Optimal Power Flow Analysis of IEEE-30 bus System using Soft Computing Techniques

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Abstract— *This paper is focused at providing a solution to optimal power flow problem in power systems by using soft computing approaches. The proposed approach finds the optimal setting of OPF control variables which include generator active output, generator bus voltages, transformer tap-setting and shunt devices with the objective function of minimizing the fuel cost. Soft computing optimization methods have been implemented based on genetic algorithm and particle swarm optimization. The proposed soft computing techniques are modelled to be flexible for implementation to any power systems with the given system line, bus data, generator fuel cost parameter and forecasted load demand. Proposed soft computing optimization techniques have been analyzed and tested on the standard benchmark IEEE 30-bus system. Results obtained after applying both optimization techniques on American Electric IEEE 30-bus system with the same control variable maximum & minimum limits and system data have been compared and analyzed. Proposed methods efficiently optimize and solve the optimal power flow problem with high efficiency and wide flexibility for implementation and analysis on different power system networks.*

Keywords— optimal power flow, Fuel cost minimization, Genetic algorithm, Particle swarm optimization.

I. INTRODUCTION

The OPF Problem has been discussed since its introduction by Carpentier in 1962. As the OPF is a very large, non-linear mathematical programming problem, it has taken decades to develop efficient algorithm for its solution. Many different mathematical techniques have been employed for its solution. OPF has been applied to regulate generator active power outputs and voltages, shunt capacitors/reactors, transformer tap settings and other controllable variables to minimize the fuel cost, network active power loss, while keeping the load bus voltages, generators reactive power outputs, network power flows and all other state variables in the power system in their operational and secure limit .By considering the maximum / minimum outputs of generator, maximum MVA flows on transmission lines and transformers and bus voltages at their specified values, the primary goal of OPF is to minimize the generation cost for a particular given load demand. The secondary goal or another importance of OPF problem is the determination of marginal cost data. The marginal cost data deals with pricing MW transactions cost of auxiliary equipment that are required for reactive power (MVAr) for voltage support. The third goal of OPF is to monitor system security issues and also carry out necessary corrective actions. For planning studies, Optimal Power Flow is used to determine the maximum stress that a planned transmission system can withstand. To provide a preventive dispatch, the OPF can be set up if the security constraints are incorporated. In case of emergency, when some component of the system is overloaded or a bus is experiencing a voltage violation, the Optimal Power Flow can provide a corrective dispatch, which tells the system's operators what kind of adjustments can be performed in order to mitigate the overload or voltage violation problems. The calculation of the optimum generation pattern in order to achieve the minimum cost of the generation together while transmission system limitations are not violated. The OPF can be calculated by checking optimum settings for generation voltages, transformers taps and switch-able capacitors or static VAr components (called "Voltage- VAR" optimization) periodically.

II. PROBLEM FORMULATION

There are three types of buses in Power System:

i. Load Bus (PQ Bus)

ii. Generator Bus (PV Bus)

iii. Slack Bus (Swing Bus)

There are four variables named as

i. Real Power (P)

ii. Reactive Power (Q)

iii. Voltage Magnitude (V)

iv. Voltage Angle (δ)

Out of these four variables, two variables are known at each bus. In Load Bus, Real Power and Reactive Power are known i.e. active and reactive powers are injected into the network and Voltage Magnitude and Voltage Angle are unknown. Voltage Magnitude and Voltage Angle are to be calculated in this. In Generator Bus, Real Power and Voltage Magnitude are specified. The Reactive Power and Voltage Angle are to be determined. Voltage magnitude is kept constant at a specified value by injection of reactive power. These buses are also known as Regulated Buses/ Voltage Controlled Buses. In Slack Bus, Voltage Magnitude and Voltage Angle are known and Real Power and Reactive Power are to be determined. This Bus makes up the difference between the scheduled load and generator power that are caused by losses in the network. This Bus is taken as Reference Bus. If slack bus is not specified then the generation bus with usually with a maximum active power P is taken as reference bus.

TABLE I
TYPE OF BUS AND ITS VARIABLES

TYPE OF BUS	KNOWN VARIABLE	UNKOWN VARIABLE
Load Bus (P-Q Bus)	P,Q	V, δ
Generator Bus (PV bus)	P,V	Q, δ
Slack Bus (V- δ Bus)	V, δ	P,Q

III. METHODOLOGIES

The main aim of electric supply utility is provide the Smooth electrical energy to the consumers taking into account that the electrical power is generated with minimum cost. It is only possible when the total demand is shared to all the units. This will lead to cost minimization. The objective function is represented by quadratic curves of second order. The major considerations for the fulfilling the objective of this is minimize the fuel cost the general definition of optimization problem is given by:

$$\text{Minimize: } f(x, u) \quad \text{(i)}$$

Subject to:

$$g(u, x) = 0 \quad \text{(ii)}$$

$$h(u, x) \geq 0$$

Where,

f: Objective Function (iii)

g: Equality Constraints (iv)

h:Inequality Constraints (v)

u and x represents a set of controllable and dependent variables respectively.

A. Objective Function

No more than 3 levels of headings should be used. All headings must be in 10pt font. Every word in a heading must be capitalized except for short minor words as listed in Section III-B.

The main objective function helps to minimize the operating cost. The objective function is the function of the real power generation. The objective function for the OPF reflects the costs associated with generating power in the system. The quadratic cost model for generation of power will be utilized. The Objective Function is the function of real power generation

$$F = \text{ai} + \text{bi}\,(\text{Pgi}) + \text{ci}\,(\text{Pgi})^2$$

Where:

Pgi is the amount of generations in MW at generator i

ai , bi , ci are the cost coefficients

This objective function will minimize the total system costs, and does not necessarily minimize the costs for a particular area within the power system. It is scalar function of the variable of the problem. So the objective function for the whole power system for cost minimization is

$$F = \sum_{i=1}^{NG} (\text{ai} + \text{bi}\,(\text{Pgi}) + \text{ci}\,(\text{Pgi})^2)$$

Where

ai, bi, ci are the cost coefficients

NG is the number of generation including the slack bus

B. The Controls

In Optimal Power Flow Problem, the objective function can be minimized directly by adjusting the values of the control variables and satisfy the constraints. The control variables can be given as:

i. Active Power Generation

ii. Reactive Power Generation

iii. Transformer Tap Ratio

iv. Generator Bus Voltage

The Control variables help in making the desired results. For example, the active power generation cost is minimized by controlling the active power generation. The main function of the control variables is to minimize the cost of generation by adjusting them to appropriate values.

C. The Dependent Variables

These are those variables which are not under control. These include all type of variables that are free to assume value to solve the particular problem. The main dependent variables are the complex bus voltage angle and magnitude.

D. Inequality Constraints

In Optimal Power Flow Problem, the equality constraints reflect the physics of the power system. The objective function can be minimized only when the power system is running under normal condition while the network components are operating within limits i.e. The net power generation should be equals to the sum of total demand and total losses.

This can be achieved by the active and reactive power analysis:

Pi = Pload + PLoss

Qi = Qload + QLoss

Where:

Pi & Qi are the active and reactive power outputs Pload & Qload are the active and reactive load power Ploss & Qloss are the active and reactive power loss.

IV. SOFT COMPUTING SOLUTION

A. PARTICLE SWARM OPTIMISATION

PSO simulates the behaviours of bird flocking. Suppose the Optimal Power flow (OPF) is allocating loads to plants for minimum cost while meeting the network constraints. It is formulated as an optimization problem of minimizing the total fuel cost of all committed plant while meeting the network (power flow) constraints. The variants of the problems are numerous which model the objective and the constraints in different ways. The basic OPF problem can described mathematically as a minimization of problem of minimizing the total fuel cost of all committed plants subject to the constraints [1].

Minimize

$$\sum_{i=1}^{n} F_i P_i$$

F (Pi) is the fuel cost equation of the 'ith' plant. It is the variation of fuel cost ($ or Rs) with generated power (MW).Normally it is expressed as continuous quadratic equation.

$$F_i(P_i) = aP_i^2 + b_i P_i + c_i$$

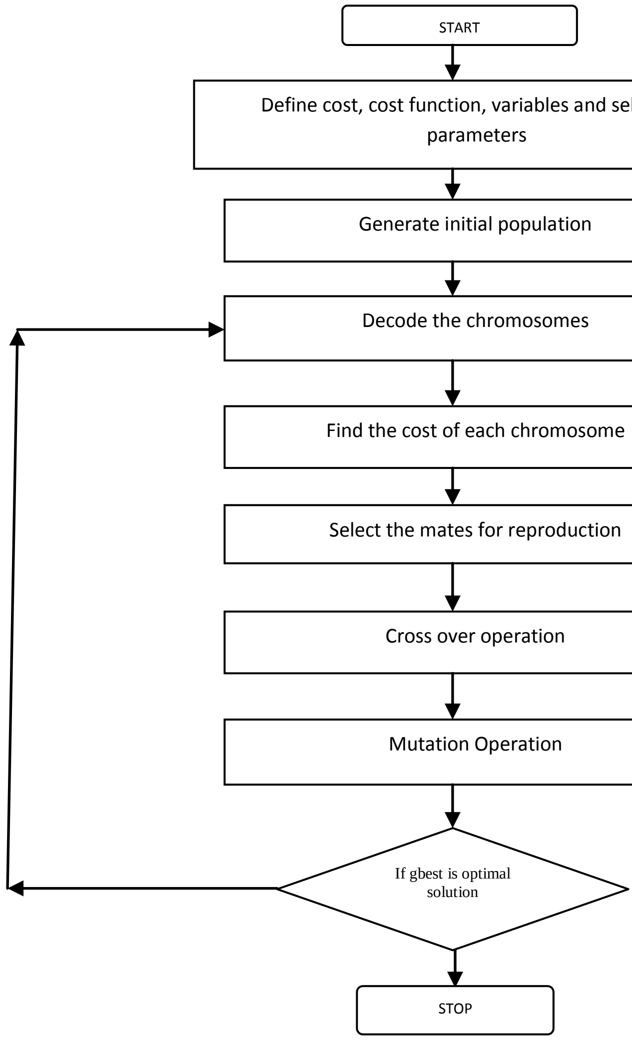
$$P_i^{\min} \le P_i \le P_i^{\max}$$

PSO is used to solve optimization problems. In PSO, each potential solution optimization search space is a bird called the particles. All particles have a function to be optimized by the decision of the appropriate value (fitness value), each particle has a speed determines the direction and distance they fly. Then the particles follow the current optimal particle search in the solution space.

PSO is initialized by a group of random particles (random solution), and then find the optimal solution by iteration. In each iteration, the particle by tracking the two extremes to update themselves; the first one is the optimal solution found by the particle itself, this solution called individual extreme; other extreme is the best find of the entire population now solution, this is a global extreme extremes. Alternatively, you can do the entire population but only using a portion of the particles as a neighbour, then all neighbours' extremes is local maxima.

A genetic algorithm (GA) [2, 3, 4, 5] is an optimization technique using artificial intelligence. The method is based on Darwin's survival of the fittest hypothesis. In a GA, candidate solutions to a problem are analogous to individual animals in a population. Although the initial population can be a random collection of bizarre individuals, the individuals will interact and breed to form future generations. Stronger individuals will reproduce more often than will weaker individuals. Presumably, the population will get collectively stronger as generations pass and weaker individuals die out. The quantitative application of these basic ideas to an actual algorithm is a combination of science and art.

B. FLOW CHART OF GA



V. RESULTS

1. **Results of OPF by Genetic Algorithm-** The value of converged genetic algorithm is expressed as follows

   a. **The value of objective function (Output Cost Function) =** 802.296

   b. **P_{gg}(Output of Control Variable)** = 177.9992 , 51.8479, 20.3332, 17.6587, 12.3484, 12.8551

   c. **TL(Transmission Loss) =** 9.6426

2. **Results of OPF by PSO-** The value of converged PSO algorithm is expressed as follows-

   a. **The value of objective function (Output Cost Function) =** 801.8436

   b. **P_{gg} (Output of Control Variable)** = 176.7579, 48.8068, 21.6709, 21.6709, 12.0757, 12.0000

   c. **TL(Transmission Loss) =** 9.3374

VI. CONCLUSION

This paper mainly studied the PSO method and GA method. It is used to provide the solution involving numerical analysis. The PSO method and GA method needs less number of iterations to reach convergence, and is more accurate and not sensitive to the factors. In addition, this project also studied optimal power flow based the IEEE 30 bus system. Optimal power flow is the condition that the cost of overall power system is the lowest. This project concerns a general cost minimization problem to solve the power flow problem based on IEEE 30 bus system.

A conclusion section must be included and should indicate clearly the advantages, limitations, and possible applications of the paper. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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