Optimal Power Flow using Hybrid Intelligent Algorithm

T. Hariharan[1*] and K. Mohana Sundaram[2]

[1]Department of EEE, Dhirajlal Gandhi College of Technology, Anna University, Salem – 636309, Tamil Nadu, India; thariharanme@gmail.com
[2]Department of EEE, Vel Tech Multi Tech, Anna University, Chennai - 600025, Tamil Nadu, India; kumohanasundaram@gmail.com

Abstract

Optimal Power Flow (OPF) is the important for operation and planning of the power system. The OPF results are used in operation to improve the quality and generation cost of the power system. In planning the results of OPF is used to forecast future electric load expansion based on past and current operating details. The generation cost in OPF may reduce by adjusting the control variables generated real power; voltage magnitude and transformer tap position. Flexible AC Transmission System (FACTS) devices are further helpful for reducing generating cost as well as to improve the quality of the power supply. This paper investigates the helpfulness of three types of FACTS devices namely, STATCOM, SSSC and UPFC. To find optimal values of these control variables including FACTS devices hybrid intelligent algorithm Real Coded Genetic Algorithm-Differential Evolution (RGA-DE) is used for solving OPF problem. RGA has good selection and crossover operator but lays less emphasis on mutation operator whereas DE has good mutation process. To validate the work with other published work, IEEE 30 bus system is to be considered for the simulation.

Keywords: DE, FACTS, Hybrid RGA-DE, NR, OPF, Power Flow, RGA

1. Introduction

Many optimization techniques have been used to solve OPF problem. They are Linear Programming (LP), Non Linear Programming (NLP), Quadratic Programming (QP), Newton-based solution and Interior Point (IP) methods. Alsac and Stott[1] introduced optimal power flow concept, then in Clements, et al.[2] tried to find minimum generating cost and losses in the power system, using Newton's power flow, Lagrangian multipliers, gradient method and penalty method for soft limited inequality constraints. Alsac and Stott[1] improved the Dommenl and Tinney work by incorporating new constraints for steady-state security. They analysed OPF, with and without outage condition and considering security in both case is presented in a neat way to understand in detail.

Intelligent optimization algorithms used to solve OPF are listed in this section. Anastasios G. Bakirtzis, et al.[3]

used Enhanced Genetic Algorithm (EGA) to solve OPF, which is Binary coded GA. Number of bits in the chromosome is reduced to enhance the performance of the algorithm. Combined Economic Emission Dispatch problem are discussed in the following literatures. Abido[4] used Niched Pareto Genetic Algorithm (NPGA); Non dominated Sorting Genetic Algorithm (NSGA) and Strength Pareto Evolutionary Algorithm (SPEA) to solve Environmental Economic Dispatch (EED). Hariharan T. and Gopalakrishnan M.[5] used to solve the Optimal Reactive Power Flow with the Facts Devices and considered the equipment limits. In Fuel Cost function valve point loading was ignored. Gnanadass, et al.[6] used DE algorithm to solve PF. Mandal KK., et al.[7] used Multi Objective Differential Evolution (MODE) algorithm to solve Environmental Economic Power Dispatch (EEPD) problem. In this work small population is considered to get optimal solution to achieve external pareto-optimal

solution is used. Hemamalini S., et al. used[8] technique into Sequential Quadratic Programming (SQP) to improve the performance of proposed algorithm. In this algorithm SQP is used to generate initial population for DE, these initial population individuals are nearer to optimal.

Christober C. Asir Rajan[9] have proposed a novel approach for solving the short term unit commitment problem using the genetic algorithm based tabu search method with cooling and banking constraints. Generator real power except slack bus, generator voltage magnitudes, transformer tap settings are considered as control variables and converted into vector of DE algorithm. Irfan Mulyawan Malik and Dipti Srinivasan[10] used GA to solve OPF for which they considered elitism and non uniform mutation rate. Lal Raja Singh R., et al.[11] used firefly algorithm to solve non-convex valve point loaded economic dispatch. Taher Niknam, et al.[12] used firefly algorithm to solve dynamic economic dispatch for 24 hrs. Load forecast of one day is used for this dynamic economic dispatch. Abdel-Fattah Attia, et al.[13] used adapted genetic algorithm in which the population size is altered based on fitness function for solving OPF. They assert fast convergence better solution to OPF. DE algorithm gives more importance to mutation, than crossover and selection operation and finds global optimal solution. Mohanasundaram K. and Rajasekar N.[14] used to find the location of optimal solution. Anurag Gupta, et al.[15] used Evolutionary Programming (EP) technique to solve non smooth fuel cost function OPF. Probabilistic search technique of EP makes it flexible to find optimal solution for a non convex problem. Gopalakrishnan R., et al.[16] used ant colony algorithm and included the production cost with valve point loading. Molzahn DK., et al.[17] used semi definite programming technique to solve large scale OPF. In this technique, large size power system network matrix is decomposed into many smaller matrices and then combined small matrices to its original form to find OPF solution. Random localization concept is implemented in DE algorithm to find reactive power dispatch.

Recent research works and literatures are used intelligent algorithms to solve OPF. Some of the famous algorithms are Genetic Algorithm (GA), Simulated Annealing (SA), Ant Colony Algorithm (ACA), Bee Algorithm (BA), Differential Evolution (DE), Particle Swarm Optimization (PSO), Harmony Search (HS) and Firefly Algorithm (FA). This paper explains the RGA-DE Algorithm with Standard IEEE 30 Bus System

by using the Facts devices named as STATCOM, SSSC and UPFC[18]. The rest of the paper organized by follows: Section 2 describes the problem Formulation work brief explanation; Section 3 gives the FACTS and Section 4, 5 and 6 explains the proposed technique RGA, DE and Hybrid RGA-DE; Section 7 gives the numerical results and Section 8 describes conclusion and the corresponding discussions.

2. Problem Formulation

2.1 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[19] is considered as objective function of OPF and the problem is stated as (1) and (2),

2.1.1 Objective Function:

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

$$\text{Where, } C_t = \sum_{i=1}^{N_G} \left(\alpha_i + \beta_i P_{Gi} + \lambda_i P_{Gi}^2 \right) \tag{2}$$

2.1.2 Subjected to Equality Constraints[18]

$$\sum_{i=1}^{NG} P_{Gi} = P_D + P_L \tag{3}$$

$$\sum_{i=1}^{NG} Q_{Gi} = Q_D + Q_L \tag{4}$$

2.1.3 Inequality Constraints (5–9)

Limits on control and dependant variables

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \quad \text{for } i = 1 \text{ to } N_G \tag{5}$$

$$Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max} \quad \text{for } i = 1 \text{ to } N_G \tag{6}$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad \text{for } i = 1 \text{ to } N_B \tag{7}$$

$$T_i^{\min} \leq T_i \leq T_i^{\max} \quad \text{for } i = 1 \text{ to } N_T \tag{8}$$

$$MVA_i \leq MVA_i^{\max} \quad \text{for } i = 1 \text{ to } Nbr \tag{9}$$

where

C$_t$ = Total generation cost

α, β, γ = Cost coefficients of the generator

P$_{Gi}$, Q$_{Gi}$ = Active and Reactive power generation ith generator

ng = Total number of generators

P$_D$, Q$_D$ = Active and Reactive power Demand

P$_L$, Q$_L$ = Active and Reactive power Loss

V$_i$ = Voltage at ith bus

t$_i$ = Transformer tap position

MVA$_i$ = MVA flow in ith branch

N$_B$ = Number of buses

N$_G$ = Number of generators

N$_T$ = Number of transformers

Nbr =Number of branches

The main purpose of OPF program is to determine the settings of control variables for economic and secure operation of power system[20]. Among a number of different objectives that an OPF problem may be formulated for the main objective is to minimise the fuel cost subject to network and generator operation constraints. Because of its financial implication, the OPF problem has been studied over the past few decades. Many optimisation techniques have emerged so far and have been applied to solve this problem.

3. Flexible Ac Transmission Device (FACTS)

In the advent of Flexible Ac Transmission Systems (FACTS), utilities are able to control power flow, increase transmission line stability limits, and improve security of transmission systems[1]. In addition, FACTS devices can be used to maximize power transfer capability and minimize transmission system power loss, leading to an efficient utilization of the existing power systems.

3.1 Static Compensator (STATCOM)

Among the FACTS device STATCOM is best voltage controlled and reactive power support shunt connected device. It consists of Voltage Source Converter (VSC) and DC source. Where the DC source can be converted into a Three-Phase AC source. In this Voltage Source Converter consist of both (IGBT) and (GTO) for turn ON and turn OFF the gate signal. In STATCOM the power consumed by the device very less. This shunt connected device may supply or absorb reactive power from the system.

3.2 Static Synchronous Series Compensator (SSSC)

The SSSC also called as S^{3}C. It has DC-AC converter and it is connected to a transmission line by series connection through a transformer. It can be acts as a synchronous voltage source as it can inject sinusoidal voltage of variable and controllable amplitude and phase angle in series. This voltage is almost in quadrature with the line current. A small amount of the injected voltage is lies in phase with line current which provides the losses in the inverter. The injected voltage provides the effect of fixing an inductive or capacitive reactance in series with transmission line. The importance is the injected voltage must be quadrature with line current. This capacitive or inductive reactance makes the smooth and steady power flow in the power flow in the power transmission line.

3.3 Unified Power Flow Controller (UPFC)

The UPFC having the better effect on efficient steady state transmission. Because of its design and working principle this having such technology. This technology has settling effect on steady state, dynamic and transient stabilities. The major components of UPFC are two AC/DC converters, series and shunt transformer and the capacitor. One AC/DC converter is connected in series with the transmission line through a series transfer. And the other is connected in parallel with the transmission line through shunt transformer. The DC output side of the both converter is connected with the capacitor. This capacitor gives DC voltage for the converter operation. Now the entire system of UPFC is capable of both supplying and absorbing real and reactive power from the system. The power balance between the series and shunt converter is a pre requisite to maintain a constant voltage across the DC capacitor. The power flow capacity and transient stability are improved by series branch of UPFC which inject the voltage of variable magnitude and phase angle. These series branch can exchange real power with transmission line to improve above said quality of transmission line. The shunt branch of UPFC system is exchange a current and power factor angle of controllable magnitude with power system. It is normally controlled to balance the real power absorption or injection into the power system by the series branch, plus the losses by regulating the DC voltage at desired value.

4. Hybrid RGA-DE

Hybrid GA-DE algorithm uses advantage of GA and DE to find global optimal value. In this algorithm GA selection, crossover is chosen and mutation is chosen from DE[21], maximum generation is considered as stopping criteria. This fusion of algorithms provides best solution as compared to individual algorithms.

4.1 Initialization

Random initial values of all control variables are chosen within its minimum and maximum limits, is the first step to start the hybrid algorithm. Group of these 15 genes are called chromosome (Y) as given in Equation 11, group of these chromosomes forms a population as given in Equation 10, in this work 80 chromosomes are considered. Maximum number of generation is taken as 200 generation. Initial values of these genes are chosen randomly using a random number generated by MATLAB software as per the Equation 12.

$$Pop = [Y1, Y2, \ldots Ynp] \quad (10)$$

$$Y = [Gene1, Gene2, \ldots Gene15] \quad (11)$$

$$Gene = Gene_{min} + \eta . (Gene_{max} - Gene_{min}) \quad (12)$$

Where,

Pop - Population
Y - Chromosome
np - Population size
Gene$_{max}$, Gene$_{min}$ - Gene maximum and minimum limit
η - Random number within [0 1]

4.2 Selection

Selection is the process of choosing high fitness chromosome to the mating pool. In this hybrid algorithm versatile Roulette Wheel selection is used.

4.3 Crossover

Crossover is the process of sharing vital information among the fittest chromosomes in the mating pool. Single point crossover is used in this hybrid algorithm.

4.4 Mutation

To improve mutation process, 'DE/rand/1' mutation rule is used. Mutation is carried out for all chromosomes in the population. A selected chromosome for mutation is called target vector, apart from target vector three more distinct chromosomes are selected to perform mutation. The model of OPF based on Hybrid RGA-DE Algorithm is shown in Figure 1.

In this approach DE/rand/1 rule is used, and it is achieved by adding the weighted difference of two randomly selected vectors as given in Equation 13.

$$Y_1^G = Y_a^G + SF(Y_b^G - Y_c^G) \quad (13)$$

Where,

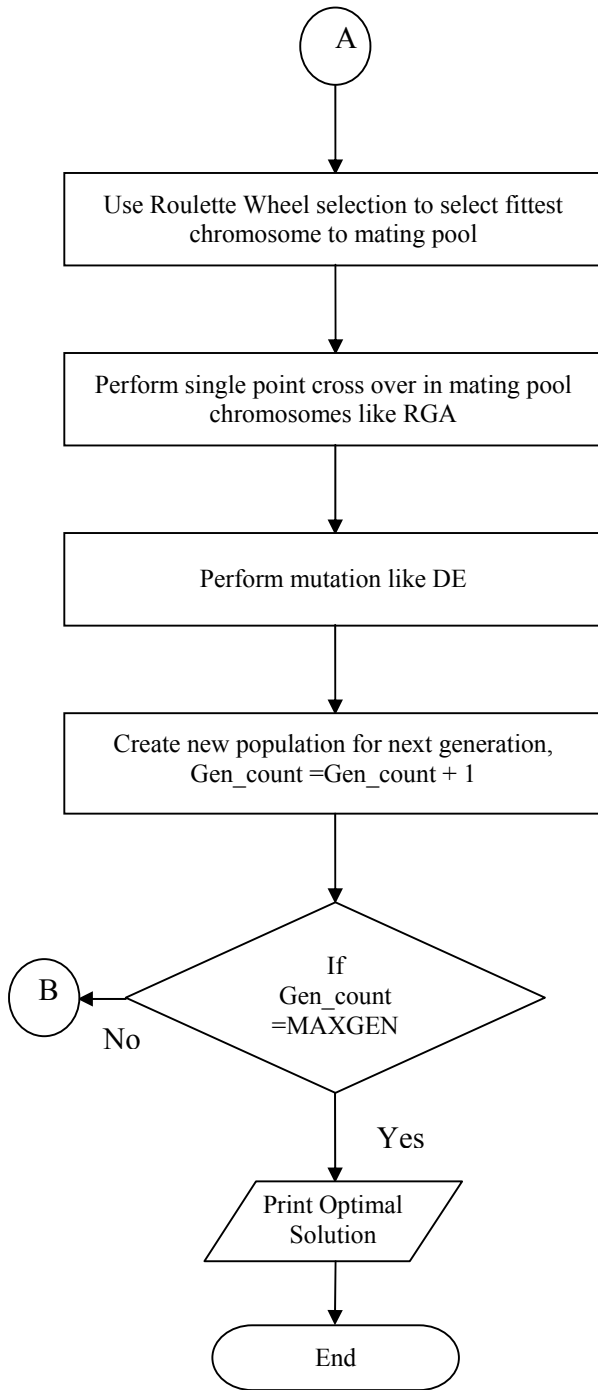Ya, Yb, Yc = randomly chosen vectors, from the population a ≠ b ≠ c
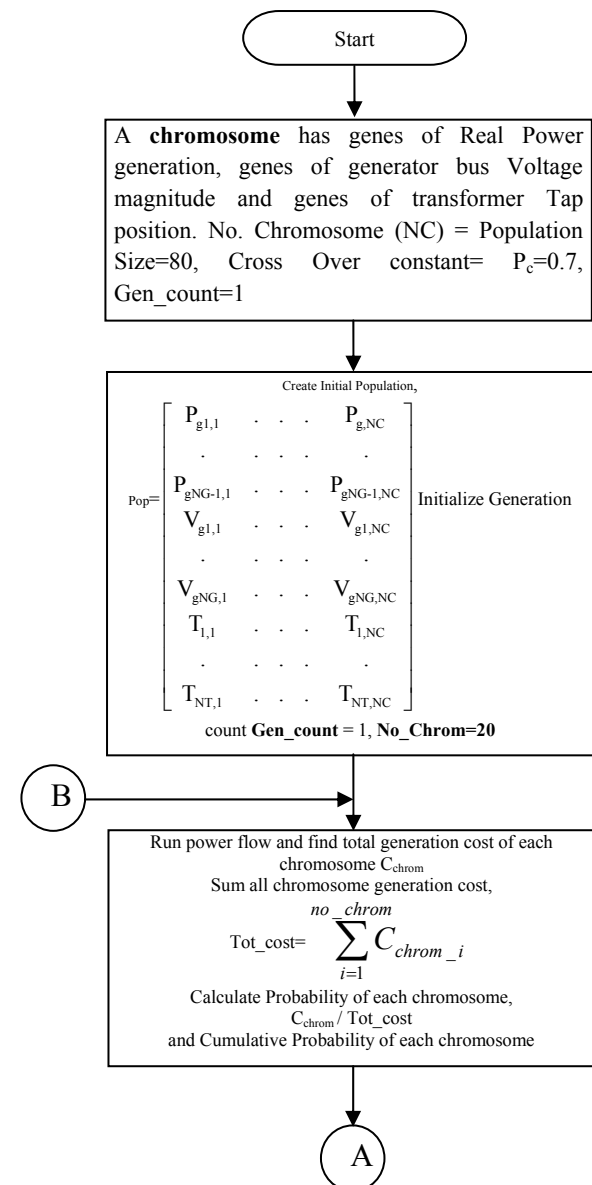
Figure 1. Flow Chart for OPF based on Hybrid RGA-DE Algorithm.

5. Numerical Results and Discussion

To evaluate performance of Hybrid RGA-DE algorithm, standard 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 and 4 transformer tap position are considered as control variables. Base MVA of the system is 100 MVA. Three FACTS devices are considered in this work, they are shunt connected STATCOM, series connected SSSC and hybrid FACTS device UPFC. For STATCOM and SSSC two more control variables are included as control variables for their location and their size. For UPFC three control variables are included in the control variables for the position, shunt and series injection.

Table 1 gives generator real power limits and cost coefficient of generators. Constants α, β, γ are fuel cost coefficients of the generator.

Control variables considered in this OPF are real power generation except slack bus generator; generator
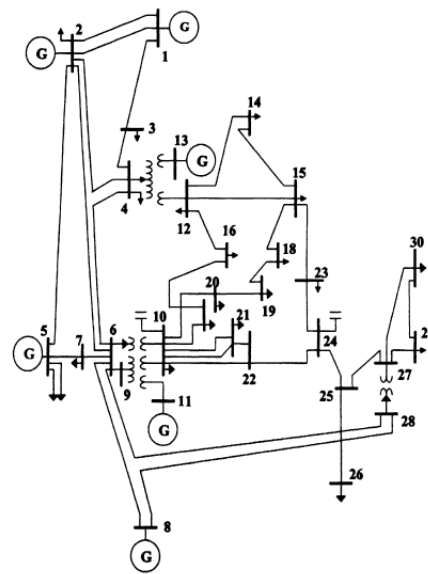

Figure 2. IEEE 30 bus system structure.

Table 1. Generator cost coefficients for OPF

Sl. No	Bus No	Pmin (MW)	Pmax (MW)	α ($/hr)	B($/Mwhr)	γ($/Mw²hr)
1	1	50	400	0	2	0.0038
2	2	20	160	0	1.75	0.0175
3	5	15	100	0	1	0.0625
4	8	10	70	0	3.25	0.0083
5	11	10	60	0	3	0.025
6	13	12	80	0	3	0.025

bus voltage magnitude and transformer tap position. Limits on control variable - real power generation is given in Table 1 and other control variables limits are given in Table 2.

5.1 OPF with STATCOM

This section provides numerical results of OPF solved by hybrid Real coded Genetic Algorithm (RGA) and Differential Evolution (DE) algorithm. This RGADE algorithm includes STATCOM for the optimization. This STATCOM need two control variables for the optimization namely its location and size. Considered test system has 4 transformers and 6 generators including slack, hence 5 real powers generation (P_G) except slack bus, 6 generators voltage magnitude (V_G) and 4 transformers tap position, STATCOM location and STATCOM size to the total 17 variables are taken as control variables. All these control variables have real value bounded between lower and upper limits are considered to code RGADE. It has 17 genes for a chromosome, 20 such chromosomes forms the population. This population is evolving iteration by iteration to find global optimal solution. The maximum number of iteration it may evolve is taken as 30 iterations. Crossover and mutation constants are taken as 0.7 and 0.01 respectively. Results of RGADE used to solve OPF with STATCOM are given below.

From the Figure 3 it is clear that the generation of OPF with STATCOM is less as compare to base case and which gives reduced generating cost. Slack generator contributes more for real power generation and 4th generator contribution is less as compared to others.

Figure 4 shows convergence characteristic curve drawn for number of iteration verses generating cost of RGADE. The results are given in the Table 2 gives the

Table 2. Limits on other control and dependent variables

Types of Variable	Description	Lower Limit	Upper Limit
Control	Transformer Tap Position (pu)	0.90	1.10
Control	PV bus voltage (pu)	0.95	1.05
Dependent	PQ bus voltage(pu)	0.95	1.05
Control	STATCOM size (Mvar)	0	250
Control	STATCOM size (Mw)	0	20
Control	UPFC Shunt size (Mvar)	0	250
Control	UPFC series size (Mw)	0	20
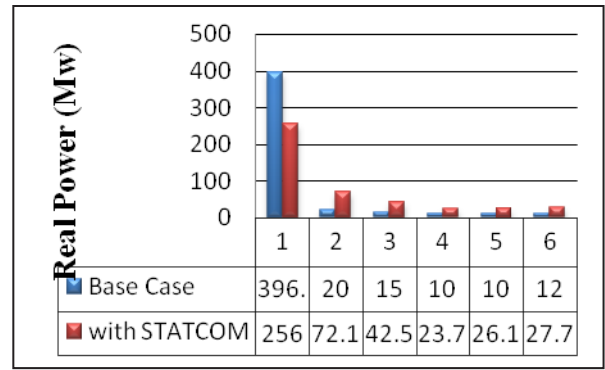
Figure 3. Real power generation of all generators with STATCOM.

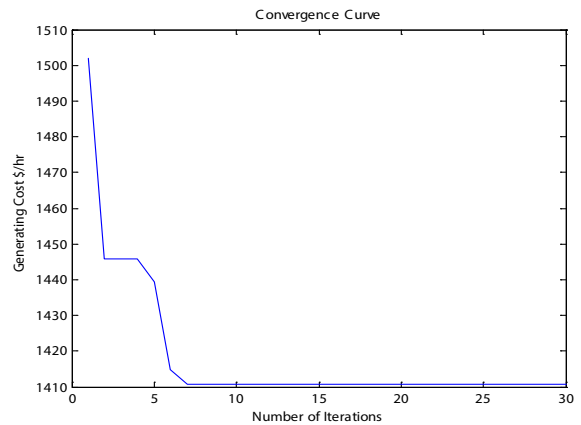|	1	2	3	4	5	6
Base Case	396.	20	15	10	10	12
with STATCOM	256	72.1	42.5	23.7	26.1	27.7

Figure 4. Convergence curve – RGA.

values of control variables for the OPF with and without STATCOM. After connecting STATCOM the results are improved, the generating cost is reduced and loss is reduced as given in the Table 3.

5.2 OPF with SSSC

This section provides numerical results of OPF solved by hybrid Real coded Genetic Algorithm (RGA) and Differential Evolution (DE) algorithm. This RGADE algorithm includes SSSC for the optimization. This SSSC need two control variables for the optimization namely its location and size. For the considered test case, 5 particles of real power (P_G) generation except slack bus, 6 particles of generator bus voltages (V_G), 4 particles of transformer tap position (T) and SSSC location and SSSC size constitutes a vector. 20 vectors are considered for the population, this population is initialised within the solution space. This population is evolving iteration by iteration to find global

optimal solution. The maximum number of iteration it may evolve is taken as 30 iterations. Mutation process use scaling factor is taken as 0.7 and crossover constant for crossover process is taken as 0.2.

From the Figure 5 it is clear that the generation with SSSC is less as compare to base case. The generating cost is reduced as compare to base case the loss is also reduced as given the Table 3 below.

Figure 6 shows convergence characteristic curve drawn for number of iteration verses generating cost. Number of iteration is taken as 30 and control variables are taken as 17, for the OPF with SSSC is given above. The Table 3 gives the result of OPF with SSSC. From the table it is clear that the generating cost and loss are reduced after connecting SSSC in the test case IEEE 30 bus system.

Table 3. Comparison of FACTS devices

Control Variables	Base case	With STATCOM	With SSSC	With UPFC
P_{g1} (MW)	396.14	255.989	198.184	170.743
P_{g2} (MW)	20	72.193	75.586	78.735
P_{g3} (MW)	15	42.5746	50.000	44.499
P_{g4} (MW)	10	23.7257	25.247	10.000
P_{g5} (MW)	10	26.1031	26.184	19.242
P_{g6} (MW)	12	27.7499	30.000	12.000
V_{g1} (pu)	1.050	1.035	1.060	1.060
V_{g2} (pu)	1.003	1.020	1.011	1.034
V_{g3} (pu)	0.960	0.960	0.987	1.110
V_{g4} (pu)	0.970	1.020	0.950	1.001
V_{g5} (pu)	1.050	1.007	0.950	0.991
V_{g6} (pu)	1.050	1.000	0.980	1.000
T_1 (pu)	0.978	1.100	0.061	0.900
T_2 (pu)	0.969	0.900	0.955	1.100
T_3 (pu)	0.932	0.904	1.085	0.900
T_4 (pu)	0.968	0.911	0.917	0.945
Loss (MW)	38.042	23.2384	16.3693	10.2764
Cost ($/hr)	**1557.27**	**1410.77**	**793.66**	**591.11**

5.3 OPF with UPFC

This section provides numerical results of OPF solved by hybrid Real coded Genetic Algorithm (RGA) and Differential Evolution (DE) algorithm. This RGADE algorithm includes UPFC for the optimization. This UPFC need three control variables for the optimization namely its location and shunt and series power injection size.

Considered test system has 4 transformers and 6 generators including slack, hence 5 real powers generation (P_G) except slack bus, 6 generators voltage magnitude (V_G) and 4 transformers tap position, UPFC location and UPFC shunt and series size to the total 18 variables are taken as control variables. All these control variables have real value bounded between lower and upper limits are considered to code RGADE. It has 18 genes for a chromosome, 20 such chromosomes forms the population. This population is evolving iteration by iteration to find global optimal solution. The maximum number of iteration it may evolve is taken as 30 iterations. Crossover and mutation constants are taken as 0.7 and 0.01 respectively. Results of RGADE used to solve OPF with UPFC are given
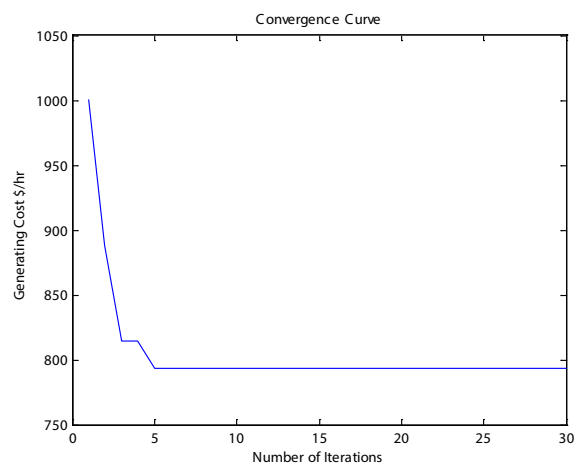

Figure 5. Real power generation of all generators with SSSC.

Figure 6. Convergence curve of OPF with SSSC.

below, from the Figure 7 it is clear that the generation with UPFC is less as compare to base case and gives less generating cost. Slack generator contributes more for real power generation and 4th generator contribution is less as compared to others. Figure 8 shows convergence characteristic curve drawn for number of iteration verses generating cost.

Table 3 compares the three FACTS devices considered in the work. They are STATCOM, SSSC and UPFC. STATCOM is a shunt device connected in parallel in the bus which injects MVar and improves system voltage and reduce losses and the generating cost. SSSC is series device which is connected in the line and injects real power in the receiving bus and improves the OPF solution. UPFC is the combination of STATCOM and SSSC, which has
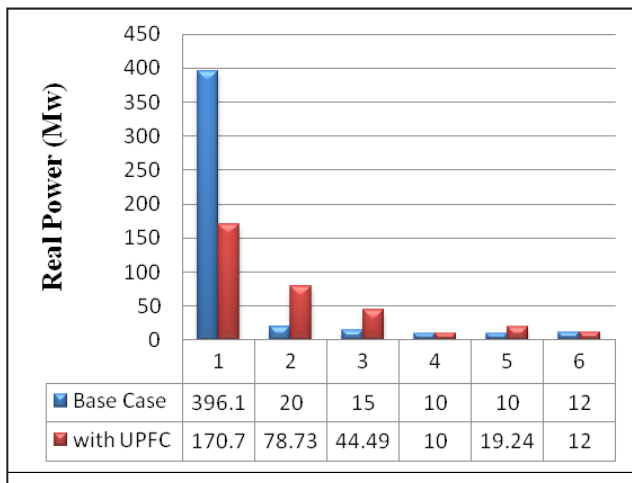
shunt and series injection and their by it reduce the losses more effectively and reduce the generating cost as low as possible as compared to other two FACTS devices.

6. Conclusion

This paper explained a hybrid algorithm for OPF analysis for minimization of generating cost. Hybrid Real coded Genetic Algorithm-Differential Evolution (RGA-DE) algorithm are developed. RGA and DE algorithms are implemented to compare the developed hybrid algorithm. Optimal power flow and Combined Economic Emission Dispatch problem are power system optimization problem having objective of minimization of cost subjected to power balance equality constraints and control, dependent variables limits of inequality constraints. Hybrid RGA-DE gives minimum generating cost and hybrid RGA-DE takes less number of iterations. Hence it is implemented to solve OPF problem. From the results, the base case generating cost of OPF is reduced from 1557.27 $/hr to 1410.77 $/hr using STATCOM, further the generating cost is reduced to 793.66 $/hr when SSSC is used. Finally UPFC gives minimum generating cost of 591.11 $/hr.

	1	2	3	4	5	6
Base Case	396.1	20	15	10	10	12
with UPFC	170.7	78.73	44.49	10	19.24	12

Figure 7. Real power generation of all generators with UPFC.
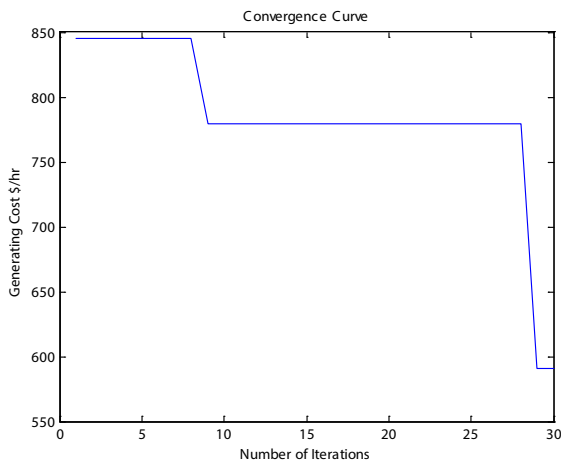
Figure 8. Convergence curve of OPF with UPFC.

7. References

1. Alsac O, Stott B. Optimal load flow with steady state security. IEEE Trans Power Apparat Syst. 1974 May; PAS-93(3):745–51.
2. Clements KA, Davis PW, Frey KD. An interior point algorithm for weighted least absolute value power system state estimation. IEEE PES Winter Meeting; 1991.
3. Bakirtzis AG, Biskas PN, Zoumas CE, Petridis. Optimal power flow by enhanced genetic algorithm. IEEE Transactions on Power Systems. 2002 May; 17(2):229–236.
4. Abido MA. Environmental/Economic power dispatch using multi objective evolutionary algorithms. IEEE Trans on Power Systems. 2003; 18(4):1529-37.
5. Hariharan T, Gopalakrishnan M. Fuzzy logic and cuckoo search based integrated technique for modeling Optimal Reactive Power Flow (ORPF). International Journal of Applied Engineering Research. 2014; 9(24):8205-11.
6. Gnanadass R, Venkatesh P, Padhy NP. Evolutionary programming based optimal power flow for units with non-smooth fuel cost functions. Electric Power Components and Systems. 2004; 33(3):349-61.
7. Mandal KK, Chakraborty N. Differential evolution based environmentally constrained economic dispatch. IEEE Conference (INDICON 2008); 2008. p. 471–76.

8. Hemamalini S, Simon SP. Emission constrained economic dispatch with valve-point effect using particle swarm optimization. IEEE Conference - TENCON 2008; 2008. p. 1–6.

9. Rajan CCA. Genetic algorithm based TABU search method for solving unit commitment problem with cooling-banking constraints. Journal of Electrical Engineering. 2009; 60(2):69-78.

10. Malik IMM, Srinivasan D. Optimum power flow using flexible genetic algorithm model in practical power systems. IPEC 2010; 2010 Oct 27-29. p. 1146 – 51.

11. Singh LR, Rajan CCA. A hybrid particle swarm optimization employing genetic algorithm for unit commitment problem. International Review of Electrical Engineering (IREE). 2011 May; 6(7):3211-17.

12. Niknam T, et al. Modified honey bee mating optimisation to solve dynamic optimal power flow considering generator constraints. IET Gener Transm Distrib. 2011 Oct; 5(10):989-1002.

13. Attia AF, Turki YAA, Abusorrah AM. Optimal power flow using adapted genetic algorithm with adjusting population size. Electric Power Components and Systems. 2012; 40(11):1285-99.

14. Mohanasundaram K, Rajasekar N. Genetic algorithm based proportional integral controller design for induction motor. Journal of Computer Science. 2011; 7(3):416-20.

15. Gupta A, Swarnkar KK, Wadhwani S, Wadhwani AK. Combined economic emission dispatch problem of thermal generating units using particle swarm optimization. International Journal of Scientific and Research Publications. 2012 Jul; 2(7):1-7.

16. Gopalakrishnan R, Krishnan A. Intelligence technique to solve combined economic and emission dispatch. Proceedings of the International Conference on Pattern Recognition, Informatics and Medical Engineering; 2012 Mar 21–23. p. 347–52.

17. Molzahn DK, et al. Implementation of a large-scale optimal power flow solver based on semi definite programming. IEEE Transactions on Power Systems. 2013 Nov; 28(4):3987-98.

18. Ravi CN, Selvakumar G, Rajan CCA. Hybrid real coded genetic algorithm-differential evolution for optimal power flow. International Journal of Engineering and Technology (IJET). 2013 Aug-Sep; 5(4):3404-12.

19. Momoh JA. A generalized quadratic-based model for optimal power flow. IEEE Trans Syst, Man, Cybern. 1986; SMC-16.

20. Maheswari S, Vijayalakshmi C. Implementation of lagrangian optimization model for optimal power flow in power system. Indian Journal of Science and Technology. 2012; 5(6):2835-9.

21. Vanitha R, Baskaran J, Sudhakaran M. Multi objective optimal power flow with statcom using de in WAFGP. Indian Journal of Science and Technology. 2015; 8(2):191-8.