International Journal on Electrical Engineering and Informatics - Volume 7, Number 4, December 2015

Multi Objective Optimization based optimal Reactive Power Planning Using Improved Differential Evolution Incorporating FACTS

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Abstract: Optimal reactive power planning is one of the major and important problems in electrical power systems operation and control. This is nothing but multi-objective, nonlinear, minimization problem of power system optimization. This paper presents the relevance of New Improved Differential Evolution (NIDE) algorithm to solve the Reactive Power Planning (RPP) problem based on Multi-objective optimization. Minimization of total cost of energy loss and cost of FACT controlers installments are taken as the objectives incorporating (RPP) problem. With help of New Voltage Stability Index (NVSI), 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 FACT controllers SVC, TCSC, and UPFC are considered for reactive power planning. The approach applied to IEEE 30 and 72-bus Indian system for minimization of active power loss. Simulation results are compared with other optimization algorithm.

Keywords: Reactive Power Planning, FACTS, Differential Evolution, New Improved Differential Evolution, Multi-objective optimization.

1. Introduction

One of the most challenging 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 improves the voltage profile. The second objective minimizes the allocation cost of additional reactive power sources. Reactive power planning is a nonlinear 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

Received: July 11st, 2014. Accepted: November 16th, 2015
DOI: 10.15676/ijeei.2015.7.4.7

[18,19].Despite of several positive features, it has been observed that DE sometimes 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 decorates with increase in dimensionality of the objective functions. 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 load ability is calculated using New Voltage Stability Index (NVSI). This method does not consider the resistance [21] of the transmission line. 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 load ability. The smallest maximum load ability 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 a 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.

2. Nomenclature

List of Symbols

N_I =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

3. 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.

$$W_C = h\sum d_1 p_{loss,1} \tag{1}$$

where, (P_{loss})$_,$ denotes the network real power loss during the period of load level l. It can be expressed in the following equation in the duration d_l:

$$P_{loss} = \sum gk\left(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}\right) \tag{2}$$

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

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

Here, Q_{Ci} can be either positive or negative, capacitance or reactance installation .So the absolute values are used to compute the cost. The third term represents the cost of FACTS Controllers. Using Siemens AG Data base [14], cost function for SVC and TCSC are developed as follows:

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

The objective function is expressed as

$$\text{Min } F_C = W_C + C_{facts} \tag{5}$$

The functions should satisfy the real and reactive power constraints (equality constraints)
Load Flow Constraints:

$$0 = Q_i - V_i\sum V_j\left(G_{ij}\sin\theta_{ij} + B_{ij}\cos\theta_{ij}\right)\ i \in N_{B-l} \quad j \in N_l \tag{6}$$

$$0 = Q_i - V_i\sum V_j\left(G_{ij}\sin\theta_{ij} + B_{ij}\cos\theta_{ij}\right)\ i \in N_{PQ} \quad j \in N_l \tag{7}$$

And also satisfy the inequality constraints like reactive power generation, bus voltage and FACTS controller installment as follows:
Generator Reactive Power Capability Limit

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \tag{8}$$

Voltage Constraints:

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{9}$$

FACTS Reactive Power Limit:

$$-100 \le Q_{facts} \le 100 \tag{10}$$

FACTS Reactance Limit:

$$-0.8X_{Line} \le 0.2 \le X_{facts} \tag{11}$$

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

$$\text{Min } F_C = F_C + \sum \alpha \left(V_i - V_i^{\lim}\right)^2 + \sum \beta \left(Q_{gi} - Q_{gi}^{\lim}\right)^2 \qquad (12)$$

$i \in N_{Og\lim}$ $i \in N_{V\lim}$

Subjected to

$$0 = \mathrm{P_i} - V_i \sum V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}\right) \; i \in N_{B-l}$$

$j \in N_l$

$$0 = \mathrm{Q_i} - V_i \sum V_j \left(G_{ij} \sin\theta_{ij} + B_{ij} \cos\theta_{ij}\right) \; i \in N_{PQ}$$

$j \in N_l$

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:

$$V_i^{\lim} = \begin{cases} V_i^{\min} & if \;\; V_i \prec V_i^{\min} \\ V_i^{\max} & if \;\; V_i \succ V_i^{max} \end{cases} \qquad (13)$$

$$Q_{gi}^{\lim} = \begin{cases} Q_{gi}^{\min} & if \;\; Q_{gi}^{\min} \prec Q_{gi}^{\min} \\ Q_{gi}^{\max} & if \;\; Q_{gi}^{\max} \succ Q_{gi}^{\max} \end{cases}$$

4. NVSI Formulation

The NVSI is derived from the voltage quadratic equation at the receiving bus on a two-bus system [12],[13],[15],[17]. The general 2-bus representation is illustrated in Figure 1.

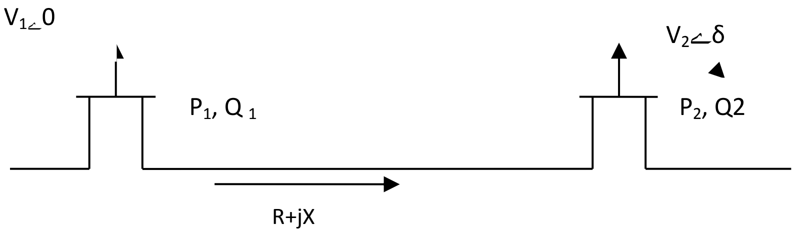

Figure 1. Model of two bus system

From figure 1. Current flowing between bus 1 and 2 is

$$I = \frac{\mathrm{V_2} < 0 - V_2 < \delta}{R + jX} \qquad (14)$$

$$I^* = \frac{\mathrm{V}_1^* - V_2^*}{R - jX} \qquad (15)$$

Comparatively resistance of transmission line is negligible. This equation may be rewritten as

$$I^* = \frac{V_1^* - V_2^*}{jX} \tag{16}$$

And the receiving end power

$$S = V_2 I^* \tag{17}$$

Incorporating in equation (17) in and solving

$$P_2 = \frac{V_1 V_2}{X} \sin\delta \tag{18}$$

$$Q_2 = \frac{V_2^2}{X} + \frac{V_1 V_2}{X} \sin\delta \tag{19}$$

Eliminating $\boldsymbol{\delta}$ from equations yields

$$(V_2^2)^2 + (2Q_2 X - V_1^2)V_2^2 + X^2(P_2^2 + Q_2^2) = 0 \tag{20}$$

This is an equation of order of two V_2.This condition have at least one solution is

$$(2Q_2 X - V_1^2) - 4X^2(P_2^2 + Q_2^2) \geq 0 \tag{21}$$

$$\frac{2X\sqrt{(P_2^2 + Q_2^2)}}{2Q_2 X - V_1^2} \leq 1 \tag{22}$$

Taking suffix “i” as the sending bus and “j” as the receiving bus, NVSI can be defined by

$$NVSI_{ij} \frac{2X\sqrt{(P_j^2 + Q_j^2)}}{2Q_j X - V_i^2} \tag{23}$$

Variable definition follows
Z = Line Impedance
X = Line Reactance
Q_j = Reactive power at the receiving end
V_i = sending end voltage
θ = line impedance angle
$\boldsymbol{\delta}$ = angle difference between the supply voltage and receiving voltage
P_i = sending end real power

A. Determining the maximum load-ability for Weak Bus Identification

The following steps are implemented:

Step 1: Run the load flow program for the base case.
Step 2: Evaluate the NVSI value for every line in the system.
Step 3: Gradually increase the reactive power loading by 0.01pu at a chosen load bus until the load flow solution fails to give results for the maximum computable NVSI.
Step 4: Extract the stability index that has the highest value.
Step 5: Choose another load bus and repeat steps 3 and 4.
Step 6: Extract the maximum reactive power loading for the maximum computable NVSI for every load bus. The maximum reactive power loading is referred to as the maximum load-ability of a particular bus.

Step 7: Sort the maximum load-ability obtained from step 6 in ascending order. The smallest maximum load-ability is ranked the highest, implying the weakest bus in the system.

Step 8: Select the weak buses as the FACT controller's installation site for the RPP Problem.

5. IEEE 30 Bus system

Simulation results have been obtained by using MATLAB 7.5 (R2007b) software package on a 2.93 GHz, Intel® Core™2 Duo Processor. IEEE 30-bus system [3] has been used to show the effectiveness of the algorithm. The network consists of 6 generator-buses, 21 load-buses and 41 branches, of which four branches, (6- 9), (6- 10), (4- 12) and (27-28) are under load-tap setting transformer branches. The buses for possible VAR source installation based on max load buses are 25, 26, 29 and 30. The maximum load ability and FVSI values for the IEEE 30 bus system are given in table 1.

Table 1. Bus Ranking and NVSI Values

Rank	Bus	Qmax(p.u)	NVSI
1	30	0.27	1.032
2	26	0.32	1.180
3	29	0.35	1.049
4	25	0.50	1.010
5	15	0.54	1.001
6	27	0.60	1.003
7	10	0.65	1.017
8	24	0.69	1.007
9	14	0.78	1.011
10	18	0.79	1.015

The parameters and variable limits are listed in Tables 2 and 3. All power and voltage quantities are per-unit values and the base power is used to compute the energy cost.

Table 2. Parameters

S_B (MVA)	h (\$/puWh)	e_i(\$)	C_{ci} (\$/puVAR)
100	6000	1000	30,00,000

Table 3. Limits

Q_c		V_g		V load		T_g	
min	max	min	max	min	max	min	max
- 0.12	0.35	0.9	1.1	0.96	1.05	0.96	1.05

Three cases have been studied. Case 1 is of light loads whose loads are the same as those in [3]. Case 2 and 3 are of heavy loads whose loads are 1.25% and 1.5% as those of Case 1. The duration of the load level is 8760 hours in both cases [6].

Initial Power Flow Results

The initial generator bus voltages and transformer taps are set to 1.0 pu. The loads are given as,

Case 1: $P_{load} = 2.834$ and $Q_{load} = 1.262$
Case 2: $P_{loa\,d} = 3.5425$ and $Q_{load} = 1.5775$
Case 3: $P_{load} = 4.251$ and $Q_{load} = 1.893$

Table 4. Initial generations and power losses

	P_g	Q_g	Ploss	Qloss
Case 1	3.008	1.354	0.176	0.323
Case 2	3.840	2.192	0.314	0.854
Case 3	4.721	3.153	0.461	1.498

Table 5.Optimal generator bus voltages.

Bus	1	2	5	8	11	13
Case 1	1.10	1.09	1.05	1.09	1.10	1.10
Case 2	1.10	1.10	1.09	1.10	1.10	1.10
Case 3	1.10	1.10	1.08	1.09	1.09	1.09

Table 6.Optimal transformer tap settings.

Branch	(6-9)	(6-10)	(4-12)	(27=28)
Case 1	1.0433	0.9540	1.0118	0.9627
Case 2	1.0133	0.9460	0.9872	0.9862
Case 3	1.0131	0.9534	0.9737	0.9712

Table 7. Optimalvar source installments.

Bus	26	28	29	30
Case 1	0	0	0	0
Case 2	0.0527	0.030	0.022	0.031
Case 3	0.0876	0.029	0.027	0.047

Table 8.Optimal generations and power losses Using NIDE

	Pg	Qg	Ploss	Qloss
Case 1	2.989	1.288	0.159	0.266
Case 2	3.808	1.867	0.266	0.652
Case 3	4.659	2.657	0.417	1.190

The optimal generator bus voltages, transformer tap settings, VAR source installments, generations and power losses are obtained as in Tables V - VIII.Form Table VIII,the active power losse is considerably reduced for case 1 from 0.176 to 0.159 using NIDE.

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

$$P_C^{Save}\% = \frac{P_{loss}^{int} - P_{loss}^{opt}}{P_{loss}^{int}} \text{ x } 100\ \% \tag{24}$$

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

Table 9. Comparison Results

Variables	Case-1		Case-3	
	EP	NIDE	EP	NIDE
V1	1.05	1.05	1.05	1.05
V2	1.044	1.044	1.022	1.022
$T_{6\text{-}9}$	1.05	1.0433	0.9	1.013
$T_{4\text{-}12}$	0.975	1.031	0.95	0.973
$Q_{C\ 17}$	0	0	0.0229	0.297
$Q_{C\ 27}$	0	0	0.196	0.297
P_G	2.866	2.989	5.901	4.659
Q_G	0.926	1.288	2.204	2.657
P_{loss}	0.052	0.159	0.233	0.417
Q_{loss}	0.036	0.266	0.436	1.190

As shown in Table Similar results were obtained both approaches for the Case-1 and Case-2 NI DE adjusted the voltage magnitude of all PV buses and transformer tap settings such that total losses decreased.

6. Modeling 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 .

A. 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 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

$$X_{ij} = X_{line} + X_{r\,\mathrm{csc}} \tag{25}$$

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 $0.2\ X_{line}$.

B. SVC

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

$$\Delta Q_i = Q_{SVC} \tag{26}$$

C. UPFC

The decoupled model of UPFC is used to provide independent shunt and series reactive compensation. The shunt converter operates as a standalone STATIC synchronous Compensator (STATCOM) and the series converter as a standalone Static Synchronous Series Compensator (SSSC). This feature is included in the UPFC structure to handle contingencies (e.g., one converter failure). In the stand alone mode, both the converters are capable of absorbing or generating real power and the reactive power output can be set to an arbitrary value depending on the rating of UPFC to maintain bus voltage.

7. New Improved Differential Evolution (NIDE)

Differential Evolution was first proposed over 1994-1996 by Storn and Price at Berkeley.DE is a mathematical global optimization method for solving multi-dimensional functions. The main idea of DE is to generate trial parameter vectors using vector differences for perturbing the vector population.

In order to improve the performance of differential evolution, the proposed novel algorithm which will generate a dynamical function for changing the differential evolution parameter mutation factor replace traditional differential algorithm use constant mutation factor.

A. Main Steps of the NIDE Algorithm

The working procedure algorithm is outlined below:

- Initialize the population set uniformly
- Sort the population set S in ascending order
- Partition S into *p* sub populations $S^1, S^2, \ldots.., S^P$ each containing m points, such that

  $$S^k = \left\{ X_J{}^k, f_j^k : X_J{}^k = X_{k+p(j-1)} \quad j = 1, \ldots\ldots, m \right\}$$

  $$K = 1, \ldots\ldots\ldots\ldots, p$$
- Apply improved DE algorithm to each sub population S^k to maximum number of generation G_{max}
- Replace the sub populations $S^1, S^2, \ldots S^p$ and check whether the termination
- criterion met if yes then stop otherwise go to step 2

Using, Selection, Cross over Factor, Mutation Factor and Recombination are Calculated.

B. New Improved Differential evolution for OPF using TCSC

Step 1: Parent vectors of size NP are randomly generated. Elements in a parent vector are real power generation of the generating units excluding slack bus, voltage magnitude and

$$P_i = \left[P_{G1}^i \ldots\ldots P_{Gm}^i \ldots. P_{Gn}^i, V_1^i \ldots V_n^i \ldots \delta_1^i \ldots\ldots \delta_m^i \ldots X_{TCSC1}^i \ldots\ldots X_{TCSCn}^i\right]^T$$

The reactive power generations, transmission loss, slack bus generations and line flows are calculated. Cost of generation is calculated for each parent vector pi.

Step 2: Perform mutation for each target vector as described in Section 4.2

Step 3: Perform crossover for each target vector and create a trial vector as mentioned in Section 4.3.

Step 4: Perform selection for each target vector, by comparing its cost with that of the trial vector. The vector that has lesser cost of the two would survive for the next generation.

Step 5: Stop if the maximum number of generations is reached otherwise go to Step 2

8. Case Study

Table 10. Comparison Results

Variables	Case-1		Case-3	
	IDE	EP	IDE	EP
V1	1.05	1.05	1.05	1.05
V2	1.044	1.044	1.022	1.022
T_{6-9}	1.05	1.0433	0.9	1.013
T_{4-12}	0.975	1.031	0.95	0.973
$Q_{C\,17}$	0	0	0.0229	0.297
$Q_{C\,27}$	0	0	0.196	0.297
P_G	2.866	2.989	5.901	4.659
Q_G	0.926	1.288	2.204	2.657
P_{loss}	0.052	0.159	0.233	0.417
Q_{loss}	0.036	0.266	0.436	1.190

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. FACTS locations are identified based on the FVSI technique. The greatest load ability and FVSI values for the real time system are given in Table 10.

Table 11. Bus Ranking and FVSI Values

Rank	Bus	Q_{max}(p.u)	NVSI
1	25	0.23	0.9837
2	27	0.27	0.9841
3	56	0.28	0.9964
4	52	0.35	0.9925
5	45	0.43	0.9843
6	59	0.45	0.9932
7	37	0.47	0.9972
8	46	0.48	0.9887
9	68	0.56	0.9863
10	64	0.57	0.9897
11	30	0.59	0.9852
12	29	0.63	0.9922
13	36	0.658	0.9787
14	49	0.67	0.9858
15	55	0.71	0.9871
16	19	0.712	0.9936
17	17	0.732	0.997
18	53	0.74	0.9856
19	16	0.77	0.9879
20	61	0.81	0.9989
21	18	0.85	0.9947
22	57	0.856	0.9937
23	26	0.87	0.9859
24	23	0.881	0.9986
25	33	0.893	0.9783
26	48	0.9	0.9949
27	34	0.911	0.9929
28	59	0.925	0.9893
29	51	0.96	0.9801
30	40	0.962	0.9857
31	42	0.982	0.9862
32	**38**	0.988	**0.9999**
33	22	0.99	0.9931
34	43	1.01	0.9976
35	19	1.1	0.9798
36	32	1.13	0.998
37	18	1.19	0.9879
38	41	1.22	0.9899
39	52	1.27	0.9871
40	45	1.3	0.9759
41	54	1.34	0.9795
42	28	1.354	0.9889
43	26	1.378	0.9567
44	60	1.39	0.9854
45	21	1.415	0.9912
46	59	1.42	0.9877
47	44	1.47	0.9945
48	47	1.51	0.9947
49	50	1.54	0.9858
50	20	1.59	0.9857
51	31	1.61	0.9982
52	36	1.75	0.9865
53	32	1.61	0.9789
54	39	1.88	0.9658
55	69	1.93	0.9687
56	66	1.98	0.9723
57	46	2.03	0.9834

The proposed method compares the effectiveness of Evolutionary Programming (EP), and Improved Differential Evolution (IDE) to solve reactive power planning problem incorporating FACTS controllers Like TCSC, SVC and UPFC considering voltage stability, with help of Fast Voltage Stability Index (FVSI).The critical lines and buses are identified to install the FACT controllers.

As shown in Table 11 in both approaches for the case 1 and case 3 using IDE adjusted the voltage magnitude of all PV buses and transformer tap settings such that total real and reactive power losses decreased as comparing with EP.

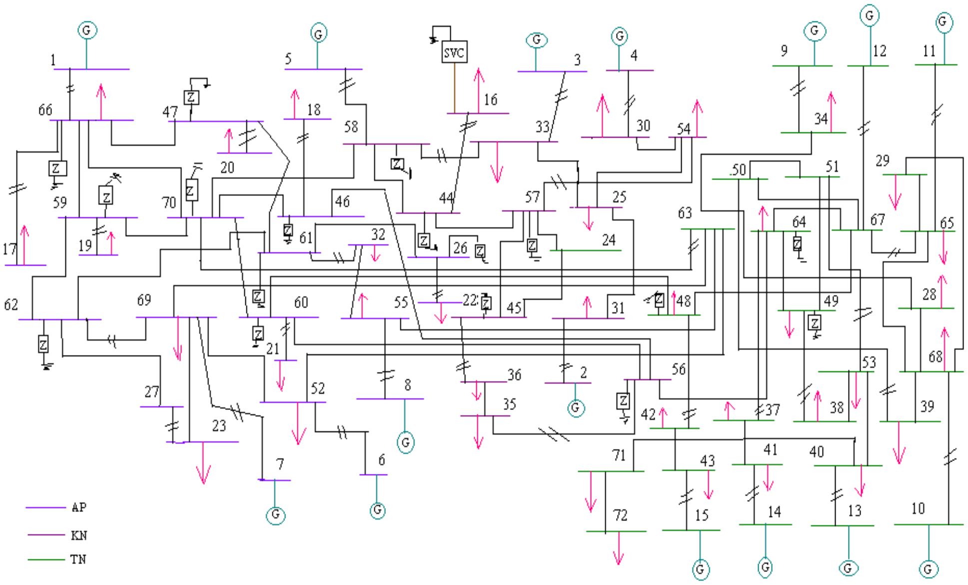

Figure 2. Indian network.

From Table 11, bus 25 has the smallest maximum load-ability implying the critical bus and branch 26-28 has the maximum FVSI close to one indicates the critical line referred to bus 38. Hence, SVC is installed at bus 25, TCSC is installed in the branch 26-38. UPFC is installed at midpoint of branch 26-38.Two cases have been studied. Case 1.is the light load, case 2 is heavy loads and whose load is 125%.

Table 13. Optimal Generator Bus Voltages

BUS	Case 1			Case 2		
	SVC	TCSC	UPFC	SVC	TCSC	UPFC
1	1.0999	1.0999	1.0999	1.0999	1.0999	1.0999
12	1.0859	1.0876	1.0821	1.0994	1.0982	1.0977
15	1.0951	1.0924	1.0857	1.0999	1.0988	1.0884
24	1.0994	1.0897	1.0791	1.0996	1.0874	1.0741
35	1.0854	1.0796	1.0774	1.0802	1.0784	1.0721

FACTS device settings, optimal generator bus voltages and optimal generation and power losses are obtained as in Table 13 to 15.

Table 14. FACTS Device Settings

Parameters	**FACTS Location**	**Case 1**	**Case2**
X_{TCSC}	26-28	-0.1672	-0.08006
Q_{svc}	Bus 30	0.2	0.2
Q_{UPFC}	26-28	0.1974	0.29421
Q_{UPFC}	26-28	-0.0432	-0.06732

Table 15. Optimal Generations and Power losses

		$P_{g(MW)}$	**$Q_{g(MVAR)}$**	**$P_{loss(MW)}$**	**Qloss(MVAR)**
Case 1	SVC	30.017	10.994	0.1655	0.3054
	TCSC	29.895	13.678	0.1642	0.2849
	UPFC	29.876	11.644	0.1639	0.2651
Case 2	SVC	38.965	18.159	0.2976	0.7781
	TCSC	38.724	18.043	0.2835	0.7054
	UPFC	38.701	17.975	0.2687	0.6827

Table 16. Performance Comparison

Loading	FACT Devices	USING EP		USING IDE	
		P_{Csave} %	$W_{C\ Save}$ (\$)	P_{Csave} %	$W_{C\ Save}$ (\$)
Case-1	SVC	8.832	8.42×10^6	9.182	8.67×10^6
	TCSC	9.507	9.07×10^6	9.807	9.19×10^6
	UPFC	9.669	9.22×10^6	9.988	9.30×10^6
Case-2	SVC	9.040	1.55×10^7	10.04	1.64×10^7
	TCSC	13.341	2.29×10^7	14.46	2.37×10^7
	UPFC	17.851	3.06×10^7	16.65	3.15×10^7

From table 14 the UPFC gives more savings on the real power and annual cost compared to SVC and TCSC for both cases.

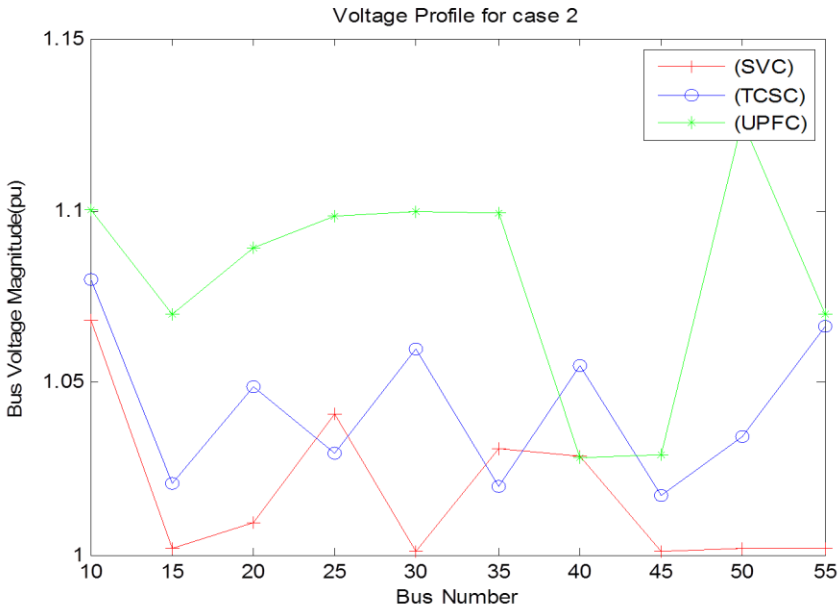

Figure 3. Voltage profile improvement for case 2 using FACT Devices.

Figure 3, illustrated the response for Bus number Vs Bus voltage magnitude. From plot, using IDE approach for case 2 with FVSI, UPFC controller gives the better voltage magnitude.

9. Conclusion

In this Paper, New Improved Differential Evolution Algorithm is implemented for optimal reactive power planning problem. The ability of this algorithm has been assessed by testing on IEEE-30 Bus, Indian utility 72 Bus systems. The obtained results are compared with other method reported in given references. It is concluded that, the obtained results in this paper are better than the obtained in other reported papers.

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