# Voltage stability performance of Particle Swarm Optimization based OPF analysis by the comparison and controlling the power flow

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***Abstract-*** *The main objective of OPF is improvement in voltage stability. There are many conventional methods to calculate load flow problems such as Gauss Seidel (GS) Method, Newton-Raphson (NR) Method, Linear Programming (LP) Method, Fast De-Coupled (FD) Method, Non-Linear Programming (NLP) Method, Quadratic Programming (QP) Method, Interior Point (IP) Method, etc. All these methods have certain drawbacks. Particle Swarm Optimization (PSO) optimizes a difficulty by comprising a group of candidate answers, referred to as simple numerical procedures over the particles location and speed. In this research various intelligent and optimizations techniques are proposed to overcome drawbacks of the PSO in OPF. The performance of Particle Swarm Optimization based optimal power on the IEEE 30 bus system is analyzed. In this analysis the objective function of PSO is programmed in order to attain voltage stability with minimum cost function. Voltage stability performance of PSO based OPF is analyzed by the comparison of each bus voltage before and after PSO based OPF. Bat algorithm is an optimization algorithm inspired by the echolocation of bats. Bats perform echolocation for updating their position. Bat echolocation is a system in which a series of loud ultrasound waves are emitted to create echoes. To minimize the best cost and total losses in this research BAT algorithm is proposed for the same IEEE 30 bus system.*

**Keywords-** *Voltage stability, Particle Swarm Optimization, echolocation, power flow*

## 1. INTRODUCTION

The Optimal Power Flow (OPF) problem is defined as a static nonlinear optimization problem to determine all adjustable variables like real power generations, transformer tap positions, angle of the phase shifter, shunt capacitor capacity and or reactor etc., for minimizing the operating costs, transmission line losses or other appropriate objective functions [1]. Optimal Power Flow is analyzed for 30 bus system using various controllers. In an IEEE bus system, each bus has its specified voltage. But due to increase in load demand, in some cases voltage of bus is deviated from its rated value. Retaining of rated voltage of the bus even after load demand is stated as voltage stability in power system. While shunt capacitors and angle of the phase shifter transformer tap positions are discrete in nature, real power generation and bus voltages are continuous variables. Due to more number of variables and more number of boundary constraints it has to be solved using nonlinear programming techniques. The OPF solution gives the optimal active and reactive power dispatch for a static power system loading condition [2] [3].

Particle Swarm Optimization (PSO) is an experimental maximization method on the basis of group maximization formatted by Eberhart & Kennedy in the year 1995 and motivated by communal activities of bird congregation or fish schooling. PSO optimizes a difficulty by comprising a group of candidate answers, referred to as simple numerical procedures over the particles location and speed. In this research various intelligent and optimization techniques are proposed to overcome drawbacks of PSO in OPF.

The main objectives of the study was to develop the optimal power flow model for IEEE 30 bus system and to analyze the performance of PSO based optimal power on the IEEE 30 bus system with the priority of the minimum cost function to attain voltage stability.

## 2. METHODOLOGY

The Electrical systems have strict power quality measures. Hence, the reactive power and bus voltage values must be maintained within the specified limits and any deviations from this should be corrected. Automatic control of Secondary Voltage Control (SVC) is needed because of the fact that manual control will lead to the occurrence of emergency states. The SVCs can be used to correct the deviations from the limit. This analysis is about the control of bus voltage and reactive power without the use of SVC, but through the use of an intelligent algorithm as memory. An allowance of -5% and +5% are taken into consideration and there occurs an unstable state if these voltage constraints are exceeded. A proper control action should be taken in that case to protect the system.

### *2.1 Limitation of the study*

Various optimization algorithms are analyzed in this research for optimum power flow. The main limitations in the optimization algorithms are their processing time in real time implementation. Number of iterations decides the execution time, based on this execution time high speed controller such as DSP or FPGA has to be selected. This limits the application of low speed and low memory controllers in implementation.

The main purpose of optimal power dispatch problem has so far been confined to minimize the total generation cost of a power system. However, in order to meet environmental regulations enforced in recent years, emission control has become one of the important operational objectives. Besides, the passing of the Clean Air Act Amendments of 1990 due to the increasing public awareness of the environmental protection, minimum cost function has to be modified in the design or operational strategies of the utilities to reduce pollution and atmospheric emissions of thermal plants [4].

System security is another important factor in power system operation and system planning. Thus, it becomes very essential to maintain good voltage profiles and to limit line flows within the prescribed limits.

OPF [5] is a nonlinear programming problem and is used to determine optimal outputs of generators, bus voltage, and transformer tap, setting in the power system. In an OPF algorithm the objective is to find steady state operation point which minimizes loss, generation cost, etc. or maximizes social welfare, load ability, etc. while maintaining an acceptable system performance in terms of limits on generators real and reactive powers, line flow limits, output of various compensating devices etc.

Since its introduction as network constrained economic dispatch by Carpentier J. 1962 and its definition as optimal power flow by Dommel and Tinney 1968, the OPF problem has been the subject of intensive research. The OPF optimizes a power system operating objective function (such as the operating cost of thermal resources) while satisfying a set of system operating constraints, including those dictated by the electric network. OPF has been widely used in power system operation and planning [6].

OPF programs based on mathematical programming approaches are used daily to solve very large OPF problems. However, they are not guaranteed to converge to the global optimum of the general non-convex OPF problem, although some empirical evidence on the uniqueness of the OPF solution within the domain of interest still exists.

### *2.2 Objectives of OPF*

The objectives, which the OPF will need to accomplish, are discussed here. The primary goal of a generic OPF is to minimize the costs of meeting the load demand for a power system while maintaining the security of the system. The costs associated with the power systems may depend on the situation, but in general, they can be attributed to the cost of generating power (megawatts) of each generator.

From the viewpoint of an OPF, the maintenance of system security requires keeping each device in the power system within its desired operation range at steady state. This will include the maximum and minimum output for generators, maximum MVA flows on transmission lines and transformers, as well as keeping the system bus voltages within the specified ranges. It should be noted that the OPF only addresses steady state operation of the power system [7].

The standard OPF problem can be written in the following form

$$Min.\ F(x)$$

$$\text{Subject to: } h(x) = 0 \text{ and } g(x) \geq 0 \quad (3.1)$$

Where $F(x)$ is the objective function,

$h(x)$ is the equality constraints, and

$g(x)$ is the inequality constraints.

and x is the vector of control variables (like generated active and reactive power, generation bus voltage magnitudes, transformer taps, etc.).

The essence of the optimal power flow problem resides in reducing the objective function and simultaneously satisfying the load flow equations (equality constraints) without violating the inequality constraints [8], [9].

### *2.3 Optimal Power Flow Formulation*

The most commonly used objective in the OPF problem formulation is the minimization of total cost of real power generation. The individual costs of each generating unit are assumed to be the function, only because of active power generation and are represented by quadratic curves of second order.

The optimal power flow problem can be defined by specifying the following five attributes and can be explained as:

1. The controls
2. The dependent variables
3. The equality
4. Objective function
5. Inequality Constraint

### *2.3.1 Objective Function*

The objective function of the entire power system can then be written as the sum of the quadratic cost model at each generator.

$$Fi = ai + biPgi + ciPgi2$$

where i = 1, 2, 3…………..ng.

*ng* = number of generators including the slack bus,

*Pgi* is the generated active power at bus i.

*ai*, *bi*, *ci* are the unit costs curve for *i*th generator

### 2.3.2 Variables

Following are the variables used in the formulation of OPF:

#### 2.3.2.1 Control variables

The control variables in an optimal power flow problem are the quantities whose value can be adjusted directly to help minimize the objective function and satisfy the constraints.

The control variables can be given as:

1. Active power generation
2. Reactive power generation
3. Transformer tap ratio
4. Generator bus voltage

Different classes of the optimal power flow problem restrict the quantities that can be controlled. For instance, an OPF algorithm for minimizing the active power generation cost might limit the controls to active power generation. The aim of the OPF is to adjust the control variables in order to minimize the total operating cost of meeting the particular load demand for a power system.

#### 2.3.2.2 Dependent variables

These variables are the optimal power flow variables that do not control. These include all type of variables that are free, within limits, to assume value to solve the problem. The main dependent variables are the complex bus voltage angles and magnitude.

### 2.3.3 Constraints

The cost is optimized with the following constraints.

#### 2.3.3.1 Equality constraints

In order to minimize the equation, it is essential to know whether the power system is running under normal conditions, i.e. load and losses, power demand is satisfied and the network components are operating within limits. This can be achieved by the active and reactive power analysis:

$$P_i = P_{Load} + P_{Loss} \quad (3.3)$$

$$Q_i = Q_{Load} + Q_{Loss} \quad (3.4)$$

Where,

$Q_i^{net}$ & $P_i^{net}$ are the reactive and active power outputs.

$Q_{Load}$ & $P_{Load}$ are the reactive and active load power.

$Q_{Loss}$ & $P_{Loss}$ are the reactive and active power loss.

The power flow equations of the network can be given as:

$$G(V, \delta) = 0 \quad (3.5)$$

where,

$$g(V, \delta) = \begin{cases} Pi((V,\delta)) \\ Qi((V,\delta)) \\ Pm((V,\delta)) \end{cases}; \; P_i^{net}, Q_i^{net} \text{ and } P_m^{net}$$

Where *Pi* & *Qi* are the calculated real and reactive power at PQ bus

*Pinet* & *Qinet* are the specified real and reactive power for the PQ bus

*V* & *δ* are the magnitude and phase angle of the voltage at different buses.

#### 2.3.3.2 Inequality constraints

In a power system, devices and components have functioning limits and these limits are formed for security constraints. Thus the necessary objective function can be minimized by sustaining the network components inside the security limits. This conveys the concept of inequality constraints.

The main normal type of inequality constraints are the lower bus voltage limits at the generation at load buses, lower bus voltages limits at some generators, upper bus voltage limits at the generation at load buses, maximum line loading limits and limits on tap setting. These include the following:

The inequality constraints on real power generation at ith bus:

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max} \quad (3.7)$$

### *2.4 Optimal Power Flow using Newtons Method*

OPF solutions are carried out to determine the optimum operating state of a power network subjected to physical and operational constraints.

### *2.4.1 General Formulation*

An objective function, which may incorporate economic, security, or environmental aspects of the power system, is formulated and solved using a suitable optimization algorithm, such as Newtons method.

The constraints are physical laws that manage power generation and transmission system availability, operating strategies, and the design limits of the electrical equipment. This sort of problem is typically articulated as a static, nonlinear programming problem, with the objective function characterized as a nonlinear equation and the constraints characterized by nonlinear or linear equations.

More often than not, the objective function is considered to be the cost of generation, reflecting the economic aspects of the electrical power system [10], [11], [12]. Hence, the mathematical formulation minimizes active power generation cost by suitable adjustment of the control parameters.

The OPF problem can be formulated as follows:

$$\text{Minimize } f(x) \text{ subject to } h(x) = 0 \text{ and } g(x) \leq 0 \quad (3.18)$$

In this expression, $x$ is the vector of state variables, $f(x)$ is the objective function to be optimized, $h(x)$ represents the power flow equations, and $g(x)$ consists of state variable limits and functional operating constraints.

In general, the aim is to optimize an objective function with the solution satisfying a number of equality and inequality constraints. Any solution point that satisfies all the constraints is said to be a feasible solution. A local minimum is a feasible solution point where the objective function is minimized within a neighborhood. The global minimum is a local minimum with the lowest value in the complete feasible region [13].

### *2.4.2 Variables*

Variables that can be adjusted in pursuit of the optimal solution are termed control variables, such as active power generation, taps and phase angles in tap-changing and phase-shifting transformers respectively, and voltage magnitudes at the generator buses. The control parameters are taken to be continuous quantities. Such a representation is well handled by the OPF formulation and provides a suitable representation of controls with small discrete steps.

Dependent variables are those that depend on the control variables. They can take any value, within limits, as dictated by the solution algorithm. Examples of dependent variables are voltage phase angles at all uses, except the slack bus; voltage magnitudes at all load buses; reactive power at all generation buses; active power generation costs; and active and reactive power flows (network losses) in transmission lines and transformers.

In addition to control and dependent variables, active and reactive power loads and network topology and data from a set of fixed parameters must be specified at the outset of the study.

### *2.4.3 Objective Function*

The main aim of the OPF solution is to determine the control settings and system state variables that optimize the value of the objective function. The selection of the objective function should be based on careful analysis of the power system security and economy.

Arguably, power generation cost is the most popular objective function in OPF studies, where the thermal generation unit costs are generally represented by a non-linear, second-order function [14].

Where

$$F_T = \sum_{k=1}^{ng} Fk(Pgk)$$

Where the fuel cost of unit k is, is the active power generated by unit k, and ng is the number of generators in the system, including the slack generator. More specifically,

$$F_k(P_{gk}) = a_k + b_k P_{gk} + c_k P^2_{gk}$$

where $a_k$, $b_k$, and $c_k$ are the cost coefficients of unit k.

In a slack bus voltage and phase angle not varied but generator output power can vary. So it should be noted that it is crucial to include the slack generator contribution in the OPF formulation, equation (3.14), otherwise the minimization process will dispatch all the generating units at their minimum capacity while assigning the rest of the required generation to the slack generator, which would be seen by the optimization procedure as having zero generation cost and infinite generation capacity.

### *2.4.4 Equality Constraints*

The power flow equations provide a means for calculating the power balance that exists in the network during steady-state operation. They must be satisfied, unconditionally, if a feasible solution is to exist [14], [15] otherwise the OPF problem is said to be infeasible, with attempts being made to find a limited but still useful solution by relaxing some of the network constraints.

The power flow equations represent the link between the control variables and the dependent variables as:

$$P_k(V, \Theta) + P_{dk} - P_{gk} = 0$$

$$Q_k(V, \Theta) + Q_{dk} - Q_{gk} = 0$$

Where

$P_k$ and $Q_k$ are, respectively, the active and reactive power injections at bus k;

$P_{dk}$ and $Q_{dk}$ are, respectively, the active and reactive power loads at bus k;

$P_{gk}$ and $Q_{gk}$ are, respectively, the scheduled active and reactive power generations at bus k; V and $\Theta$ are, respectively, the nodal voltage magnitudes and angles.

It should be noted that all equality constraints in the power network are nonlinear. However, they are incorporated in a liberalized form within the OPF formulation.

### *2.4.5 Inequality Constraints*

All variables have upper and lower limits that must be satisfied in the optimal solution. Constraints on control variables reflect the bounds of the operating conditions of the equipment used for power dispatch. Arguably, limits on the generated active power and voltage magnitude at the generating units are the most important of such bounds.

Functional constraints result from the application of limits on control variables, with constraints on voltage magnitudes at load buses and on active and reactive power flows in transmission lines being the most popular.

## 3. CONCLUSION

One important aspect of OPF is to determine the optimal settings of control variables for economic operation while satisfying various equality and inequality constraints.

In this research work, the optimal power flow model for IEEE 30 bus system is developed and analyzed using Matlab. And the performance of PSO based optimal power for the IEEE 30 bus system is analyzed for the aspect of voltage stability with the objective of bringing in minimum cost function. PSO results in Best Cost (F Value) in the range of 7.8189e+06 and TL value of 3.1048e+03 with a process of 50 iterations.

BAT algorithm in OPF is also analyzed for the IEEE 30 bus system. It reduces around 3% of Best Cost (F Value), and TL value compared to PSO controller. At the same time, it increases iterations around 6% compared to PSO controller. Hence, to control the iterations the GA method is proposed for OPF.

GA reduces around 12% of Best Cost (F Value) compared to PSO controller. 13% of TL value and 40% of iterations are reduced compared to PSO controller with the help of GA in OPF. Hence GA results in minimum Best Cost and TL value with less number of iterations compared to PSO and BAT in OPF. Therefore OPF using GA is optimum for IEEE 30 bus system.

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