OPTIMAL PLACEMENT OF UNIFIED POWER FLOW CONTROLLER (UPFC) TO IMPROVE VOLTAGE STABILITY

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Abstract : Voltage stability is one of the challenging and burning issues of modern large power system. In this paper, an algorithm has been developed to determine the optimal location of UPFC which supplies VARs subject to operational inequality constraints based on sensitivity of minimum eigen value and real & reactive loss index for the enhancement of voltage stability. The load flow solution is carried out with continuation power flow method using MATLAB software. Sensitivity of minimum eigen value is the change in minimum eigen value of load flow Jacobian to the change in reactive power which is to be injected and change in losses with respect to change in system load. Ranking of load buses has been evaluated based on sensitivity of these indexes using power flow technique. Highest sensitivity of transmission line and buses which are connected across, indicates weakest line and the order of other lines so on. Order of sensitivity of line for the placement of UPFCs is again obtained and verified using developed Genetic Algorithm based algorithm. First two to three lines are selected which have higher order sensitivity for injection of VARs through UPFC. Developed algorithm has been implemented on IEEE 30-bus system.

Keywords : Unified Power Flow Controller; Voltage Stability; Continuation power flow: minimum eigen value sensitivity index; Real & reactive Power Index.

I. INTRODUCTION

Electric power systems are the largest, most expensive and stressed man-made systems in the world. At any instant of time, a power system operating condition should be stable, meeting various operational constraints, and it should also be secure in the event of any stressed conditions [1]. In every year, the demand of electrical energy becomes increased, due to fast growing societies. Generally, the new power generating stations are located far away from the high power consumption areas [2]. In order to obtain the continually increasing power demand, power transfer capabilities must be increased by using interconnected transmission systems via long transmission lines or grid topology [3 and 4]. In the present time, power system are being operated closer to their stability limits due to economic and environmental constraints [5]. The existing transmission line is not capable of supporting this huge power demand [6 and 7]. Voltage stability is the major problem for this. Voltage stability or voltage collapse deals with the ability of a power system to maintain acceptable voltage levels at all buses in the system in any condition whether it is normal or during disturbance [8] . A heavily loaded system enters a state of voltage instability due to a sudden large disturbance or a change in system condition [9]. It causes a progressive and uncontrollable decline in voltage. The main factor causing voltage instability in any power system is the inability of the system to meet its sudden growing demand for reactive power [10]. There are two different approaches (i.e. static and dynamic) available, as a tool to analyze the voltage collapse problem in a system. The static approach is based on power flow analysis and dynamic analysis is based on time domain simulation. Power system operation mainly depends on the interaction of three things - power sources, loads and network [11]. During a load pickup, there are some events, which can induce voltage collapse via loss of generating unit, a transmission line or a transformer [12]. There are different evaluation techniques are available to analyze the voltage stability, such as likes, P-V curve method, Q-V curve method, Modal analysis method, and Index method etc. In this paper, "weakest bus identify by the minimization sensitivity of minimum eigen value method" and also verified by the voltage difference between base value & it's value corresponding to maximum reactive power loading. Obtained values have been optimized using optimization technique namely GA then verify the results by executing continuation power flow method for desired voltage stability margin to secure state of the system [13]. Section-II describes concept of Genetic Algorithm. Section-III presents formulation of objective function for the ranking of transmission lines based on voltage stability index, sensitivity of minimum eigen value and mitigation of real & reactive power losses subject to inequality constraints. Section-IV presents developed algorithm for the solution of problem. Section-V presents results and discussion. Section-VI describes conclusion of the paper.

II. CONCEPT OF GENETIC ALGORITHM

Genetic Algorithm (GA) is a search-based optimization technique based on the principle of Genetics & Natural Selection [13]. In GAs, we have a pool or a population of possible solutions to the given problem. These solutions then undergo recombination and mutation (like in natural genetics), producing new children, and the process is repeated over various generations. Each individual (or candidate solution) is assigned a fitness value (based on its objective function value) and fitter individuals are given a higher chance to mate and yield more "fitter" individuals. This is in line with the Darwinian Theory of **''Survival of the Fittest''**.

In this way we keep "evolving" better individuals or solutions over generations, till we reach a stopping criterion. Genetic Algorithms are sufficiently randomized in nature, but they perform much better than random local search. The algorithm of GA is as follows:

(i) [Start]: Generate random population of n chromosomes (i.e. suitable solutions for the problem).

(ii) [Fitness]: Evaluate the fitness f(x) of each chromosome x in the population.

(iii) [New Population]: Create a new population by repeating following steps until the new population is complete.

- **[Selection]:** Select two parent chromosomes from a population according to their fitness (better the fitness, bigger the chance to be selected).
- **[Crossover]:** With a crossover probability, crossover the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.
- **[Mutation]:** With a mutation probability, mutate new offspring at each locus (position in chromosome).
- **[Accepting]:** Place new offspring (children) in the new population.

(iv) [Replace]: Use new generated population for a further run of the algorithm.
(v) [Test]: If the end condition is satisfied, stop, and return the best solution in current population.
(vi) [Loop]: Go to step (ii).

III. PROBLEM FORMULATION

A multi-objective optimization problem consists of multiple objective functions subject to inequality constraints are to be optimized [14]. The inequality constraints represent the operating limits of the system and Vars which is to be injected through UPFC in the system [15]. Here, a problem to rank the transmission line based on minimization of Voltage Stability Index, minimization of real & reactive power loss and sensitivity of minimum eigen value of load flow Jacobian [16].

A. Voltage Stability Index (F_1)

For maintaining the voltage stability is the major problem in a power system. Voltage stability is evaluated at each bus of the system by an indicator, L-index. At load bus j, L- index can be written as-

$$L_j = |L_j| = \left|1 - \frac{\sum_{i\varepsilon\alpha_G} C_{ij} V_i}{V_j}\right| \; j\varepsilon\alpha_L \quad (1)$$

where,

α_L = set of load buses
α_G = set of generator buses
V_i = complex voltage at generator bus i
V_j = complex voltage at load bus j
C_{ij} = elements of matrix C which can be calculated by equation (2)

$$[C] = -[Y_{LL}]^{-1}\,[Y_{LG}] \quad (2)$$

Sub matrices of Y bus matrix are $[Y_{LL}]$ and Y_{LG} and it can be calculated using equation (3).

$$\begin{bmatrix} Y_L \\ Y_G \end{bmatrix} = \begin{bmatrix} Y_{LL} & Y_{LG} \\ Y_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} V_L \\ V_G \end{bmatrix} \quad (3)$$

The minimization of voltage stability index is the 1^{st} objective function consideration.
Where, F_1 = Voltage Stability Index = $L_{max.}$

B. Power Loss (F_2) in MW

The 2^{nd} objective function considering the minimization of real power loss can be expressed as-

$$F_2 = P_{loss} = \sum_{i=1}^{N_L} g_{i,j}\,[V_i^2 + V_j^2 - 2\,V_i\,V_j\cos(\delta_i - \delta_j)] \quad (4)$$

where,

V_i = voltage magnitude at bus i
V_j = voltage magnitude at bus j
$g_{i,j}$ = conductance of line i,j
N_L = total number of transmission lines

C. Sensitivities of minimum eigenvalue with respect to System load

Sensitivity of minimum eigenvalue λ_{min} of load flow Jacobian with respect to an element a_{ij} can be written as follows:

$$\frac{\partial\lambda_{min}}{\partial a_{ij}} = \eta_{min\,i}\,\xi_{min\,j} \quad (5)$$

where,

$[a_{ij}]$- is the element of [J']
λ_{min} – is the minimum eigenvalue of [J'],
η_{min}^T, ξ_{min} – are right and left eigenvectors corresponding to λ_{min},
$\eta_{min\,i}$, $\xi_{min\,j}$ – are respective elements of η_{min}^T and ξ_{min}.

Rescheduling variables are recative control variable i.e. $Q_1, Q_2, \ldots\ldots, Q_n, \ldots\ldots, Q_{NL,}$ (n≠ slack bus).
Each element of Jacobian can be assumed a function of these reactive power control variables are as follows:

$$F_3 = \partial\lambda_{min}/\partial Q_n = \sum \eta_{min\,i}\,\xi_{min\,j}\,\partial a_{ij}/\partial Q_n \quad (6)$$

Equation (6) is requires:

Minimum eigenvalue of load flow jacobian,

Left and right eigenvectors corresponding to minimum eigenvalue,

Sensitivity elements of Jacobian with respect to MVARs-injection $\partial a_{ij}/\partial Q_n$.

The partial derivatives $\partial a_{ij}/\partial Q_n$ can be evaluated using equation (6) -

$$\left.\begin{aligned}
&\partial H_i/\partial Q_n = V_iV_jY_{ij}\cos(\delta_i-\delta_j-\theta_{ij})(S_{1\,in}-S_{1\,jn}) + sin(\delta_i-\delta_j-\theta_{ij})Y_{ij}(V_jS_{3\,in}+V_iS_{3\,jn})\\
&\partial H_{ij}/\partial Q_n = -2\,V_i\,B_{ii}\,S_{3\,in}\\
&\partial N_{ij}/\partial Q_n = S_{3\,in}Y_{ij}\cos(\delta_i-\delta_j-\theta_{ij}) - V_iY_{ij}\,sin(\delta_i-\delta_j-\theta_{ij})(S_{1\,in}-S_{1\,jn})\\
&\partial N_{ii}/\partial Q_n = [G_{ii}-(Q_i/V_i^2)\ \ S_{3\,in}\\
&\partial M_{ij}/\partial Q_n = V_iV_jY_{ij}\ sin(\delta_i-\delta_j-\theta_{ij})(S_{1\,in}-S_{1\,jn}) - Y_{ij}\cos(\delta_i-\delta_j-\theta_{ij})(V_iS_{3\,jn}+V_j\,S_{3\,in})\\
&\partial M_{ii}/\partial Q_n = -2\,G_{ii}\,S_{3\,in}\\
&\partial L_{ij}/\partial Q_n = Y_{ij}\,sin(\delta_i-\delta_j-\theta_{ij})\,S_{3\,in} + V_iY_{ij}\cos(\delta_i-\delta_j-\theta_{ij})(S_{1\,in}-S_{1\,jn})\\
&\partial L_{ii}/\partial Q_n = -[Q_{g\,i}/V_i^2 + B_{ii}]\,S_{3\,in}
\end{aligned}\right\}\quad (7)$$

Sensitivity expression $\partial\lambda_k/\partial Q_n$ is written as follows:

$$SQ_n = \partial\lambda_{\min}/\partial Q_n = \sum_{ij}\left(\frac{\partial\lambda_{\min}}{\partial H_{ij}}\right)\left(\frac{\partial H_{ij}}{\partial Q_n}\right) + \sum_{ij}(\partial\lambda_{\min}/\,\partial N_{ij})(\partial N_{ij}\big/\partial Q_n) + \sum_{ij}\frac{\partial\lambda_{\min}}{\partial M_{ij}}(\partial M_{ij}/\partial Q_n)$$
$$+\sum_{ij}(\partial\lambda_{\min}/\,\partial L_{ij})\ (\partial L_{ij}/\partial Q_n) \qquad (8)$$

In fact SQ_n , for n = 1,2,3,.....................,NG

(n ≠ slack bus) is obtained by substituting eq. (7) and (5) in eq. (8).

D. Fitness Function

Considering all the three objective functions from equation (1,4 and 6), the fitness function (FF) is expressed in equation (9). Fitness function,

$$F = h_1F_1 + h_2F_2 + h_3F_3 \qquad (9)$$

Where $h_1, h_2,$ *and* h_3 are weighting factor of minimization of VSI objective function, weighting factor of power loss minimization objective function, weighting factor of maximization of sensitivity of change in minimum eigen value of load flow Jacobian w.r.t. change in reactive power control variable i.e. injected vars via UPFC as objective function.

$$h_1 + h_2 + h_3 = 1 \qquad (10)$$

Inequality Constraints

The objective function (ranking of transmission line to identify the location of UPFC) evaluated subject to inequality constraints of the system to be satisfied under current operating condition as well as at next predicted load condition after the reactive power rescheduling are given as [17] :

(i) Power Flow Constraints:

$$\underline{P} = \underline{f}\,(\underline{V}, \delta)$$
$$\underline{Q} = \underline{g}\,(\underline{V}, \delta) \qquad (11)$$

(ii) Reactive Power Generation Constraint:

$$Q_{g\,k} \le Q^0_{g\,k} \le Q^-_{g\,k} \qquad k = 1,2,3,\ldots\ldots\ldots\ldots NG \qquad (12)$$

(iii) Transmission Line constraints: If the current or power flows more than the rated current/power, then the transmission line will get damaged [18]. So the line flow must be limited to its rated value.

$$S_{Li} \le S_{Li}^{max} \qquad \text{where i = 1,2,3,.................}N_{TL} \qquad (13)$$

(iv) Inequality constraint on minimum eigenvalue of load flow Jacobian:

$$\lambda_{\min}{}^0 \ge \lambda_{\min}{}^{th} \qquad (14)$$

(v) Transformer Tap constraints:- To maintain the voltage level, transformers are used. Hence transformer tap settings are required.

$$T_i^{min} \le T_i \le T_i^{max} \qquad \text{where i = 1,2,3,...................}N_T \qquad (15)$$

(vi) Inequality constraint on load bus voltages:

$\underline{V}_i \le V_i^0 \le \overline{V}_i$ i = NG + 1,.............................NB (16)

The maximum reactive power of the UPFC is limited by the network power transfer [19]. It is stressed that reactive power rescheduling is performed at current loading condition. Further, constraints as in equation no. (11) - (16) are ascertained by performing load flow solution at current operating condition (after reactive power rescheduling) and predicted loading condition (accounting reactive power rescheduling) [20].

III. PROBLEM SOLUTION

The objective of this paper is to determine the optimum loacation for the placement of UPFC device which is used to supply required Vars into the system for the improvement in voltage stability and also simultaneously minimize the losses subjected to current operating consaints. GA based algorithm has been developed to determine the optimal location for the placmen of UPFC is as follows:

Step-1: Data input; Reactive power control variables and system parameters (resistance, reactance, and susceptance etc.).
Step-2: Base case load flow solution is obtained using continuation power flow methodology.
Step-3: Next interval load is predicted.
Step-4: Obtain load flow solution for the predicted next interval load and execute power flow program. This process is continued until stressed condition of the system where a load bus voilate threshold value .
Step-5: Initialization; Generate population of size 'M' for reactive power control variables, which is obtained from the first step of the GA algorithm.

$\underline{U}_{ij} < U_{ij} < \overline{U}_{ij}$ j = 1, 2, 3, ...,NC

$U_i^0 = [u_{i\,1}^0,\ u_{i\,2}^0, u_{i\,3}^0, \dots \dots \dots, u_{i,NC}^0]^T$

Step-6: Run continuation power flow program for each vector of the population and monitor all inequality constraints eq. no. (11) - (16). If, a vector satisfies the constraints call it 'F' (feasible). Otherwise, call it 'NF' (not- feasible).
Step-7: Selection strategy applied to select appropriate load which satisfy all inequality constraints equation (11) - (16).
Step-8: Calculate indexes using eq. (1, 4 and 6) for the feasible vectors.
Step-9: Based on the value of indexes, identify the best solution vector U_{best}. This is selected as a base vector and simultaneously monitor the change in bus voltages.
Step-10: Fitness function evaluate and satisfy using equation no. 9.
Step-11: Set generation count k = 1.
Step-12: Select target vector i = 1
Step-13: Apply uniform crossover to get trial vector $t_i^{(k)}$. If the trial vector satisfy inequality constraints call it 'F' otherwise, 'NF [13]'.
Step-14: Select two vectors U_{r1} and U_{r2} such that base $\neq$ i $\neq$ r1 $\neq$ r2.
Step-15: Generate a mutated vector $\rho_i^{(k)}$ subject to inequality constraints [13].
Step-16: If any component of mutated vector i.e. $\rho_i^{(k)}$ violates the bounds on decision variable u_j then apply bounce back technique and bring the violated variables within limit.
Step-17: Run continuation power flow program for each vector of the Muted solution and monitor all inequality constraints.
Step-19: Calculate objective function using eq. 9 and rank the load buses according indexes. Go to next step. If not go to step- 5.
Step-20: Two to three load buses can be selected which are having highest sensitivities for injecting Vars from the UPFC.
Step-21: Stop.

IV. RESULT AND DISCUSSION

IEEE 30- Bus system;

This test system consists of 6 generators, 24 load bus and 41 transmission lines. The problem to be addressed for identifying the optimal location (line number) of UPFC by using GA. Continuation power flow program has been executed to obtain the active power, reactive power flows, load bus voltage magnitude and angle of the system. It is desirable to keep the voltage deviations between ±5% i.e. 0.95 - 1.05pu and all inequality constraints should be within feasible limits to avoid voltage collapses during operating conditions. Load on the system increased progressively subjected to desired voltage stability limit but under stressed operating condition a few load buses voltages decreases below the desired limit as shown in Table-1. This is due to shortage of Vars which is required to keep voltages within limit at all load buses of the system. As we know there is strong coupling between voltage and reactive power. To avoid this situation additional Vars required to injected at appropriate location of the system. So appropriate location is determined using eqn no, 1,4 and 6. These indexes are used to rank the system load buses. Table -1 shows the power flow solution for system under stressed condition. Table-2 shows the ranking of load buses using indexes. Table-3 shows the ranking of load buses using genetic algorithm. Table -4 shows the transmission line power flows and losses of the system without UPFC. Transmission line losses also helps to determine appropriate location of UPFC. The objective of the thesis has been achieved to determine the appropriate location of UPFC which is given in Table-3.

Table 1. Power Flow solution for IEEE 30-Bus System under stressed condition.

Total active load: 391.488 MW
Total Reactive Load: 209.998 MVAR
Total load: 444.254 MVA
Voltage stability limit: 469.35 MVA

Bus No.	Voltage Magnitude (pu)	Angle δ°	P_G MW	Q_G MVAR	P_L MW	Q_L MVAR
1	1.0493	0	143.637	-2.388	-	-
2	1.0453	-1.855	90.48	68.823	29.976	21.133
3	0.9449	-3.771	-	-	3.315	1.997
4	0.7809	-4.507	-	-	10.499	2.662
5	1.0291	-6.513	56.55	55.012	130.128	31.616
6	0.7785	-5.344	-	-	-	-
7	0.7993	-6.347	-	-	31.496	18.138
8	1.0362	-5.649	35.061	41.431	41.442	49.920
9	0.8512	-6.752	-	-	-	-
10	0.8409	-8.673	-	-	8.012	3.328
11	1.0256	-4.562	31.668	34.259	-	-
12	0.9378	-7.785	-	-	15.472	12.480
13	1.0410	-6.323	40.716	40.973	-	-
14	0.9383	-8.725	-	-	8.565	2.662
15	0.8565	-8.849	-	-	11.327	4.160
16	0.9218	-8.439	-	-	4.835	2.995
17	0.8676	-8.815	-	-	12.433	9.651
18	0.9425	-9.498	-	-	4.420	1.498
19	0.8137	-9.688	-	-	13.123	5.658
20	0.7858	-9.493	-	-	3.039	1.165
21	0.9025	-9.154	-	-	24.175	18.637
22	0.9069	-9.149	-	-	-	-
23	0.8237	-9.343	-	-	4.420	2.662
24	0.8378	-9.652	-	-	12.018	11.149
25	0.8886	-9.651	-	-	-	-
26	0.9430	-10.078	-	-	4.835	3.827
27	0.9489	-9.384	-	-	-	-
28	0.8152	-5.808	-	-	-	-
29	0.9318	-10.632	-	-	3.315	1.498
30	0.8372	-11.528	-	-	14.643	3.162

Table 2 : Ranking of Load Buses of IEEE-30 bus System for the determination of location of UPFC for the injection of required VARs based on active & reactive Power Loss and Minimum Eigen Value indexes

S. No.	Bus No.	Bus voltages (pu)	Sensitivity of indexes	Rank
1	6	0.7785	0.6723	1
2	4	0.7809	0.6512	2
3	20	0.7858	0.6064	3
4	7	0.7993	0.5396	4
5	19	0.8137	0.5063	5
6	28	0.8152	0.4275	6
7	23	0.8237	0.4083	7
8	30	0.8372	0.3285	8
9	24	0.8378	0.2975	9
10	10	0.8409	0.2573	10
11	9	0.8512	0.2064	11
12	15	0.8565	0.1845	12
13	17	0.8676	0.1286	13
14	25	0.8886	0.1133	14
15	21	0.9025	0.0947	15
16	22	0.9069	0.0741	16
17	16	0.9218	0.0537	17
18	29	0.9318	0.0510	18
19	12	0.9378	0.0478	19
20	14	0.9383	0.0432	20
21	18	0.9425	0.0328	21
22	26	0.9430	0.0315	22
23	3	0.9449	0.0307	23
24	27	0.9489	0.0264	24
25	5	1.0291	0.0176	25
26	11	1.0256	0.0087	26

27	8	1.0362	0.0059	27
28	13	1.0410	0.0031	28
29	2	1.0453	0.0016	29
30	1	1.0493	0.0011	30

Table 3 : Ranking of Load Buses of IEEE-30 bus System for the determination of location of UPFC for the injection of required VARs using Genetic Algorithm.

S. No.	Bus No.	Bus voltages (pu)	Sensitivity of indexes	Rank
1	6	0.7787	0.6721	1
2	4	0.7812	0.6510	2
3	20	0.7860	0.6063	3
4	7	0.7994	0.5392	4
5	28	0.8138	0.5059	5
6	19	0.8154	0.4271	6
7	23	0.8238	0.4078	7
8	30	0.8374	0.3283	8
9	24	0.8379	0.2971	9
10	10	0.8411	0.2568	10
11	15	0.8514	0.2061	11
12	9	0.8568	0.1842	12
13	17	0.8679	0.1283	13
14	25	0.8887	0.1128	14
15	21	0.9029	0.0943	15
16	16	0.9072	0.0738	16
17	22	0.9224	0.0534	17
18	29	0.9321	0.0503	18
19	12	0.9380	0.0472	19
20	14	0.9386	0.0427	20
21	26	0.9429	0.0323	21
22	18	0.9432	0.0312	22
23	3	0.9457	0.0301	23
24	27	0.9493	0.0260	24
25	5	1.0292	0.0171	25
26	11	1.0256	0.0087	26
27	8	1.0362	0.0059	27
28	13	1.0410	0.0031	28
29	2	1.0453	0.0016	29
30	1	1.0493	0.0011	30

Table 4: Transmission Line Power Flows and Losses of the IEEE 30-Bus System without UPFC

Total active load: 391.488 MW
Total Reactive Load: 209.998 MVAR
Total load: 444.254 MVA
Voltage stability limit: 469.35 MVA

Line #	From Bus	To Bus	Injection Power				Line Losses	
			From		To		$I^2 Z$	
			P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1	1	2	58.61	-10.9	-58	9.84	6.193074	5.31367
2	1	3	40.18	7.77	-39.48	-7.11	6.999989	8.201534
3	2	4	31.47	9.03	-30.9	-9.24	5.749271	5.024883
4	3	4	37.08	5.91	-36.9	-5.82	1.815559	1.501689
5	2	5	45.46	8.24	-44.53	-6.54	9.390476	11.29155
6	2	6	39.36	7.85	-38.5	-7.2	8.734857	7.595082
7	4	6	34.85	-4.56	-34.71	4.6	1.442361	1.443932
8	5	7	0.33	6.7	-0.3	-7.67	0.242075	0.173272
9	6	7	22.63	2.79	-22.5	-3.23	1.381842	1.212903
10	6	8	11.96	-3.57	-11.94	3.18	0.181556	0.173272
11	6	9	12.65	-1.89	-12.65	2.21	0	0.924116
12	6	10	11.25	2.03	-11.25	-1.36	0	1.934869
13	9	11	-20	-6.17	20	7.02	0	2.454684

14	9	10	32.65	3.96	-32.65	-2.86	0	3.205529
15	4	12	25.36	18.03	-25.36	-15.93	0	6.064514
16	12	13	-20	-3.26	20	3.79	0	1.530568
17	12	14	8.01	2.29	-7.93	-2.13	0.786742	0.462058
18	12	15	18.54	6.45	-18.31	-5.99	2.360227	1.328417
19	12	16	7.61	2.95	-7.55	-2.83	0.585014	0.346544
20	14	15	1.73	0.53	-1.72	-0.52	0.070605	0.028879
21	16	17	4.05	1.03	-4.04	-1	0.131124	0.086636
22	15	18	6.16	1.54	-6.11	-1.45	0.413544	0.231029
23	18	19	2.91	0.55	-2.91	-0.54	0.050432	0.028879
24	19	20	-6.59	-2.86	6.61	2.89	0.171469	0.086636
25	10	20	8.89	3.78	-8.81	-3.59	0.827088	0.519816
26	10	17	4.98	4.84	-4.96	-4.8	0.151297	0.115515
27	10	21	16.28	9.58	-16.17	-9.33	1.170027	0.721966
28	10	22	7.94	4.31	-7.89	-4.2	0.564841	0.317665
29	21	22	-1.33	-1.87	1.33	1.87	0.010086	0
30	15	23	5.67	2.48	-5.64	-2.4	0.363112	0.20215
31	22	24	6.55	2.33	-6.5	-2.24	0.534581	0.231029
32	23	24	2.44	0.8	-2.43	-0.79	0.080692	0.057757
33	24	25	0.23	0.41	-0.23	-0.41	0	0
34	25	26	3.55	2.37	-3.5	-2.3	0.45389	0.20215
35	25	27	-3.32	-1.96	3.33	1.99	0.161383	0.086636
36	28	27	16.62	6.5	-16.62	-5.33	0	3.378801
37	27	29	6.19	1.67	-6.1	-1.51	0.887607	0.490937
38	27	30	7.09	1.67	-6.93	-1.36	1.664263	0.895238
39	29	30	3.7	0.61	-3.67	-0.54	0.342939	0.173272
40	8	28	1.94	0.58	-1.94	-2.74	0.040346	0.028879
41	6	28	14.72	3.23	-14.68	-3.76	0.383285	0.375422

V. CONCLUSION

The combination of VSI, active & reactive power loss and sensitivity of minimum eigen value of load flow Jacobian indexes have been used as multiple objective function to rank the load buses for the placement of UPFC subject to operational inequality constraints. A new fitness function has been formulated and evaluate the optimal location of UPFC which supplies regulated Vars to achieve enhanced voltage stability limit. All the objectives are monitored using developed closed form algorithm. Developed algorithm has been implemented on IEEE 30-bus system and the results justify the strength of algorithm form any bus system. Proposed algorithm shows the best convergence characteristics for both standard and ill conditioned system.

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