_end = 0.40; %Final inertia weight

w_varyfor = floor(0.7*100);

w_now = w_start;

inertdec = (w_start-w_end)/w_varyfor; %Inertia weight's change per iteration

iter=0;
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
% Initialize size of Swarm, no. of control variables and Velocity
%size of swarm=50 (user may change it), no. of control variables=vg1, vg2,
%vg3, vgr (Generator bus voltage in pu), T1, T2, T3
%(Transformer tap position), QC4, QC13 (Injected reactive power of
%capacitors in MVAR)
Swarm=[unifrnd(0.90,1.10,50,4),unifrnd(0.95,1.05,50,3),unifrnd(0,20,50,2)];
VStep =[unifrnd(0.04,0.04,50,4),unifrnd(0.002,0.002,50,3), unifrnd(4,4,50,2)];
for i=1:50 % no of particles
    global bus gen branch v1 v2 v3 vr
    v1=Swarm(i,1);
    v2=Swarm(i,2);
    v3=Swarm(i,3);
    vr=Swarm(i,4);
    bus(1,VM)=Swarm(i,1);
    bus(2,VM)=Swarm(i,2);
    bus(3,VM)=Swarm(i,3);
    bus(r,VM)=Swarm(i,4);
    gen(1,VG)=Swarm(i,1); % gen1
    gen(2,VG)=Swarm(i,2); % gen2
    gen(3,VG)=Swarm(i,3); % gen3
    gen(r,VG)=Swarm(i,4); % genr
    branch(3,TAP)=Swarm(i,5);% T1, transformer tap
    branch(18,TAP)=Swarm(i,6); % T2
    branch(20,TAP)=Swarm(i,7); % T3
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
bus(4,BS)=Swarm(i,8); % QC4, capacitor
bus(13,BS)=Swarm(i,9); % QC13, capacitor

global bus gen branch Yf Yt Ybus

[Ybus, Yf, Yt] = makeYbus(baseMVA, bus, branch);% construct Ybus

[MVAbase,bus,gen,branch,success,et]=runpf; % run NR load flow

global V

global Ybus

bbb=branch(:,[PF,QF]).^2; % ans. is P(from)^2, Q(from)^2

ccc=bbb';

ddd=(sum(ccc))';

eee=sqrt(ddd); %actual values of apparent powers "From bus injection"

fff=branch(:,[PT,QT]).^2;

ggg=fff';

hhh=(sum(ggg))';

iii=sqrt(hhh); %actual values of apparent powers "To bus injection"

jjj=[];

for count_1=1:21 % jjj will contain actual max. apparent power.("from" bus power is
compared with "to" bus power)

    if eee(count_1)>=iii(count_1)

        jjj(count_1)=eee(count_1);

    else

        jjj(count_1)=iii(count_1);

    end

end

end

%penalty value calculation for line flow violations
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
for count_2=1:21 % max power is compared with thermal limit
    if jjj(count_2)>branch(count_2, RATE_A)
        kkk(count_2)=10000*((jjj(count_2)-branch((count_2), RATE_A))^2); % if limit
violates,penalty is imposed
    else
        kkk(count_2)=0; %if no violation, penalty is zero
    end
end
penalty_line=sum(kkk);% summation of all penalty of line flow violations
%penalty value calculation for bus voltage violation
lll=bus(:,VM); % voltage mag. of each bus
for count_3=1:21
    if lll(count_3)>bus(count_3,VMAX)
        penalty_volt(count_3)=10000*(lll(count_3)-bus(count_3,VMAX))^2;
    elseif lll(count_3)<bus(count_3,VMIN)
        penalty_volt(count_3)=10000*(bus(count_3,VMIN)-lll(count_3))^2;
    else
        penalty_volt(count_3)=0;
    end
end
penalty_volt=sum(penalty_volt);% summation of penalty for bus voltage violation
%penalty value calculation for reactive power violation of all
%generators(PV buses and slack bus)
mmm=gen(:,QG);% reactive power output of all generators
for count_4=1:4
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
if mmm(count_4)>gen(count_4,QMAX)
    penalty_reactive(count_4)=10000*((mmm(count_4)-gen(count_4,QMAX))^2);
elseif mmm(count_4)<gen(count_4,QMIN)
    penalty_reactive(count_4)=10000*((gen(count_4,QMIN)-mmm(count_4))^2);
else
    penalty_reactive(count_4)=0;
end
end
penalty_reactive=sum(penalty_reactive);%summation of penalty for Q limit violation
%penalty value calculation for P violation of slack generator
nnn=gen(:,PG);
if nnn(1,1)>gen(1,PMAX)
    penalty_slack=1000*((nnn(1,1)-gen(1,PMAX))^2);
elseif nnn(1,1)<gen(1,PMIN)
    penalty_slack=1000*((gen(1,PMIN)-nnn(1,1))^2);
else
    penalty_slack=0;
end
%sum of all penalties, penalty function is used to handle inequality
%constraints
global penalty_function
penalty_function=(penalty_slack)+(penalty_reactive)+(penalty_volt)+(penalty_line);
%sum of real power losses of all branches
global loss
sum_P_loss=(sum(real(loss)));
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
global penalty_function
fun_Swarm=(sum_P_loss)+(penalty_function);
% Objective function= sum of active power losses of the transmission lines
fSwarm(i,:)=sum_P_loss;
end
% Initializing the Best positions matrix and
% the corresponding function values
PBest = Swarm;
fPBest = fSwarm;
% Finding best particle in initial population
[fGBest, g] = min(fSwarm);
lastbpf = fGBest;
Best = Swarm(g,:); % Used to keep track of the Best particle ever
fBest = fGBest;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%                THE PSO LOOP                %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

while( iter < 200 )% no of iterations

    global iter

    iter = iter+1;

    if iter>190

        diary on
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
end

% Update the value of the inertia weight w

if (iter<=w_varyfor) & (iter > 1)

    w_now = w_now - inertdec; %Change inertia weight

end

% The PLAIN PSO %

% Set GBest

A = repmat(Swarm(g,:), 50, 1); %A = GBest. repmat(X, m, n) repeats the matrix X in m
rows by n columns, 50=no. of particles

% Generate Random Numbers

R1 = rand(50, 9); % 50=No. of particles, 9=dimension of the problem(size of swarm=no. of
variables)

R2 = rand(50, 9);

% Calculate Velocity

VStep = w_now*VStep + 2.0*R1.*(PBest-Swarm) + 2.0*R2.*(A-Swarm);% c1=c2=2

% Apply Vmax Operator for v > Vmax

changeRows = VStep > 0.003;

VStep(find(changeRows)) = 0.003;

% Apply Vmax Operator for v < -Vmax

changeRows = VStep < -0.003;

VStep(find(changeRows)) = -0.003;

% ::UPDATE POSITIONS OF PARTICLES::

Swarm = Swarm + 0.729 * VStep; % Evaluate new Swarm, Chi=0.729

for j=1:50 %no of particles

    v1=Swarm(j,1);
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
v2=Swarm(j,2);
v3=Swarm(j,3);
vr=Swarm(j,4);
bus(1,VM)=Swarm(j,1);
bus(2,VM)=Swarm(j,2);
bus(3,VM)=Swarm(j,3);
bus(r,VM)=Swarm(j,4);
gen(1,VG)=Swarm(j,1); % gen1
gen(2,VG)=Swarm(j,2); % gen2
gen(3,VG)=Swarm(j,3); % gen3
gen(r,VG)=Swarm(j,4); % genr
branch(3,TAP)=Swarm(j,5); % T1, transformer tap
branch(18,TAP)=Swarm(j,6); % T2
branch(20,TAP)=Swarm(j,7); % T3
bus(4,BS)=Swarm(j,8); % QC4, capacitor
bus(13,BS)=Swarm(j,9); % QC13, capacitor
[Ybus, Yf, Yt] = makeYbus(baseMVA, bus, branch);
[MVAbase,bus,gen,branch,success,et]=runpf;
global V
bbb=branch(:,[PF,QF]).^2; % ans. is P(from)^2, Q(from)^2
ccc=bbb';
ddd=(sum(ccc))';
eee=sqrt(ddd); % actual values of apparent powers "From bus injection"
fff=branch(:,[PT,QT]).^2;
ggg=fff';
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
hhh=(sum(ggg));  
iii=sqrt(hhh); %actual values of apparent powers "To bus injection"  
jjj=[];  
for count_1=1:21 % jjj will contain actual max. apparent power.("from" bus power is  
compared with "to" bus power)  
    if eee(count_1)>=iii(count_1)  
        jjj(count_1)=eee(count_1);  
    else  
        jjj(count_1)=iii(count_1);  
    end  
end  
%penalty value calculation for line flow violations  
for count_2=1:21 % max power is compared with thermal limit  
    if jjj(count_2)>branch(count_2, RATE_A)  
        kkk(count_2)=10000*((jjj(count_2)-branch((count_2), RATE_A))^2); % if limit  
violates,penalty is imposed  
    else  
        kkk(count_2)=0; %if no violation, penalty is zero  
    end  
end  
penalty_line=sum(kkk);% summation of all penalty of line flow violations  
%penalty value calculation for bus voltage violation  
lll=bus(:,VM); % voltage mag. of each bus  
for count_3=1:21  
    if lll(count_3)>bus(count_3,VMAX)
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
penalty_volt(count_3)=10000*(lll(count_3)-bus(count_3,VMAX))^2;
elseif lll(count_3)<bus(count_3,VMIN)
    penalty_volt(count_3)=10000*(bus(count_3,VMIN)-lll(count_3))^2;
else
    penalty_volt(count_3)=0;
end
end
end
penalty_volt=sum(penalty_volt);%summation of penalty for bus voltage violation
%penalty value calculation for reactive power violation of all
%generators(PV buses and slack bus)
mmm=gen(:,QG);% reactive power output of all generators
for count_4=1:4
    if mmm(count_4)>gen(count_4,QMAX)
        penalty_reactive(count_4)=10000*((mmm(count_4)-gen(count_4,QMAX))^2);
    elseif mmm(count_4)<gen(count_4,QMIN)
        penalty_reactive(count_4)=10000*((gen(count_4,QMIN)-mmm(count_4))^2);
    else
        penalty_reactive(count_4)=0;
    end
end
end
penalty_reactive=sum(penalty_reactive);%summation of penalty for Q limit violation
%penalty value calculation for P violation of slack generator
nnn=gen(:,PG);
if nnn(1,1)>gen(1,PMAX)
    penalty_slack=1000*((nnn(1,1)-gen(1,PMAX))^2);
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
elseif nnn(1,1)<gen(1,PMIN)
    penalty_slack=1000*((gen(1,PMIN)-nnn(1,1))^2);
else
    penalty_slack=0;
end

%sum of all penalties
global penalty_function
penalty_function=(penalty_slack)+(penalty_reactive)+(penalty_volt)+(penalty_line);

%sum of real power losses of all branches
global loss
sum_P_loss=(sum(real(loss)))
global penalty_function
fun_Swarm=(sum_P_loss)+(penalty_function);
fSwarm(j,:)=sum_P_loss;
end

% Updating the best position for each particle
changeRows = fSwarm < fPBest;          % latest fswarm-previous fswarm
fPBest(find(changeRows)) = fSwarm(find(changeRows)); %fitness value
PBest(find(changeRows), :) = Swarm(find(changeRows), :); %position
lastbpart = PBest(g, :);

% Updating index g
[fGBest, g] = min(fPBest);

%Update Best. Only if fitness has improved.
if fGBest < lastbpf
    [fBest, b] = min(fPBest);
```

## PSO Based Reactive Power Optimization of Utility Grid With Wind Generation

```
fbest(iter) = fBest;

figure(1);

plot(fbest, '-b' );

title('Total Active power losses (MW)');

xlabel('Iteration number');

ylabel('Total Active power losses (MW)');

fBest;

Best = PBest(b,:);

end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%                END OF PSO LOOP                %%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[fxmin, b] = min(fPBest)

xmin = PBest(b, :)

diary off

return
```