VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

SOLVING OPTIMAL POWER FLOW WITH FACTS DEVICE USING DE ALGORITHM

A. Chandra Sekar[1] and P. Rajasekar[2]
[1]ME (PSE), Department of E.E.E, SMK Fomra Institution of Tech, Chennai, India
[2]M.E. Department of E.E.E, SMK Fomra Institution of Tech, Chennai, India
E-Mail: acsekar.85@gmail.com

ABSTRACT

In a power system, load flow is analyzed to know the real and reactive power flow in the lines connecting buses, bus voltage magnitude, and phase angle. Load flow analysis is required for a power system planning and operation. Economic operation of power system requires adjustment in real power generation of generators. Economic Load Dispatch (ELD) problem is solved to know this optimal real power generation. Optimal Power Flow (OPF) problem is a combination of economic load dispatch and power flow problem. OPF finds economic real power generation schedule for each generator and satisfies real and reactive power balance which is the objective of power flow problem. Flexible AC Transmission Systems (FACTS) devices are used to control transmission power to improve power system performance. STATCOM is a shunt connected latest FACTS device used to control reactive power and voltage in the power system. In this proposed work OPF is solved by including a STATCOM to improve the system performance and to reduce the generating cost. To minimize the generating cost for the power system with STATCOM, intelligent algorithm Differential Evolution (DE) is used. DE has three main operation, they are Mutation, Crossover and Selection. To validate the work with other published work, IEEE 30 bus system is considered for the simulation.

Keywords: FACTS, Newton's method, optimal power flows, STATCOM, voltage source converter.

INTRODUCTION

Optimal Power Flow (OPF) [3] is a minimization problem has objective to reduce generating cost and subject to equality and inequality constraints on control and dependent variables. This OPF problem is a combination of Economic Load Dispatch (ELD) [4] and power flow analysis problems. Objective function of OPF and ELD is same, which is finding optimal generating pattern of committed generators in the power system. The objective of power flow analysis is to balance real and reactive power flow, which is included in the equality constraint of OPF problem. Other boundary conditions and limits are taken care by the inequality constraints in the OPF problem. Other objectives like loss minimization, voltage profile and stability improvement may include and this OPF problem becomes a multi objective optimization problem. Many optimization techniques have been used to solve OPF problem. They are Linear Programming (LP) [5], Non Linear Programming (NLP) [5], Quadratic Programming (QP) [5], Newton-based solution and Interior Point (IP) methods. Since OPF problem is nonlinear in nature Lagrange multiplier, sequential unconstrained minimization techniques are used in NLP. QP is another form of NLP, uses sensitivity based methods. Gradient method, Newton based solution and Kuhn-Tucker conditions are commonly used to solve OPF.

Recent research works and literatures are used intelligent algorithms to solve OPF. Some of the famous algorithms are Genetic Algorithm (GA) [11], Simulated Annealing (SA), Ant Colony Algorithm (ACA), Bee Algorithm (BA), Differential Evolution (DE) [3], Particle Swarm Optimization (PSO), Harmony Search (HS), and Firefly Algorithm (FA).

POWER FLOW ANALYSIS AND ECONOMIC LOAD DISPATCH

In power engineering, the power-flow study, or load-flow study, is a numerical analysis of the flow of electric power in an interconnected system. A power-system uses simplified notation such as a one-line diagram and per-unit system, and focuses on various aspects of AC power parameters, such as voltages, voltage angles, reactive power and real power. It describes the power systems in normal steady-state operation.

Power-flow or load-flow studies are depicted for planning future expansion of power systems as well as in discoursing the best operation of existing systems. The principal information obtained from the power-flow study is the phase angle and magnitude of the voltage at each bus, and the real and reactive power flowing in each line.

NEWTON RAPHSON SOLUTION METHOD

There are various methods of solving the resulting nonlinear system of equations. The most popular is known as the Newton-Raphson method. This method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses). Next, a Taylor Series is emphasized, with the higher order terms ignored, for each of the power balance equations included in the system of

VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

equations. The result is a linear system of equations that can be expressed as:

$$\begin{bmatrix} \Delta\theta \\ |\Delta V| \end{bmatrix} = -J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (1)$$

Where ΔP and ΔQ are called the mismatch equations:

$$\Delta P_i = -P_i + \sum_{k=1}^{n} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \quad (2)$$

$$\Delta Q_i = -Q_i + \sum_{k=1}^{n} |V_i||V_k|(G_{ik}\sin\theta_{ik} + B_{ik}\cos\theta_{ik}) \quad (3)$$

and J is a matrix of partial derivatives known as

$$J = \text{a Jacobian: } \begin{bmatrix} \frac{\partial \Delta P}{\partial \theta} & \frac{\partial \Delta P}{\partial |V|} \\ \frac{\partial \Delta Q}{\partial \theta} & \frac{\partial \Delta Q}{\partial |V|} \end{bmatrix} \quad (4)$$

The linearized system of equations is solved to determine the next guess (m + 1) of voltage magnitude and angles based on:

$$\theta^{m+1} = \theta^m + \Delta\theta \quad (5)$$

$$|V|^{m+1} = |V|^m + \Delta| \quad (6)$$

The process continues until a stopping condition attains. A common stopping condition is to terminate if the norm of the mismatch equations is below a specified tolerance.

Economic Load Dispatch Problem

The economic dispatch problem (EDP) [12] is one of the important problems in operation and control of modern power systems. The objective of the EDP of electric power generation is to schedule the committed generating unit outputs so as to meet the required load demand at minimum operating cost while satisfying all unit and system equality and inequality constraints

Description of Economic Dispatch Problem

The objective of the EDP [15] is to minimize the total fuel cost at thermal power plants subjected to the operating constraints of a power system. Therefore, it can be formulated mathematically as an optimization problem (minimization) with an objective function and constraints. The equality and inequality constraints are represented by Eqs.

Given by:

$$\sum_{i=1}^{n} P_i - P_l - P_d = 0 \quad (7)$$

$$P_i^{min} \le P_i \le P_i^{max} \quad (8)$$

In the power balance criterion, an equality constraint must be satisfied, as shown in Eq. (7). The generated power must be the same as the total load demand plus total line losses. The generating power of each generator should lie between maximum and minimum limits represented by Eq. (8), where Pi is the power of generator i(in MW); n is the number of generators in the system; PD is the system load demand (in MW); PL represents the total line losses (in MW) and $P_i^{min}$and P_i^{max} are, respectively, the minimum and maximum power outputs of the i-th generating unit (in MW). The total fuel cost function fc is formulated as follows.

$$\min fc = \sum_{i=1}^{n} Fi(Pi) \quad (9)$$

Where Fi is the total fuel cost for the generator unity i (in \$/h), which is defined by equation:

$$F_i(P_i) = a_iP_i^2 + b_iP_i + c \quad (10)$$

where ai, bi and ci are cost coefficients of generator i.

A cost function is obtained based on the ripple curve for more accurate modeling. This curve contains higher order Non linearity and discontinuity due to the valve point effect, and should be refined by a sinusoidal function. Therefore, Eq. (10) can be modified, as:

$$\tilde{F}_i(P_i) = F(P_i) + |e_i \sin(f_i(P_i^{min} - P_i))| \quad (11)$$

where ei and fi are constants of the valve point effect of generators. Hence, the total fuel cost that must be minimized, according to Eq. (9), is modified to:

$$\min f_c = \sum_{i=1}^{n} \tilde{F}i(Pi) \quad (12)$$

where $\tilde{F}_i$ is the cost function of generator i(in \$/h) defined by Eq. (11). In the case study presented here, we disregarded the transmission losses, PL; thus, PL = 0. The Eq. (12) represents the fitness function. We are minimizing the fitness function.

FLEXIBLE AC TRANSMISSION SYSTEM

ARPN Journal of Engineering and Applied Sciences

CONTROLLER

The FACTS is a concept based on power-electronic controllers. Which enhance the value of transmission networks by increasing the use of their capacity? As these controllers operate very fast, they enlarge the safe operating limits of a transmission system without risking stability. Needless to say, the era of the FACTS was triggered by the development of new solid-state electrical switching devices. Gradually, the use of the FACTS has given rise to new controllable systems. Today, it is expected that within the operating constraints of the current-carrying thermal limits of conductors, the voltage limits of electrical insulating devices, and the structural limits of the supporting infrastructure, an operator should be able to control power flows on lines to secure the highest safety margin as well as transmit electrical power at a minimum of operating cost.

STATCOM

A static synchronous compensator (STATCOM), also known as a "static synchronous condenser" ("STATCON"), is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices. It is inherently modular and electable. The parameters of STATCOM can be calculated during iterative process and the final value will be updated after the convergence is achieved. This representation of generator buses reduces the number of required equations with respect to the classical and improved versions of the current injection methods. In addition of that the developed model reduces the complexities of the computer program codes and enhances the reusability by avoiding modifications in the Jacobian matrix. The performance of the developed STATCOM model has been tested using standard IEEE 30 systems.

Working Principle of STATCOM

A STATCOM is a controlled reactive-power source. It provides the desired reactive-power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage-source converter (VSC). A single-line STATCOM power circuit is shown in Figure-1(a), where a VSC is connected to a utility bus through magnetic coupling. In Figure-1(b), a STATCOM is seen as an adjustable voltage source behind a reactance-meaning that capacitor banks and shunt reactors are not needed for reactive-power generation and absorption, thereby giving a STATCOM a compact design, or small footprint, as well as low noise and low magnetic impact. The exchange of reactive power between the converter and the ac system can be controlled by varying the amplitude of the 3-phase output voltage, Es, of the converter, as illustrated in Figure-1(c). That is, if the amplitude of the output voltage is increased above that of the utility bus voltage, Et, then a current flows through the reactance from the converter to the ac system and the converter generates capacitive-reactive power for the ac system. If the amplitude of the output voltage is decreased below the utility bus voltage, then the current flows from the ac system to the converter and the converter absorbs inductive-reactive power from the ac system. If the output voltage equals the ac system voltage, the reactive-power exchange becomes zero, in which case the STATCOM is said to be in a floating state. A STATCOM provides the desired reactive power by exchanging the instantaneous reactive power among the phases of the ac system. The mechanism by which the converter internally generates and/ or absorbs the reactive power can be understood by considering the relationship between the output and input powers of the converter. The converter switches connect the dc-input circuit directly to the ac-output circuit. Thus the net instantaneous power at the ac output terminals must always be equal to the net instantaneous power at the dc-input terminals. Assume that the converter is operated to supply reactive-output power. In this case, the real power provided by the dc source as input to the converter must be zero. Furthermore, because the reactive power at zero frequency (dc) is by definition zero, the dc source supplies no reactive power as input to the converter and thus clearly plays no part in the generation of reactive-output power by the converter. In other words, the converter simply interconnects the three output terminals so that the reactive-output currents can flow freely among them. If the terminals of the ac system are regarded in this context, the converter establishes a circulating reactive-power exchange among the phases. However, the real power that the converter exchanges at its ac terminals with the ac system must, of course, be supplied to or absorbed from its dc terminals by the dc capacitor.

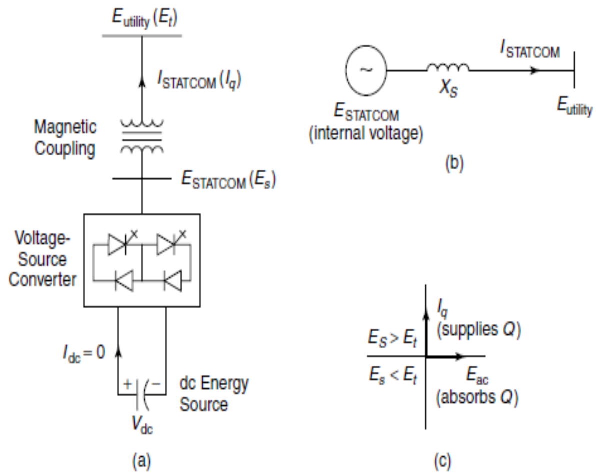

Figure-1. The STATCOM principle diagram: (a) a power circuit (b) an equivalent (c) a power exchange.

The VSC has the same rated-current capability when it operates with the capacitive- or inductive-reactive current. Therefore, a VSC having a certain MVA rating gives the STATCOM twice the dynamic range in MVAR (this also contributes to a compact design). A dc capacitor bank is used to support (stabilize) the controlled dc voltage needed for the operation of the VSC. The reactive power of a STATCOM is produced by means of power-electronic equipment of the voltage-source-converter type. The VSC may be a 2-level or 3-level type, depending on the required output power and voltage. A number of VSCs are combined in a multi-pulse connection to form the STATCOM. In the steady state, the VSCs operate with fundamental-frequency switching to minimize converter losses. However, during transient conditions caused by line faults, a pulse width–modulated (PWM) mode is used to prevent the fault current from entering the VSCs. In this way, the STATCOM is able to withstand transients on the ac side without blocking.

DE BASED OPF OVERVIEW

Differential Evolution was first proposed over1994-1996 by Storn and Price at Berkely. The ability of DE is to optimize nonlinear, non-continuous and non-differential real world problems. Compare to other population based Meta heuristic algorithms, DE emphasis on Mutation than Recombination or Crossover. It mutate vector with a help of randomly selected a pair of vector in the same population. The mutation guides the vector towards the global optimum. The distribution of the difference between randomly sampled vectors is determined by the distribution of these vectors. The distribution of the vector is mainly determined by the corresponding objective function. This enables DE function robustly and more as a generic global optimizer. DE works on population of vectors, where vector is a group of decision variables. Selection of decision variable is based on their impact on the problem to be optimized. These decision variables need to be encoded and set of initial values are chosen from the solution space. By mutation and recombination new vectors are created. The selection process selects the best vectors based on the selection criterion. DE is inherent minimization problem and suitable for cost minimization of OPF problem.

Basic Description

DE has good convergence characteristic and use real value control variables hence no need of encoding and decoding. Set of control variables which decide problem solution forms a vector. Set of vector forms population, evolves iteration by iteration to converge into optimal solution. Random variation in vectors used for the evolution. The basic operations in DE are encoding real world problem into DE optimization problem, mutation, recombination and selection. DE select a vector called target vector and it undergone mutation and recombination process results trail vector. Selection procedure selects either target or trail vector based on their fitness. General form of DE optimization is given below:

$$\text{Minimize } C_t = \sum_{i=1}^{NG} f_i(P_G) \ \ \$/\text{hr} \tag{13}$$

$$\text{Subject to: } g(|V|, \delta)=0 \tag{14}$$

$$X_{min} \le X \le X_{max} \tag{15}$$

Where,
C_t is total generating cost in $/hr
$g(|V|, \delta)$ is power flow balance equation
X is a set of control variable
X_{min}, X_{max} are minimum and maximum value of control variable

Encoding

Encoding is the process of converting set of control variables in OPF into vector of DE optimization problem. Ability of DE is to operate on floating point and mixed integer makes ease of encoding. Final value of vector gives optimal values of control variables is the optimal solution of OPF. For the evolution and better convergence fitness function is most important as follows.

Fitness Function

An appropriate fitness function is vital for evolution and convergence of DE. It is an OPF objective functions and penalty functions if any. DE evaluates fitness function for each vector in the population. Objective function value for a vector is called fitness for the vector. DE generate a trail vector for a target vector using mutation and recombination, greater fitness vector among target and trail vector is considered for next generation.

Mutation

Mutation is emphasised than recombination. The objective of mutation is to enable search diversity in the parameter space as well as to direct the existing vectors with suitable amount of parameter variation in a way that will lead to better results at a suitable time. It keeps the search robust and explores new areas in the search domain. Target vector is selected based on fitness function to find mutated vector by using randomly selected vector from the population other than target vector. Four types of commonly used mutation are

$$\text{DE/rand/1/ bin: } X_{r1}^{mutated} = X_{r1}+SF*(X_{r2} - X_{r3} \tag{16}$$

$$\text{DE/rand/2/bin: } X_{r1}^{mutated} = X_{r1}+SF*(X_{r2} - X_{r3})+SF*(X_{r4} - X_{r5}) \tag{17}$$

$$\text{DE/best/1/bin: } X_{r1}^{mutated} = X_{best}+SF*(X_{r1} - X_{r2}) \tag{18}$$

$$\text{DE/best/2/ bin: } X_{r1}^{mutated} = X_{best}+SF*(X_{r1} - X_{r2})+ SF*(X_{r3} - X_{r4}) \tag{19}$$

Where,

ARPN Journal of Engineering and Applied Sciences

X_{r1} is target vector
$X_{r1}^{mutated}$ is mutated vector
X_{best} is the best optimal solution in the population
SF is scaling factor
r1 to r5 are random vector position in population
r1≠ r2≠ r3≠ r4≠r5

First two mutation rules given in equation (16) and (17) are called random vector mutation rule, next two mutation rule are called best vector based mutation rule. Appropriate scaling factor should be decided based on problem domain and its range from 0 to 1. High value of scaling factor may decrease in convergence speed but escapes from local minima. Equation (16) is used to generate mutated vector for target vector using target vector, scaling factor and other two randomly selected vectors from the population. To induce more diversity four more random vectors are used as given in equation (17). In these two equation target vector and other randomly selected vectors are used. To reinforce best vector in the population equations (18) and (19) are used. Equation (18) makes diversity from the best vector using scaling factor, target vector and one randomly selected vector in the population. Equation (19) uses best vector, scaling factor, target vector and three more randomly selected vectors to generate mutated vector. In this work scaling factor is taken as 0.7.

Recombination

Recombination or crossover generates trail vector from target and mutated vector. The name recombination is most appropriate since it recombines either mutated or target vector particles (control variables) based on crossover constant. This process reinforces prior successes in the current population. Two types of commonly used recombination are Binomial recombination and Exponential recombination. Binomial recombination is simplest and most frequently used recombination. CR is crossover constant ranges from 0 to1. In this work crossover constant CR is taken as 0.2. Large value of CR speeds up convergence and low value is good for separable problem.

$$X^{trail} = \begin{cases} X^{mutated} \ if \ (rand) \le CR \\ X^{target} \ if \ (rand) > CR \end{cases} \quad (20)$$

Selection

One to one selection process is used in DE, this process decides either same vector (target) is to keep or trail vector is to use for next iteration. X is a vector, and k represents iteration number. X^k is target vector in current population and X^{k+1} is a selected vector for next iteration. For initial start, vectors are initialised by random values of control variables in the solution space using the equation (21) and rand (0, 1) is the function generates a random number in between 0 and 1. Fitness of target vector and trail vector is computed using fitness function. Target vector is replaced by trail vector if the fitness of trail vector is greater than the target vector. The condition for selection is given in equation (22) below.

$$X^0 = X_{min} + rand\ (0, 1)*(X_{max} - X_{min}) \quad (21)$$

$$X^{k+1} = \begin{cases} X^{trail} \ if \ f(trail) < f(target) \\ X^{target} \ if \ f(target) \le f(trail) \end{cases} \quad (22)$$

Selection process is repeated for every vector in the population to maintain population size same for all iterations.

Stopping Criteria

DE improves problems' solution iteration by iteration and the iteration has to be stopped either the problem is converged or iteration reached its maximum value. Stopping of iteration is important to provide solution for time complexity. In this research work maximum number of 200 iterations, is considered as stopping criteria.

OPF PROBLEM FORMULATION

The prime objective of OPF is minimization of generating cost subjected to equality constraint - power balance equation, inequality constraints - limits on real power, reactive power generation, bus voltage magnitude, and transformer tap position and MVA flow in transmission lines. Quadratic cost function with valve point loading effect is considered as objective function of OPF and the problem is stated as

Objective function

$$\text{Minimize } C_t = \sum_{i=1}^{NG} f_i(P_G) \ \ \$/hr \quad (23)$$

$$\sum_{i=1}^{NG} f_i(P_G) = \sum_{i=1}^{NG} a_i + b_i P_{Gi} + c_i P_{Gi}^2 \quad (24)$$

Subject to
Equality constraints

$$\sum_{i=1}^{NG} P_{Gi} = P_D + P_L \quad (25)$$

VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

$$\sum_{i=1}^{NG} Q_{Gi} = Q_D + Q_L \quad (26)$$

Inequality constraints
Limits on control and dependant variables

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad \text{for i=1to NG} \quad (27)$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \quad \text{for i=1to NG} \quad (28)$$

$$V_i^{min} \le V_i \le V_i^{max} \quad \text{for i=1to NB} \quad (29)$$

$$T_i^{min} \le T_i \le T_i^{max} \quad \text{for i=1to NT} \quad (30)$$

$$MVA_i \le MVA_i^{max} \quad \text{for i=1to Nbr} \quad (31)$$

$$Q_{stat}^{min} \le Q_{stat} \le Q_{stat}^{max} \quad (32)$$

NUMERICAL RESULTS AND DISCUSSIONS

CASE STUDY

To evaluate performance of developed algorithms, bench mark test case IEEE 30 bus system shown in Figure-2 is considered. Numerical result of IEEE 30 bus is presented and discussed in this chapter. The system has 6 generators include slack bus, hence 5-real power generation, 6 generator bus voltage magnitude, 4 transformer tap position and 2 STATCOM size and location.

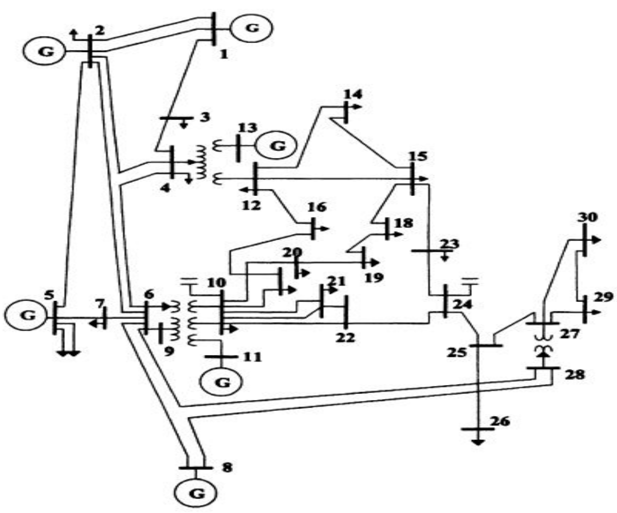

Figure-2. Single line diagram of IEEE 30 bus system.

Table-1. Gives system description of case study.

S. No	Variables	30-Bus system
1	Buses	30
2	Branches	41
3	Generators and Generator buses	64
4	Shunt reactors	2
5	Tap-changing transformer	4

The IEEE-30 bus system consists of six generators, four transformers, 41 lines, and two shunt reactors. In DE solution for OPF, the total control variables are 17. Six unit active power outputs, six generator bus voltage magnitudes, four transformers tap settings and two shunt reactors and are given in Table-1. All generator active power, and generator bus voltages and transformer tap setting and two shunt reactors are considered as continuous for simplicity. The generators cost coefficients of the IEEE 30-bus test system are given in the Table-2. The limits of variables for the IEEE-30 bus system are given in Table-3. In this section, the DE solution of the OPF is evaluated using the test system IEEE-30 bus system. The results, which follow, are the best solution over the ten runs.

Table-2 gives generator real power limits and cost coefficient of generators. Constants a, b, c are fuel cost coefficients of the generator.

VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-2. Generator cost coefficients for OPF.

S. No	Bus No	Pmin (MW)	Pmax (MW)	a ($/hr)	b ($/Mwhr)	c ($/Mw^{2}hr)
1	1	50	200	0	2	0.0038
2	2	20	80	0	1.75	0.0175
3	5	15	50	0	1	0.0625
4	8	10	35	0	3.25	0.0083
5	11	10	30	0	3	0.025
6	13	12	40	0	3	0.025

Control variables considered in this OPF are real power generation except slack bus generator; generator bus voltage magnitude and transformer tap position. Limits on control variable - real power generation is given in Table-3. The Table-4 shows the standard IEEE 30 bus dates, which are used to implement this paper.

Table-3. Limits on other control and dependent variables.

Types of Variable	Description	Lower Limit (p.u)	Upper Limit (p.u)
Control	Transformer Tap Position	0.90	1.10
Control	PV bus voltage	0.95	1.05
Dependent	PQ bus voltage	0.95	1.05
control	$Q_{STATCOM}$	0	250

Table-4. IEEE 30 bus data.

Bus No	Load		Bus No	Load	
	P (p.u)	Q (p.u)		P (p.u)	Q (p.u)
1	0.000	0.000	16	0.035	0.018
2	0.217	0.127	17	0.090	0.058
3	0.024	0.012	18	0.032	0.009
4	0.076	0.016	19	0.095	0.034
5	0.942	0.190	20	0.022	0.007
6	0.000	0.000	21	0.175	0.112
7	0.228	0.109	22	0.000	0.000
8	0.300	0.300	23	0.032	0.016
9	0.000	0.000	24	0.087	0.067
10	0.058	0.020	25	0.000	0.000
11	0.000	0.000	26	0.035	0.023
12	0.112	0.075	27	0.000	0.000
13	0.000	0.000	28	0.000	0.000
14	0.062	0.016	29	0.024	0.009
15	0.082	0.025	30	0.106	0.019

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-5. Optimal power flow result before STATCOM.

Parameters	Values
Pg1	198.142Mw
Pg2	50Mw
Pg5	15Mw
Pg8	10Mw
Pg11	10Mw
Pg13	12Mw
Vg1	1.05pu
Vg2	1.033pu
Vg5	1.01pu
Vg8	1.01pu
Vg11	1.05pu
Vg13	1.05pu
T1	0.978pu
T2	0.969pu
T3	0.932
T4	0.968pu
Fuel cost	809.258$/hr
Transmission loss	11.7548 Mw

Tables 5 and 6 gives the optimal power flow result of before STATCOM and after STATCOM, DE iterated for 100 iteration and best chromosome to yield minimum generating cost is taken. Figure-3 shows convergence characteristic curve drawn for number of iteration verses generating cost. It is converged around 32th iteration. Generating cost for this generating pattern is 805.889 $/hr and real power loss is 11.1929 MW.

Table-6. Optimal power flow result after STATCOM.

Parameters	Values
Pg1	192.565 Mw
Pg2	48.7254 Mw
Pg5	19.7473 Mw
Pg8	11.5553 Mw
Pg11	10 Mw
Pg13	12 Mw
Vg1	1.04338 pu
Vg2	1.06079 pu
Vg5	1 pu
Vg8	1.08111 pu
Vg11	1.0589 pu
Vg13	1 pu
T1	0.939804 pu
T2	0.9 pu
T3	1.09357 pu
T4	0.994835 pu
STATCOM Location	12
STATCOM Size	51.0154 Mvar
Fuel cost	805.889 $/hr
Transmission loss	11.1929 Mw

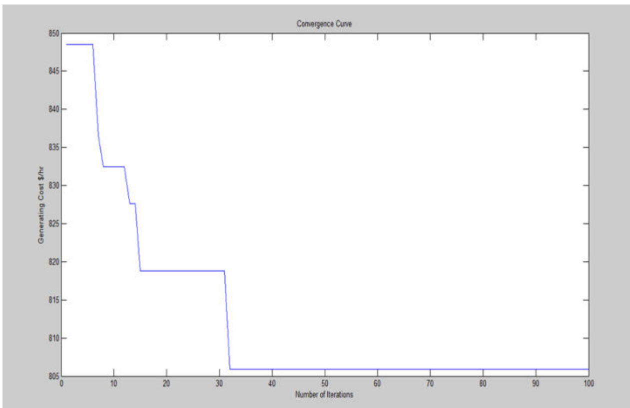

Figure-3. Convergence curve - DE with STATCOM.

CONCLUSIONS

DE is efficient minimization optimization intelligent algorithm. It emphasis mutation and converges to global minimum optimal value. DE is vector based algorithm and control variables may be used as real values. Selection of vector particle, population size, scaling factor and crossover constant are important for good convergence. Control variables values are taken as real values, objective function of OPF is taken as fitness function of DE. The problem of the research work is OPF with STATCOM which is required for the current situation of power system, since it is suffered by low voltage problem. In this research work the effect of STATCOM is analyzed using IEEE 30 bus system. The results of the IEEE 30 bus system is compared for the test system with and without STATCOM. The DE result before STATCOM is Fuel cost809.258$/hr and transmission loss 11.7548 Mw then STATCOM using DE result for fuel cost805.889 $/hr and Transmission Loss 11.1929 Mw.

REFERENCES

[1] Hong-TzerYang, Pai-chuan Yang, Ching-Lein Huang, "Evolutionary programming based economic dispatch for units with non-smooth fuel cost functions", IEEE Transactions on Power Systems, vol. 11, No. 1, February 1996, pp. 112-118.

[2] L.L. Lai, J.T. Ma, R. Yokohoma, M. Zhao, Improved genetic algorithm for optimal power flow under both normal and contingent operation states, Electrical Power Energy System. 19 (1997) 287-291.

[3] Raul E. Perez-Guerrero, Jose R. Cedeno-Maldonado, "Differential Evolution BasedEconomic Environmental Power Dispatch" pp. 191-197.

[4] N Sinha, R Chakravarthi, P K Chattopadhyay, "Improved Fast Evolutionary Program for Economic Load Dispatch with Non-Smooth Cost Curves", Institute Of Engineers Journal-EL, Vol. 84, September 2004, pp. 110-114.

[5] J.A. Momoh, M.E. El-Hawary, R. Adapa, A review of selected optimal power flow literature to 1993. Part I: Non-linear and quadratic programming approaches, IEEE Transaction on Power Systems 14 (February (1)) (1999) 96-104.

[6] Jason Yuryevich, Kit Po Wong, "Evolutionary Programming Based Optimal Power Flow Algorithm", IEEE Transactions on Power Systems, Vol. 14, No. 4, November 1999, pp.1245-1250.

[7] G. N. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technologies of Flexible AC Transmission Systems. Piscataway, NJ, USA: IEEE, 2000.

[8] P. Venkatesh, R. Gnanadass, Narayana Prasad Padhy, "Comparison and Application Of Evolutionary Programming Techniques To Combined Economic Emission Dispatch With Line Flow Constraints", IEEE Transactions On Power Systems, Vol. 18, No. 2, May 2003, pp. 688-697.

[9] M.S. Osman, M.A. Abo-Sinna, A Solution to the Optimal Power Flow using Genetic Algorithm, Elsevier Inc., 2003.

[10] P.Somasundaram, K.Kuppuswamy, R.P. Kumidini Devi, "Evolutionary Programming Based Security Constrained Power Flow", Electric Power Systems Research, Vol. 72, July 2004, pp. 137-145.

[11] J.A. Momoh, M.E. El-Hawary, R. Adapa, A review of selected optimal power flow literature. Part II: Newton, linear programming and interior point methods, IEEE Transaction on Power Systems 14 (February (1)) (1999) 105–111.

[12] R Gnanadass, P Venkatesh, T G Palanivelu, K Manivannan, "Evolutionary Programming Solution Of Economic Load Dispatch With Combined Cycle Co-Generation Effect",Institute Of Engineers Journal-EL , Vol. 85,September 2004, pp. 124-128.

[13] P.Somasundaram, K.Kuppuswamy, R.P.Kumudini Devi, "Economic Dispatch With Prohibited Operating Zones Using Fast Computation Evolutionary Programming Algorithm", Electric Power Systems Research, vol. 70, 2004, pp. 245-252.

[14] E. Acha, C. R. Fuerte-Esquivel, H. Ambriz-Perez, and C. Angeles-Camacho, FACTS Modeling and Simulation in Power Networks. New York, NY, USA: Wiley, 2005.

[15] R. Gnanadas, P. Venkatesh, Narayana Prasad Padhy, "Evolutionary Programming Based Optimal Power Flow for Units with Non-Smooth Fuel Cost Functions", Electric Power Components and Systems, Vol.33, 2005, pp. 1245-1250.