

OPTIMAL REACTIVE POWER PLANNING USING IMPROVED DIFFERENTIAL EVOLUTION INCORPORATING FACTS

K.R.VADIVELU

Assistant Professor, Department of EEE, Annamacharya Institute of technology and sciences, Karakambadi, Tirupati, Andhra Pradesh, India, +919908895631, krvadivelu@rediffmail.com

DR.G.VENKATA MARUTHEESWAR,

professor, Department of EEE, S.V.U.College of Engineering, Tirupati, Andhra Pradesh, India
marutheswarqv@gmail.com

Abstract

This paper presents the relevance of Improved Differential Evolution (IDE) algorithm to solve the Reactive Power Planning (RPP) problem. Minimization of total cost of energy loss and cost of VAR source installments are taken as the objectives incorporating (RPP) problem. This paper compares the success of Evolutionary Programming (EP), Differential Evolution (DE), Improved Adaptive Genetic Algorithm and New Improved Differential Evolution (NIDE) to solve Reactive Power Planning (RPP) problem incorporating FACTS Controllers like Static VAR Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC) and Unified power flow controller (UPFC) considering voltage stability. With help of Fast Voltage Stability Index (FVSI), the critical lines and buses are identified to install the FACTS controllers. The optimal settings of the control variables of the generator voltages, transformer tap settings and provision and parameter settings of the SVC, TCSC, UPFC are considered for reactive power planning. The test and justification of the proposed algorithm are conducted on IEEE 30-bus system and 72-bus Indian system. The Simulation results of the proposed optimization approach is better than Evolutionary Programming and Differential Evolution (DE), Self Adaptive Differential Evolution, shows that the UPFC gives enhanced results than SVC and TCSC and the FACTS controllers diminish the system losses.

Keywords: FACTS Controllers, Differential Evolution, Improved Differential Evolution, Multi-objective optimization, RPP

INTRODUCTION

One of the most stimulating issues in power system research, Reactive Power Planning (RPP). Reactive power planning could be formulated with different objective functions [6] such as cost based objectives considering system operating conditions. Reactive power planning problem required the simultaneous minimization of two objective functions. The first objective deals with the minimization of real power losses in reducing operating costs and improve the voltage profile. The second objective minimizes the allocation cost of additional reactive power sources.

Reactive power planning is a non linear optimization problem for a large scale system with lot of uncertainties. During the last decades, there has been a growing concern in the RPP problems for the security and economy of power systems [1-7]. Conventional calculus based optimization algorithms have been used in RPP for years. Recently new methods [7] on artificial intelligence have been used in reactive power planning. Conventional optimization methods are based on successive linearization [13] and use the first and second differentiations of objective function. Since the formulae of RPP problem are hyper quadric functions, linear and quadratic treatments induce lots of local minima. The rapid development of power electronics technology provides exciting opportunities to develop new power system equipment for better utilization of existing systems. Modern power systems are facing increased power flow due to increasing demand and are difficult to control.

The authors in [20] discussed a hierarchical reactive power planning that optimizes a set of curative controls, such that solution satisfies a given voltage stability margin. Evolutionary algorithms (EAs) Like Genetic Algorithm (GA), Differential Evolution (DE), and Evolutionary planning (EP) [19] have been extensively demoralized during the last two decades in the field of engineering optimization. They are computationally competent in result the global finest solution for reactive power planning and will not to be get attentive in local minima. Such intelligence modified new algorithms are used for reactive power planning recent works [18,19]. Despite of several positive features, It has been observed that DE some times does not perform as good as the expectations. Empirical analysis of DE has shown that it may stop proceeding towards a global optimum even through the population has not converged to a local optimum. It generally takes place when the objective function is multimodal having several local and global optima. Like other Evolutionary Algorithm (EA), the performance of DE deteriorates with increase in dimensionality of the objective function. Several modification have been made in the structure of DE to improve its performance go far a New Improved Differential Evolution.

Modern Power Systems are facing increased demand and difficult to control. The rapid development to fast acting and self commutated power electronics

converters ,well known Flexible AC Transmission Systems (FACTS),introduced by Hingorani.[11],are useful in taking fast control actions to ensure the security of power system. FACTS devices are capable of controlling the voltage angle and voltage magnitude[12] at selected buses and line impedances of transmission lines. In this paper, the maximum loadability is calculated using Fast Voltage Stability Index(FVSI). The reactive power at a particular bus is increased until it reaches the instability point at bifurcation. At this point, the connected load at the particular bus is considered as the maximum loadability. The smallest maximum loadability is ranked as the highest.This paper proposes the application of FACTS controllers to the RPP problem. The optimal location of FACTS controllers is identified by FVSI and an New Improved Differential Evolution(NIDE) is used to find the optimal settings of the FACTS controllers. The proposed approach has been used for the Indian 72 bus system which consists of 15 generator bus, 57 load buses.

NOMENCLATURE

List of Symbols

N_l =set of numbers of load level durations
 N_C = Set of numbers of possible VAr source installment bus
 N_E = set of branch numbers
 N_i =set of numbers of buses adjacent to bus i including bus i
 N_{PQ} = set of PQ bus numbers
 N_g = set of generator bus numbers
 N_T = set of numbers of tap setting transformer branches
 N_B = set of numbers of total buses
 h = per unit energy cost
 d_l = duration of load level l
 g_k = conductance of branch k
 V_i = voltage magnitude at bus i
 θ_{ij} = voltage angle difference between bus i and bus j
 e_i = fixed VAr source installment cost at bus i
 C_{Ci} =per unit VAr source purchase cost at bus i
 Q_{Ci} = VAr source installed at bus i
 Q_i = reactive power injected into network at bus i
 G_{ij} =mutual conductance between bus i and j
 B_{ij} =mutual susceptance between bus i and j
 G_{ii},B_{ii} = self conductance and susceptance of bus i
 Q_{gi} = reactive power generation at bus i
 T_k = Tap setting of branck k
 N_{Vlim} = set of numbers of buses in which voltage over limits
 N_{Qglim} = set of numbers of buses in which reactive power over limits

PROBLEM FORMULATION

It is aimed in this objective function in Reactive Power planning ,three objectives are considered in

optimization model.The first objective is that minimizing of the real power loss (P_{loss}) in transmission lines of a power system. This is mathematically stated as follows.

$$W_C = h \sum d_l p_{loss,l} \quad (1)$$

Where, (P_{loss}) , denotes the network real powerA loss during the period of load level l. It can be can be expressed in the following equation in the[6] duration d_l :

$$P_{loss} = \sum g_k (V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij}) \quad (2)$$

The second term represents the cost of VAR source installments which has two components,namely, fixed installment cost and purchase cost:

$$I_C = \sum (e_i + C_{Ci} |Q_{Ci}|) \quad (3)$$

Here Q_{Ci} can be either possitive or negative depending on whether the installation is capacitive or reactive. Therefore absolute values are used to compute the cost.

The Third term represents the cost of FACTS Controllers.Using Simens AG Data base,cost[14] function for SVC and TCSC are developed as follows

$$\begin{aligned} C_{TCSC} &= 0.0015s^2 - 0.173s + 153.75 \\ C_{SVC} &= 0.0003s^2 - 0.3051s + 127.38 \\ C_{UPFC} &= 0.0003s^2 - 0.2691s + 188.22 \end{aligned} \quad (4)$$

The objective function is expressed as $M_{in} F_C = W_C + C_{facts}$ (5)

The functions should satisfy the real and reactive power constraints (equality constraints)

(i) Load Flow Constraints:

$$0 = P_i - V_i \sum V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \quad (6)$$

$$0 = Q_i - V_i \sum V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) \quad (7)$$

And also satisfy the inequality constraints like reactive power generation,bus voltage and FACTS controller installment as follows

(ii) Generator Reactive Power Capabilty Limit

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max} \quad (8)$$

(iii) Voltage Constraints:

$$V_i^{min} \leq V_i \leq V_i^{max} \quad (9)$$

(iv) FACTS Reactive Power Limit:

$$-100 \leq Q_{facts} \leq 100 \quad (10)$$

(v) FACTS Reactance Limit:

$$-0.8X_{Line} \leq X_{facts} \quad (11)$$

Q_{facts} can be fewer than zero and if Q_{facts} is chosen as a negative value, say in the light load period, variable inductive reactive power should be injected at bus i by the FACTS controllers. Q_{facts} act as a control variable. The load bus voltages V_{load} and reactive power generations Q_g are state variables, which are limited by adding them as the quadratic penalty terms to the objective function. Equation (5) is therefore changed to the following generalized objective function

$$\text{Min } F_C = F_C + \sum_{i \in N_{Q_{glim}}} \alpha (V_i - V_i^{lim})^2 + \sum_{i \in N_{V_{lim}}} \beta (Q_{gi} - Q_{gi}^{lim})^2 \quad (12)$$

Subjected to

$$0 = P_i - V_i \sum_{\substack{j \in N_{B-l} \\ j \in N_l}} (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij})$$

$$0 = Q_i - V_i \sum_{\substack{j \in N_{PQ} \\ j \in N_l}} (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij})$$

Where, α and β are the penalty factors which can be increased in the optimization procedure; V_i^{lim} and Q_{gi}^{lim} are defined in the following equations:

$$V_i^{lim} = \begin{cases} V_i^{min} & \text{if } V_i < V_i^{min} \\ V_i^{max} & \text{if } V_i > V_i^{max} \end{cases}$$

$$Q_{gi}^{lim} = \begin{cases} Q_{gi}^{min} & \text{if } Q_{gi}^{min} < Q_{gi}^{min} \\ Q_{gi}^{max} & \text{if } Q_{gi}^{max} > Q_{gi}^{max} \end{cases} \quad (13)$$

MODELLING OF FACTS CONTROLLERS

SVC, TCSC and UPFC mathematical models are implemented by MATLAB programming. Steady state model of FACTS controllers in this paper are used for power flow studies [15,22]

TCSC

TCSC, the first generation of FACTS, can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line. A TCSC [11] is a series controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. In this paper, TCSC is modeled by changing the transmission line reactance as below

$$X_{ij} = X_{line} + X_{TCSC} \quad (14)$$

Where, X_{line} is the reactance of transmission line and X_{TCSC} is the reactance of TCSC. Rating of TCSC depends on transmission line where it is located. To prevent overcompensation, TCSC reactance is chosen between $-0.8X_{line}$ to $0.2X_{line}$.

SVC

SVC can be used for both inductive and capacitive compensation. In this paper SVC is modeled as an ideal reactive power injection controller at bus i

$$\Delta Q_i = Q_{svc} \quad (15)$$

UPFC

The decoupled model of UPFC is used to provide independent [10],[13] shunt and series reactive compensation. It is a combination of Static Synchronous compensator and Static Synchronous series compensator interconnected through a D.C.link. It has two control parameters a voltage source inserted in series with the line and the current source connected in shunt with the line. It is able to absorb or generate real and reactive power output depending on the rating of UPFC.

FVSI FORMULATION

The Fast Voltage Stability Index is resulting from the voltage quadratic equation at the receiving bus on a two-bus system [12,14,15,17]. The general 2-bus representation is illustrated in Figure 1.

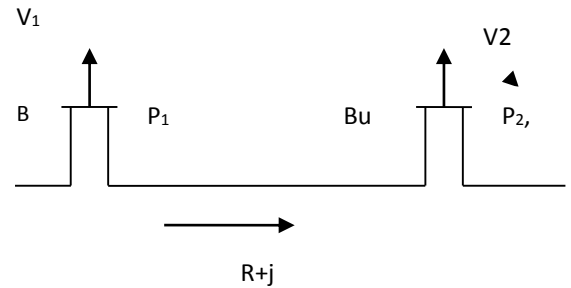


Figure 1. Model of Two bus system

From the figure, the voltage quadratic equation at the receiving bus is written as

$$V_2^2 - \left[\frac{R}{X} \sin \delta + \cos \delta \right] V_1 V_2 + \left(X + \frac{R^2}{X} \right) Q_2 = 0 \quad (16)$$

set the equation of discriminator be larger than or equal to zero yields

$$\left(\left[\frac{R}{X} \sin \delta + \cos \delta \right] V_1 \right)^2 - 4 \left(X + \frac{R^2}{X} \right) Q_2 \geq 0 \quad (17)$$

Rearranging (2), we obtain

$$\frac{4Z^2 Q_2 X}{V_1^2 (R \sin \delta + X \cos \delta)^2} < 1 \quad (18)$$

since “i” as the sending bus and “j” as the receiving end bus, Since δ is normally very small, then, $\delta \approx 0$, $R \sin \delta \approx 0$ and X receiving bus, Fast Voltage Stability Index (FVSI) can be calculated

$$FVSI_{ij} = \frac{4Z^2 Q_j}{V_i^2 X} \quad (19)$$

Where Z, X are the Impedance and reactance of the line. Where as Q_j, V are the Reactive power at the receiving end and the sending end voltage.

PROCEDURE FOR DETERMINING THE MAXIMUM LOADABILITY FOR WEAK BUS IDENTIFICATION USING FVSI

1. Using Newton Raphson method ,Run the load flow program for the base case
2. Estimate Fast voltage stability Index value for all line in the system
3. Progressively increase the Q_j at chosen load bus until the load flow fails to give the results. Calculate Fast Voltage Stability Index Values for every load variation
4. Take out the line index that has the highest value be s the most critical line with respect to a bus
5. Select another load bus repeat steps up to 4.
6. Obtain the voltage at the maximum computable FVSI prior to the divergence of the Load flow .It can be obtained from step 3.This determines the critical Voltage of a Particular bus
7. Take out the maximum Q_j loading for the maximum calculable FVSI for all test bus. It can be obtained from 5.The greatest VAR loading is referred to as the most loadability of a Particular bus.
8. Sort the greatest loadability obtained from step 7 in ascending order and the least loadability Maximum is ranked the utmost imply the Weakest bus in the system
9. Select the feeble buses as the reactive power installation site for the Reactive Power Planning

PROPOSED DIFFERENTIAL EVOLUTION (DE)

Differential Evolution is first proposed over 1994-1996 by Storn and Price at Berkeley. Differential evolution (DE) is a population based stochastic search algorithm search algorithm that operate on the populations of the possible solution vectors $\{X_i^G : i=1,2,3,\dots,N_p\}$ at each generation G [8,10,11]. Each individual element of the solution vector is composed of D -parameters, namely $X_i^G := x_{i,j}^G : j=1,2,\dots,D$. Various steps in DE are mutation, crossover and selection. The outline of the DE algorithm is as follows:

1. Initialize the population:

$x_{i,j}^G = x_j^L + R_j(x_i^U - x_j^L)$, $j=1,2,\dots,D$ where x_j^L and x_j^U are the lower And upper bounds of the parameter j respectively, and R_j is a random number ,uniformly distributed between $[0,1]$.

2. Evaluate the population using an objective function.
3. Generate a new population where each new vector is created according to:

(a) Generate a trial vector v_i^G , for each solution vector as x_i^G

$$v_i^G = x_{BEST}^G + P(x_m^G - x_n^G), i=1,2,\dots,N_p \quad (20)$$

Where x_{BEST}^G represents the best solution and $\{x_m^G, x_n^G\}$ are two arbitrary vectors at generation G such that $\{x_{BEST}^G, x_m^G, x_n^G\}$ are mutually different. The constant P is a mutation factor. In this paper Differential Evolution Random Scale Factor is used .In Which the scaled parameter F is varied in random manner in the range of

(b) Crossover the trial vector and the current vector with crossover probability CR to deliver a baby vector u_i^G i.e.,

$$u_i^G = \begin{cases} v_{i,j}^G & \text{for } R_j < CR \\ x_{i,j}^G & \text{otherwise} \end{cases} \quad (21)$$

(c) Evaluate the baby vector.

(d) Use the baby in the new generation if it is at least as good as the current vector; otherwise, the old vector is retained.

$$x_i^{G+1} = \begin{cases} u_i^G & \text{for } f(u_i^G) < f(x_i^G) \\ x_i^G & \text{otherwise} \end{cases} \quad (22)$$

4. Repeat step 3 until the termination condition is satisfied.

5.4.PROBLEM REPRESENTATION;

Generator bus voltages (V_{gi}) , transformer tap positions (t_k) and reactive power generation of

VAR sources (Q_{ci}) are the optimization variables for the VSC-RPP problem. The generator bus voltages are represented as floating point numbers, whereas the transformer tap position and the reactive power generation of FACT Devices are represented as integers[21]. The transformer tap setting with tapping ranges of $\pm 10\%$ and a tapping step of 0.025 p.u is represented from the alphabet (0,1,.....8) and the VAR sources with limits of 1 and 5 p.u and step size of 1 p.u is represented from the alphabet (0,1,.....5). with this representation, a typical chromosome of the RPP problem will look like the following:

0.981 0.971.05 4 31 -2 +1+3
 $V_1 V_2 \dots V_n Q_{FACTS1} Q_{FACTS2} Q_{FACTS3} t_1 t_2 \dots t_n$

EVALUATION FUNCTION FOR MULTI-OBJECTIVE OPTIMAL REACTIVE POWER PLANNING PROBLEM

In the optimal VAR planning problem, the objective is

CASE STUDY

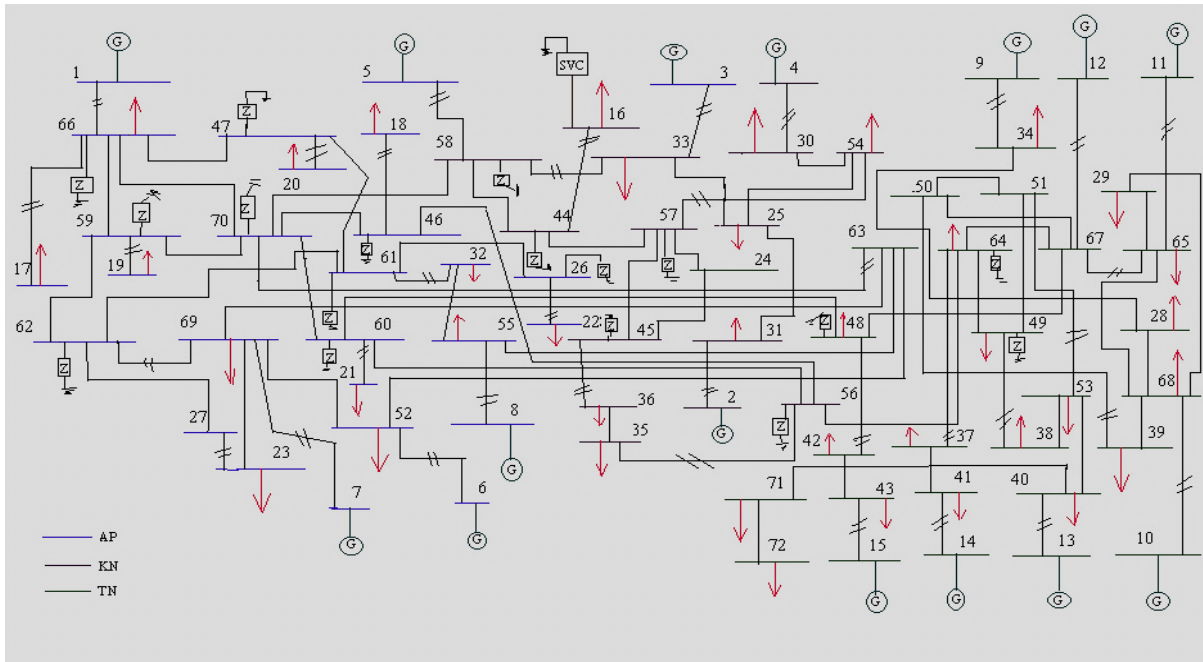


Figure 2. Indian network.

A simplified Indian 400- kV transmission network with 72 buses(55 PV buses and 15 PQ buses) and is used for testing.One line diagram is shown in figure 2.

to minimize the total real power loss while satisfying the constraints. For each individual,the equality constraints are satisfied by running Newton -Raphson algorithm and the constraints onthe state variables are taken into consideration by adding penalty function to the objective function.With the inclusion of the penalty factors, the new objective function using

$$\text{Min } F_C = F_C + \sum_{i \in N_{Q_{lim}}} \alpha (V_i - V_i^{lim})^2 + \sum_{i \in N_{V_{lim}}} \beta (Q_{gi} - Q_{gi}^{lim})^2 \quad (23)$$

Where, α and β are the penalty factors which can be increased in the optimization procedure; V_i^{lim} and Q_{gi}^{lim} are defined in the following equations:

$$V_i^{lim} = \begin{cases} \alpha V_i^{min} & \text{if } V_i < V_i^{min} \\ \alpha 1 V_i^{max} & \text{if } V_i > V_i^{max} \end{cases}$$

$$Q_{gi}^{lim} = \begin{cases} \beta Q_{gi}^{min} & \text{if } Q_{gi}^{min} < Q_{gi}^{min} \\ \beta Q_{gi}^{max} & \text{if } Q_{gi}^{max} > Q_{gi}^{max} \end{cases} \quad (24)$$

Where α, β are the penalty factor.

FACTS locations are identified based on the FVSI technique. The greatest loadability and FVSI values for the real time system are given in Table I.

TABLE I: Bus Ranking and FVSI Values

Rank	Bus	$Q_{max}(p.u)$	FVSI	Over loaded Branch
1	38	0.21	0.9837	38-53
2	49	0.27	0.9841	49 - 38
3	51	0.28	0.9964	51- 53
4	53	0.35	0.9925	53-67
5	35	0.43	0.9843	35 36
6	16	0.45	0.9932	16-58
7	46	0.47	0.9972	46 18
8	32	0.48	0.9887	32-61
9	28	0.56	0.9863	28-50
10	27	0.57	0.9897	27 23
11	66	0.59	0.9852	66-17
12	64	0.63	0.9922	64 – 37
13	60	0.658	0.9787	60- 21
14	17	0.67	0.9858	17-66
15	22	0.71	0.9871	22-26
16	29	0.712	0.9936	29-68
17	33	0.732	0.997	33 - 3
18	52	0.74	0.9856	52 6
19	43	0.77	0.9879	43 15
20	36	0.81	0.9989	36-57
21	67	0.85	0.9947	67 – 12
22	23	0.856	0.9937	23- 69
23	45	0.87	0.9859	45 – 36
24	68	0.881	0.9986	68 – 10
25	72	0.893	0.9783	72-71
26	18	0.9	0.9949	18-46
27	39	0.911	0.9929	39-68
28	65	0.925	0.9893	65- 11
29	26	0.96	0.9801	26 – 22
30	59	0.962	0.9857	59 – 19
31	71	0.982	0.9862	71-72
32	24	0.988	0.9999	24-57
33	30	0.99	0.9931	30- 4
34	19	1.01	0.9976	19-62
35	44	1.1	0.9798	44- 16
36	40	1.13	0.998	40 -13
37	63	1.19	0.9879	63-54
38	41	1.22	0.9899	41- 14
39	47	1.27	0.9871	47 - 61
40	70	1.3	0.9759	70 - 63
41	62	1.34	0.9795	62- 69
42	69	1.354	0.9889	69 - 7
43	61	1.378	0.9567	61 - 32
44	20	1.39	0.9854	20-47
45	37	1.415	0.9912	37-41
46	31	1.42	0.9877	31 - 2
47	34	1.47	0.9945	34- 9
48	21	1.51	0.9947	21-60
49	42	1.54	0.985	42-43
50	54	1.59	0.9857	54-30
51	48	1.61	0.9982	48- 42
52	25	1.75	0.9865	25 - 54
53	55	1.61	0.9789	55 - 8
54	57	1.88	0.9658	57- 54
55	58	1.93	0.9687	58- 5
56	56	1.98	0.9723	56 - 35
57	50	2.06	0.9834	50 - 39

From the Table, bus 38 has the smallest maximum loadability implying the critical bus and the branch 24 – 57 has the maximum FVSI value close to one indicates the critical line referred to bus 24. Hence, SVC is installed at bus 24, TCSC is installed in the branch 24 to 57. UPFC installed at midpoint of branch 24-57 .

The parameters and variable limits are listed in Table II. All power and voltage quantities are per-unit values and the base power is used to compute the energy cost. Where h is per unit energy cost..

TABLE II: Parameters and Limits

SB (MVA)	H (\$/puWh)	e_i (\$)	c_{ei} (\$/p.u.VAR)	dl	
				Case 1	Case 2
100	6000	1000	3000,000	8760	8760

V_g		V_{load}	
min	max	min	max
0.9	1.1	0.95	1.05

Two cases have been studied. Case 1 is the light load. Case 2 is of heavy loads whose load is 125% as those of Case 1. The duration of the load level is 8760 hours in both the cases.

A. Initial Power Flow Results

The initial generator bus voltages and the loads are given as,

Case 1: $P_{load} = 2.7821$ and $Q_{load} = 1.1890$

Case 2: $P_{load} = 3.49865$ and $Q_{load} = 1.4568$

TABLE III: Optimal Generator Bus Voltages

BUS	Case 1			Case 2		
	SVC	TCSC	UPFC	SVC	TCSC	UPFC
1	1.0529	1.0771	1.0890	1.0495	1.0821	1.0910
2	1.0659	1.0776	1.0899	1.0694	1.0782	1.0977
3	1.0620	1.0824	1.0957	1.0599	1.0688	1.0884
4	1.0694	1.0897	1.0997	1.0676	1.0874	1.0941
5	1.0454	1.0796	1.0874	1.0702	1.0784	1.0821
6	1.0773	1.0824	1.0954	1.0675	1.0699	1.0836
7	1.0628	1.0723	1.0827	1.0648	1.0689	1.0868
8	1.0536	1.0853	1.0939	1.0563	1.0626	1.0920
9	1.0574	1.0601	1.0835	1.0469	1.0614	1.0892
10	1.0556	1.0661	1.0700	1.0626	1.0839	1.0904
11	1.0574	1.0638	1.0720	1.0723	1.0849	1.0933
12	1.0450	1.0853	1.0945	1.0835	1.0982	1.0995
13	1.0537	1.0835	1.0938	1.0784	1.0913	1.0983
14	1.0535	1.0630	1.0832	1.0397	1.0634	1.0937
15	1.0999	1.0999	1.0999	1.0999	1.0999	1.0999

FACTS device settings, optimal generator bus voltages and optimal generation and power losses are obtained as in Table III to V

TABLE IV.FACTS Device Settings

Parameters	FACTS Location	Case 1	Case2
X_{TCSC}	24-57	-0.1672	-0.08006
Q_{SVC}	Bus 44	0.2	0.2
Q_{UPFC}	24-57	0.1974	0.29421
X_{UPFC}	24-57	-0.0432	-0.06732

TABLE V: Optimal Generations and Power losses

		P_g	Q_g	P_{Loss}	Q_{Loss}
Case 1	SVC	3.0017	1.0994	0.1587	0.2954
	TCSC	2.9895	1.3678	0.1614	0.2176
	UPFC	2.9876	1.1644	0.1608	0.2610
Case 2	SVC	3.8965	1.8159	0.2925	0.7629
	TCSC	3.8724	1.8043	0.2802	0.7023
	UPFC	3.8701	1.7975	0.2178	0.6793

The real power savings, annual cost savings and the total costs are calculated as,

$$P_C^{Save\%} = \frac{P_{loss}^{int} - P_{loss}^{opt}}{P_{loss}^{int}} \times 100\% \quad (25)$$

$$W_C^{save} = hd_l (P_{loss}^{int} - P_{loss}^{opt})$$

The table VI gives the performance comparison. From the comparison FVSI Based New Improved Differential Evolution Reactive Power Planning approach gives more saving comparing EP, DE and IAGE approach.

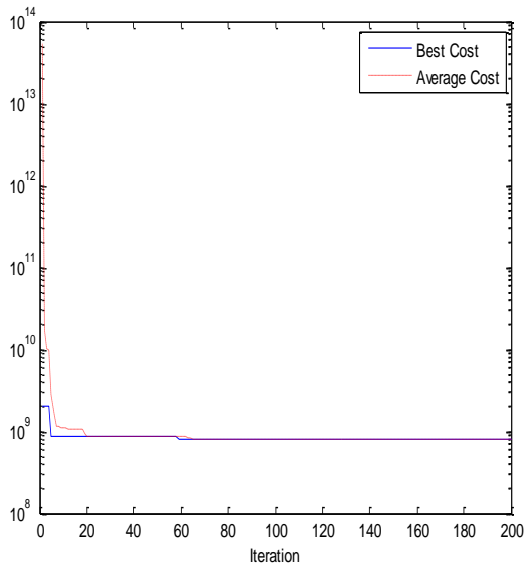


Figure.3. Convergence rate of IDE for 72 bus system. The proposed approach took 180.28 sec to reach the optimal solution as shown in fig.3.

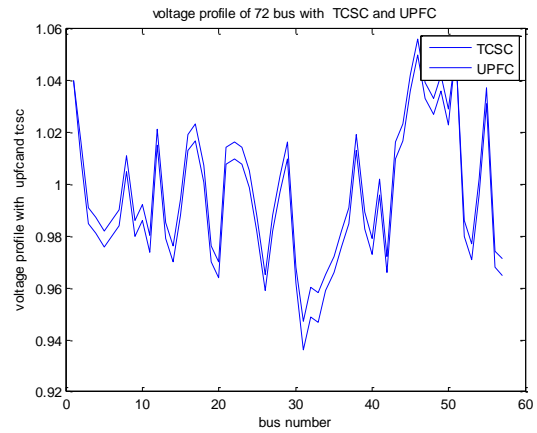


Fig.4. Voltage profile improvement for case 1 using FACTS Devices

From the above Figure 4. and Table .VI, it is clearly seen that the Voltage profile using UPFC is far better in case of Improved Differential Evolution. Figure 4 & 5 . gives the convergence and cost saving using of UPFC for case 2.

TABLE VI: Cost Comparison for Case-2 Study Incorporating UPFC controller

Method	$P_{Csave} \%$	$W_{Csave} (\$)$
Evolutionary Programming (EP)	14.8620	278103.26
Improved Adaptive Genetic Algorithm (IAGE)	15.76894	280274.61
Differential Evolution (DE)	16.6511	2950648.05
Improved Differential Evolution (IDE)	17.8201	3065206.40

CONCLUSION

In this Paper Improved Differential Evolution Algorithm with self tuned constraint has to useful to solve Reactive Power Planning in Indian 72 Bus system. FACTS controllers like SVC, TCSC and UPFC are situated in 72 Indian systems and their presentation are tabulated. New Improved Modified Differential Evolution and Fast Voltage Stability Index techniques played important role to locate the controllers and tune them to plan for reactive power. The individual maximum loadability obtained from the load buses are sorted in ascending order. The highest rank implies the critical bus in the system and the line with FVSI close to one indicates the most critical line corresponds to a bus. These are the possible locations for FACTS controllers to preserve stability of the system. Results show that the losses are reduced when using UPFC than using SVC and TCSC. By the Improved Modified Differential Evolution approach with Fast Voltage

Stability FVSI method, more savings on the energy and installment costs are achieved. Results shows that saving of annual cost is increased using UPFC than SVC and TCSC devices.

REFERENCES

- [1] A. Kishore and E.F. Hill, 1971, "Static optimization of reactive power sources by use of sensitivity parameters," *IEEE Transactions on Power Apparatus and Systems*, PAS-90, pp.1166-1173
- [2] S.S. Sachdeva and R. Billinton, 1973, "Optimum network VAR planning by nonlinear programming," *IEEE Transactions on Power Apparatus and Systems*, PAS-92, 1217 – 1225
- [3] K.Y.Lee, Y.M.Park and J.L.Ortiz, 1985, "A united approach to optimal real and reactive power dispatch," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-104, No.5, pp.1147– 1153
- [4] Kenji Iba, 1994, "Reactive Power Optimization by Genetic Algorithm," *IEEE Transactions on Power Systems*, Vol. 9, No. 2, pp. 685 – 692.
- [5] L.L.Lai and J.T.Ma, 1997, "Application of Evolutionary Programming to Reactive Power Planning Comparison with nonlinear programming approach," *IEEE Transactions on Power Systems*, Vol. 12, No.1, pp. 198 – 206
- [6] Wenjuan Zhang, Fangxing Li, Leon M. Tolbert, 2007, "Review of Reactive Power Planning: Objectives, Constraints, and algorithms," *IEEE Transactions on Power Systems*, Vol. 22, No. 4.
- [7] P.J.Angeline, 1995, "Evolution revolution: an introduction to the special track on genetic and evolutionary programming," *IEEE Expert*, 10, pp. 6 – 10
- [8] Kalyanmoy Deb, 2001, "Multi-Objective Optimization using Evolutionary Algorithms," John Wiley and Sons Ltd.
- [9] M. Noroozian, L. Angquist, M. Ghandhari, G. Anderson, 1997, "Improving Power System Dynamics by Series-connected FACTS Devices," *IEEE Transaction on Power Delivery*, Vol. 12, No.4.
- [10] M. Noroozian, L. Angquist, M. Ghandhari, 1997, "Use of UPFC for Optimal Power Flow Control," *IEEE Trans. on Power Delivery*, Vol.12, No.
- [11] N.G. Hingorani, L. Gyugyi, 2000, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems," *IEEE Press*, New York
- [12] S.N. Sing, A.K. David, 2001, "A New Approach for Placement of FACTS Devices in Open Power Markets", *IEEE Power Engineering Review*, Vol. 21, No.9, 58 - 60.
- [13] D. Thukaram, L. Jenkins, K. Visakha, 2005, "Improvement of system security with Unified Power Flow Controller at suitable locations under network contingencies of interconnected systems," *IEEE Trans. on Generation, Transmission and Distribution*, Vol. 152, Issue 5, pp. 682
- [14] www.siemens/td.com/trans.Sys/pdf/cost/EffectiveRelibTrans.pdf
- [15] M. Moghavemmi and F.M. Omar, 1998, "Technique for contingency monitoring and voltage collapse prediction," *IEE Proc. Generation, Transm and Distribution*, vol. 145, pp. 634-640
- [16] A.C.G. Melo, S. Granville, J.C.O. Mello, A.M. Oliveira, C.R.R. Dornellas, and J.O. Soto, 1999, "Assessment of maximum loadability in a probabilistic framework," *IEEE Power Eng.Soc.Winter Meeting*, vol. 1, pp. 263-268
- [17] I.Musirin, and T.K.A.Rahman, "Estimating Maximum Loadability for Weak Bus using Fast Voltage Stability Index," *IEEE Power Engineering review*, pp.50-52, 2002
- [18] Guang Ya Yang ,Zhao yang Dong, "A Modified Differential Evolution Algorithm with Fitness Sharing for power system planning," *IEEE Transaction on power Engineering* ,Vol.23, pp.514-552, 2012
- [19] Lonescu, C.F. Bulac, C., "Evolutionary Techniques, a sensitivity based approach for handling discrete variables in Reactive Power Planning," *IEEE Transaction on Power Engineering*, pp.476-480, 2012
- [20] Vaahedi, Y. Mansour, C. Fuches, "Dynamic security Constrained optimal power flow/Var Planning," *IEEE Transaction in power systems*, Vol.16. pp.38-43, 2001
- [21] J.Preetha, "Improved Differential Evolution approach for Multi Objective Reactive Power planning Incorporating voltage stability", *Journal of Electrical Engineering*,
- [22] Selvarasu, " Optimal Placement of TCSC for voltage constrained loss minimization using self-adaptive firefly algorithm", *Journal of Electrical Engineering*