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Optimal Placement of Statcom Based on Novel Mutated Voltage Stability Index & Optimal Dispatch of Reactive Power Using PSO

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Abstract: Reliable electricity supply play a vital role in modern era. Global electricity is driving the industrial sector to development and automation. To accomplish this, the Electric Power system must be powered by safe and secure margins & limits. It mostly depends on the nature of several environmental factors, working conditions, safe boundaries etc. Placing STATCOM in the power system helps to operate the power system network in a stable and reliable environment. The main function of this paper is to place a STATCOM in the electrical power system in order to obtain reliable, stable electricity and to reduce losses. Proper placement and size of STATCOM were used in the IEEE-30 bus system and the results were found to be effective.

Keywords: Optimal location of STATCOM, Reactive Power Injection, Stability, Particle Swarm Optimization

I INTRODUCTION

People who are constantly evolving and the use of energy have enhanced the interest in reliable electricitysupply. The power system plays an important role in transferring energy from generators to consumers. To prevent disturbance / event, like power outages, power system operators must determine the quality and durability of the various components of the transmission system by viewing and monitoring devices. The advent of global electrification is driving global technological advances in all sectors of the industry. With thousands of fully integrated units connected to a complex network of ac, transformers, current system of direct voltage (dc) and other complex, daily operation to deliver safe, reliable and high-energy electricity to the user is a very complex task. It requires continuous planning work in addition to continuous monitoring and operator action [1].

Increasing numbers of local system blackouts have been a constant reminder that conventional power transfer mechanisms for customers are not sufficient to maintain the safety of the power system while operating. The modern power system is a complex system, operating under complex connections, the worst conditions being very close to the limits. In addition, with the use of an extended computer and the use of electric gears, the quality is greatly increased, transmitting light to the concepts of power stability, speed, frequency stability and so on. The power system is highly inconsistent and robust, with performance parameters constantly changing. Stability from now on is a state of mind that is the concept and concept of distraction. [1] The global call for energy, especially in the developing world, has seen tremendous growth due to rapid population growth, increased economic growth, increased social inclusion, business disintegration, and urbanization. "Strengthening the power system can be achieved by improving the power profile, increasing the transmission capacity and others. Flexible AC Transmission System (FACTS) is an another solution to deal with some of those problems". [2] FACTS devices can be divided into three types, such as series controls, shunt controls and integrated Series-shunt controls. Basically, series controls inject voltage in series with line and shunt controls inject current at the point of contact into the system. Combined series-shunt controllers inject current into the system with a shunt part of the controls and inject voltage withthe help of series controllers. In the case of voltage support, shunt FACTS devices, such as STATCOM and SVC are widely used. This study focuses on the statutory performance of the majority STATCOM devices inthe power system. In particular, it is necessary to determine their appropriate location and capacity. Conventional practices such as mixed numbers and offline programs have been investigated to address this issue; however difficulties arise due to abundance local minima and great calculation effort. For the above reasons, the ideal location for a STATCOM should be determined based on technology, cost and environmental factors. The PSO Algorithm is used to solve this placement problem. In this paper, an efficientapproach that limits the total cost with minimal environmental impact through physical and mechanical reduction with the help of the use of the PSO method is proposed to select the appropriate location for a STATCOM. The proposed strategy could assist in the infrastructure of the power system by planning to increase the power transfer capacity.

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II. VOLTAGE STABILITY & ENHANCEMENT

A. Voltage Stability

Voltage stability is concerned with "the ability of the power system to maintain acceptable voltage at all bus in the system under normal conditions and after being subjected to disturbance". Voltage stability depends upon maintaining equilibrium between supply & demand.

"Progressive & uncontrollable decrease in voltage, could lead to cascaded outages & system enters a state of voltage instability when a disturbance occurs. These cascaded outages can lead to loss of synchronism of some generators which leads to system blackout."[3] Voltage instability occurs when you are trying to consume more power beyond the capacity of the network. Voltage stability is directly proportional to reactive power. Increase of reactive power in the system leads to voltage raise while shortage of reactive power reduces the voltage in the system.

Voltage stability is classified into two classes

- Small Disturbance Voltage Stability: It alludes to the system's capacity to keep up the enduring voltages when exposed to small changes in load.
- Large Disturbance Voltage Stability: It alludes to the system's capacity to keep up the enduring voltages when exposed to extensive unsettling disturbances. [3]

B. Voltage Collapse

Voltage collapse is the process via which the collection of the activities accompanying voltage instability leads to unacceptable voltage profile in a big part of the power system. It could be manifested in numerous kind of approaches. Voltage collapse may be characterized as follows:

- The initiating occasion can be because of following motives: Small gradual system adjustments such as natural increase in load, or huge sudden disturbances which include lack of generation or aloss of heavily loaded line.
- The crux of the hassle is the incapability of the system to satisfy its reactive power demands. Whilst shipping of reactive power from neighboring areas is tough, any exchange that calls for additional reactive power strength help might also ultimately lead to voltage collapse.
- The voltage collapse apart typically manifests itself as a slow decay of voltage. It's a result of morethan one process together with the actions and interactions of devices, control system and protection structures.
- Reactive compensation can be made handiest through the really apt preference of a combination of shunt capacitors, static var compensator and probably synchronous condensers".[4]

C. Strategies Of Enhancing Voltage Stability

Voltage stability of the system can be enhanced through the following strategies:

- Enhancing the localized reactive power strength (SVC, STATCOM) is effective and comparativelycheap.
- Compensating the line length reduces net reactance and power flow will increase.
- Additional transmission line can be erected. It additionally improves reliability.
- Enhancing excitation of generator, system voltage improves and Q is supplied to the system.
- By resorting strategic load shedding, voltage is going up because the reactive burden isreduced".[5]

III. PROBLEM FORMULATION

- Optimal reactive power dispatch is a complex optimization problem in which we try to "optimally" set the values of control variables like reactive power output of generators (generator bus voltages), tap ratios of transformers and reactive power output of shunt compensators like STATCOM & capacitors etc. to minimize the total transmission active power losses while satisfying a given set of constraints. [6]

$$\min \sum_{k\in N_E} P_{kloss} = \sum_{k\in N_E} g_k (v_i^2 + v_j^2 - 2v_i v_j \cos\theta_{ij}) \quad (1)$$

where,

k □ (i, j); i □ N_B (Total no. of buses)

j □ N_i (No. of buses adjustment to bus i,including bus i)

□ P_{kloss} □ Total active power losses in the transmission system g_k □ Conductance of branch k(pu)

k□N_E

v_i, v_j □ voltage magnitude(pu) of bus i and j respectively

□$_{ij}$ □ load angle difference between bus i and j(rad)

Such that

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Equality constraints:

Active power flow balance equations at all buses excluding slack bus

$$P_{gi} - P_{di} - v_i \sum_{j \in N_i} v_j (g_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0$$

Reactive power flow balance equations at all PQ buses (load buses)

$$Q_{gi} - Q_{di} - v_i \sum_{j \in N_i} v_j (g_{ij} \sin\theta_{ij} + B_{ij} \cos\theta_{ij}) = 0$$

Inequality constraints:

reactive power generation limit for each generator bus

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}, i \in N_g$$

voltage magnitude limit for each bus

$$v_i^{\min} \le v_i \le v_i^{\max}, i \in N_B$$

Power flow limit constraint of each transmission line

$$s_l \le s_l^{\max}$$

Transformer tap-setting constraint

$$T_k^{\min} \le T_k \le T_k^{\max}$$

STATCOM constraint

Static square penalty function is used to handle inequality constrains. So the Augmented objective function (fitness function)would be as equation (2)

$$F_P = \sum_{k \in N_E} P_{kloss} + Penalty\ Function \qquad (2)$$

where

$$Penalty\ Function = k_1 \times \sum_{i=1}^{N_G} f(Q_{gi}) + k_2 \times \sum_{i=1}^{N} f(V_i) + k_3 \times \sum_{m=1}^{N_L} f(S_{lm})$$

$$k_1, k_2, k_3 = 10,000$$

$$f(x) = \begin{cases} 0 & if\ x^{\min} \le x \le x^{\max} \\ (x - x^{\max})^2 & if\ x > x^{\max} \\ (x^{\min} - x)^2 & if\ x < x^{\min} \end{cases}$$

IV. PARTICLE SWARM OPTIMIZATION ALGORITHM

Particle Swarm Optimization is a biological process computation technique through individual improvement and population cooperation and competition, that relies on the simulation of simplified social models, like bird flocking, fish schooling, and also the swarming theory [7].

The particle swarm conception was impelled from the simulation of social behavior. PSO needs solely primitive mathematical operators, and is computationally cheap in terms of each memory necessities and time. The particles exhibit quick convergence to native and/or international best position(s) over a tiny low range of generations. A swarm in PSO consists of variety of particles. Every particle represents a possible answer to the optimization task. Every particle represents a candidate answer. Every particle moves to a brand new position per the new speed which incorporates its previous speed, and also the moving vectors per the past best answer and international best answer. The most effective answer is then kept; every particle accelerates within the directions of not solely the native best answer however additionally the world best position. If a particle discovers a brand new probable answer, different particles can move nearer to that so as to explore the region [8].

Let denote the swarm size. In general, there are 3 attributes, the particles' current position, current speed, and past best position, for particles within the search house to gift their options. Every particle within the swarm is updated per the aforesaid attributes. Currently, a normally used version is that the one projected by Shi [10], during which an accommodative parameter, named inertia weight, is introduced so as to boost the performance of the first version of PSO. The principle of the adaptive PSO is delineated as follows.

Fig. 1 indicates the flow chart of a PSO algorithm. At some stage in the PSO method, every capability answer is

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represented as a particle with a role vector x, known as phase weighting factor b and a moving velocity represented as v, respectively.

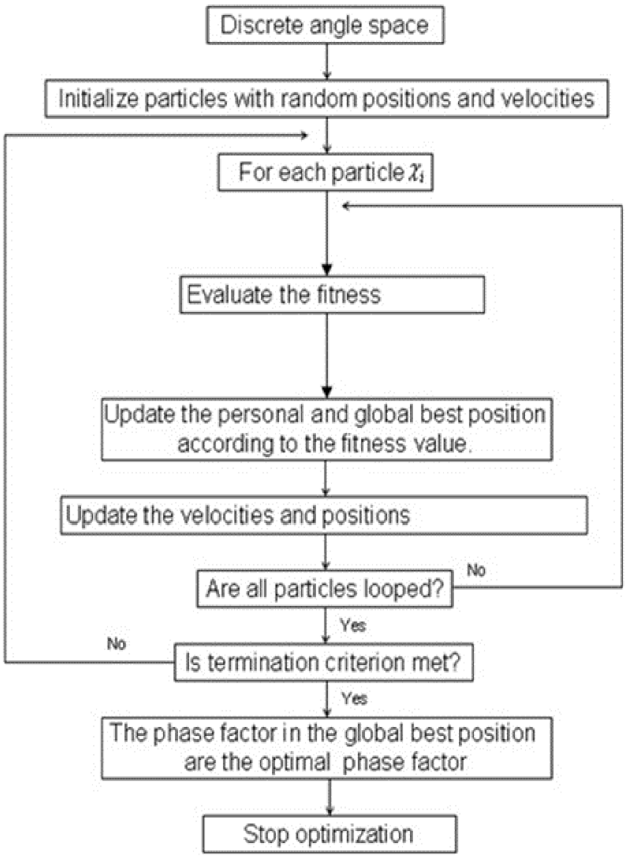

Figure 1. Flowchart of the PSO algorithm

For a K dimensional optimization,b_i is the position of the ith particle v_i is the velocity of the ith particle
$\mathbf{b}_i$ □ $(b_{i,1}, b_{i,2}, \ldots, b_{i,K})$ and $\mathbf{v}_i$ □ $(v_{i,1}, v_{i,2}, \ldots, v_{i,K})$

$$b_i^P = (b_{i,1}, b_{i,2}, \cdots, b_{i,K})$$

b^p referred to as pbest.

$$\mathbf{b}^G = \left(b_{g,1}, b_{g,2}, \cdots, b_{g,K}\right)$$

b^G refereed as global best.The new velocity $V_i(t+1)$ for particle i is updated by

$$v_i(t+1) = wv_i(t) + c_1r_1(b_i^P(t) - b_i(t)) + c_2r_2(b^G(t) - b_i(t)), \qquad (3)$$

w is called inertia weight,
V_i (t) is the old velocity of the particle i at time t .

Apparently from this equation, the new velocity is related to the old velocity weighted by using w and additionally related to the location of the particle itself and that of the global best one by means ofacceleration constants c1 and c2. The acceleration constants in Eq. (3) modify the quantity of tension in PSO. Low values permit particles to roam a ways from target regions earlier than being tugged returned, whilst excessive values bring about abrupt motion closer to, or beyond, target regions. The acceleration constants c1 and c2 are therefore called as the cognitive and social rates, respectively, due to the fact they constitute the weighting of the acceleration phrases that pull the character particle in the direction of the personal best and global best positions. The velocities of the particles are confined in [Vmin, Vmax]. If an element of the velocity exceeds threshold Vmin and Vmax , it is set to the corresponding threshold.
The inertia weight w in (3) is employed to manipulate the effect of the previous history of velocities at the current velocity. A massive inertia weight helps searching new place while a small inertia weight facilitates great-looking inside the cutting-edge seek place. Appropriate choice of the inertia weight provides a balance between worldwide exploration and

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neighborhood exploitation, and results to less iterations on common to discover a sufficiently precise solution. Experimental results advise to initialize the inertia weight to a large value, giving priority to global exploration of the search area, linear lowering, so as to reap suitable solution [7-11].

For the reason of intending to simulate the mild unpredictable element of natural swarm behavior, two random functions r1 and r2 are carried out independently to offer uniform allotted numbers in the range [0, 1] to stochastically vary the relative pull of the personal and global best particles. Based on the updated velocities, new position for particle i is computed in accordance with the following equation

$$b_i(t+1) = b_i(t) + v_i(t+1) \qquad (4)$$

The populations of particle are then moved in keeping with the new velocities and locations calculated by using (3) and (4), and have a tendency to cluster together from specific instructions. For this reason the assessment of each related health of the new populace of particles starts off evolved again. The set of rulesruns thru those techniques iteratively until it stops. These days, Clerc [12] introduced another parameter referred as constriction factor □, which may additionally assist make sure convergence. The constriction model describes the way of selecting w, c_1 and c_2 so the convergence is ensured. By choosing the values properly, the velocities of all the particles are obviated in the range of □v_{min} , v_{max} □□

V. MUTATED VOLTAGE STABILITY INDEX (MVSI)

A voltage stability indicator shows how close each transmission line is electrical instable. It has become important tools in power system stability evaluation. These indicators can be used to monitor electrical powersystem online or offline to predict near power outages or falls. To find the Mutated Voltage Stability index(MVSI), we first look at the Line Stability Index (Lmn) proposed by Moghavvemi and Umar, and the Fast Voltage Stability Index (FVSI) proposed by Musrin and Rahman.

The Line Stability Index (Lmn) is obtained based on the concept of power transmission line in a single line. Moghavvemi and Omar found this linear indication to check line stability between two buses in a connected system lowered into a single line network as shown in Figure 2.[13]

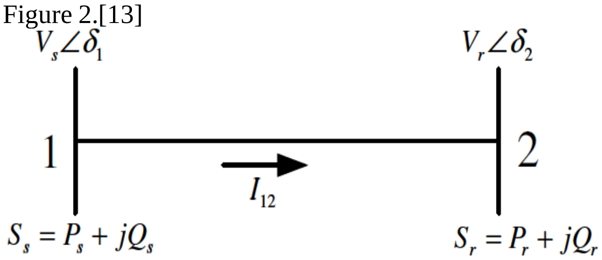

Figure 2. Single line network

The power flow through a transmission line using pie model representation for a two-bus system is used and the discriminant of the voltage quadratic equation is set to be greater than or equal to 0 (zero). If the discriminant is less than 0 (zero), the roots will be imaginary suggesting that there is instability in the system.

The expression for the index is given as

$$Lmn = \frac{4XQ_r}{|V_s|^2 \sin^2(\theta - \delta)} \le 1 \qquad (4)$$

The line index is also directly related

to the reactive power and indirectly related to the active power through the voltage phase angle .The line in the system is said to be close to instability when Lmn is close toone (1). On the other hand, if the value of Lmn is less than 1, then the system is said to be stable. [13]

The Fast Voltage Stability Index (FVSI), proposed by Musirin and Rahaman , is also based on the conceptof energy flow using a single line as shown in Figure 2. It is built according to the values of voltage and reactive power. At its discovery, the sending bus is considered to be a reference bus with an angle section of voltage set to zero. FVSI is a line indicator found in the current standard equation on the line between two buses. Its mathematical expression is given as

(5) $$FVSI = \frac{4Z^2 Q_r}{{V_s}^2 X} \le 1$$

$$FVSI = \frac{4Z^2 Q_r}{{V_s}^2 X} \le 1$$

The line in the system is said to be close to instability when FVSI is close to one (1). On the other hand, if the value of FVSI is less than 1, then the system is said to be stable. [14]

We therefore propose to combine equations (4) and (5) into one equation to calculate the approximate collapse of the electric voltage in terms of the shift function, as shown in equation (6). Each computed value from the system is tested against the limit value, to determine whether shift function is 1 or 0. The corollary combines equations (4) and (5) into a single equation to produce a new stability indicator that achieves speed and accuracy with improved stability. This is provided as

$$= \frac{4Q_r}{|V_s|^2}\left[\frac{(|Z|)^2}{X}\sigma - \frac{X}{\sin^2(\theta-\delta)}(\sigma-1)\right] \le 1 \qquad \sigma = \begin{cases} 1 & \delta < \delta_c \\ 0 & \delta \ge \delta_c \end{cases} \quad (6)$$

When MVSI is less than 1, the system is stable. The closer its value approaches one (1), then system is unstable and near voltage collapsed. Estimates of a power outage are included in the determination of heavy load capacity, identification of a weak bus in the network and critical lines regarding bus loading. This information is helpful in identifying potential points placed on compensation devices to reduce the fight against power loss on PSNs.

VI. PROPOSED ALGORITHMS

A. Algorithm for Identification of Weakest Bus based on MVSI

The following algorithm steps are followed in determining the maximum loading and identifying a weakbus:

- Enter bus and line data for IEEE 30-bus test system.
- Power flow run solution for the base case using the Newton-Raphson method.
- Line stability indices MVSI are calculated on a base charge in IEEE 30-bus system.
- A PQ Bus is selected and in the low case its reactive power capacity gradually increased whilekeeping load on other buses to the base case until the stabilization indicator approaches one (1).
- Calculate the value of the line stability for each load variation.
- The line with the highest index indicator is the busiest line.
- Then another load bus (PQ bus) is selected and steps 1-5 are repeated.

The line with the highest index is the weakest bus in the system. This nodes connected to this bus is the bestlocation for a compensation device.

B. Algorithm for Optimal reactive Power Dispatch using PSO including STATCOM

The proposed PSO algorithm for optimal reactive power dispatch including STATCOM for the IEEE 30 bus inspection system is defined as below:

- Define control variables (vg1, vg2, vg5, vg8, vg11, vg13, T1, T2, T3, T4, QC3, QC10, QC24, SC30) in their approved range, specify the size of the calculation, no iteration (= 200), consider the appropriate PSO parameter values, enter details of the 30 bus test system
- Take iter = 0
- The number of particles and their velocity are periodically determined
- With the aid of Newton raphson load flow, detect losses for each particle.
- Calculate the fitness of each particle
- Find the “best (Pbest)” of all the particles and the “global best (Gbest) particles based on their fitness
- Iter = iter + 1
- Calculate the velocity of each particle and correct it if its limit is violated
- Calculate the new position of each particle
- With the aid of load flow, obtain a loss for each particle.
- Calculate the fitness of each particle.
- In each particle if the current strength (P) is better than Pbest then Pbest = P
- Set the best of Pbest as Gbest
- Go to step no. 7, until max. no duplication completed.
- Gbest particle integration provides adjusted values of control flexibility and its durability provides areduced

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amount of loss.

VII. CASE STUDY & SIMULATION RESULTS

Simulations are performed on the following scenarios:
- The base case: Normal operational mode.
- Overload: Increase active & reactive power of about 50 percent more than base case at all buses

The contingency: Huge Increase of active & reactive power only at bus number 2.

The proposed algorithms are tested on IEEE Thirty bus system for above said scenarios. Table 1, 2 & 3shows the Mutated voltage stability indices for 30 bus system for above said 3 scenarios respectively.

Table 1: MVSI for Scenario 1

LineNo.	From Bus	To Bus	MVsi
1	1	2	0.0049
2	1	3	0.02292
3	2	4	0.02986
4	3	4	0.00652
5	2	5	0.04257
6	2	6	0.04671
7	4	6	0.01049
8	5	7	0.03685
9	6	7	0.02479
10	6	8	0.01419
11	6	9	0.07311
12	6	10	0.21855
13	9	11	0.08285
14	9	10	0.03983
15	4	12	0.12095
16	12	13	0.06511
17	12	14	0.15783
18	12	15	0.08802
19	12	16	0.13947
20	14	15	0.2453
21	16	17	0.14182
22	15	18	0.1813
23	18	19	0.11566
24	19	20	0.06469
25	10	20	0.18404
26	10	17	0.06043
27	10	21	0.07014
28	10	22	0.14939
29	21	22	0.02421
30	15	23	0.21485
31	22	24	0.22765
32	23	24	0.30435
33	24	25	0.41888

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34	25	26	0.55133
35	25	27	0.27668
36	28	27	0.43415
37	27	29	0.58613
38	27	30	0.88143
39	29	30	0 .6881
40	8	28	0.24179
41	6	28	0.07071

Table 2: MVSI for Scenario 2

LineNo.	From Bus	To Bus	MVsi
1	1	2	0.0052
2	1	3	0.0248
3	2	4	0.0337
4	3	4	0.0072
5	2	5	0.051
6	2	6	0.054
7	4	6	0.0117
8	5	7	0.0408
9	6	7	0.0277
10	6	8	0.0159
11	6	9	0.0825
12	6	10	0.2476
13	9	11	0.0907
14	9	10	0.0436
15	4	12	0.1374
16	12	13	0.0724
17	12	14	0.1755
18	12	15	0.0979
19	12	16	0.1551
20	14	15	0.2786
21	16	17	0.1605
22	15	18	0.2075
23	18	19	0.1342
24	19	20	0.0754
25	10	20	0.2086
26	10	17	0.0685
27	10	21	0.0795
28	10	22	0.1693
29	21	22	0.0279
30	15	23	0.2459
31	22	24	0.2628
32	23	24	0.3548

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33	24	25	0.4946
34	25	26	0.6541
35	25	27	0.3282
36	28	27	0.4959
37	27	29	0.688
38	27	30	1.0345
39	29	30	0.8349
40	8	28	0.2676
41	6	28	0.0791

Table 3: MVSI for Scenario 3

LineNo.	From Bus	To Bus	MVsi
1	1	2	0.0054
2	1	3	0.0242
3	2	4	0.0312
4	3	4	0.0068
5	2	5	0.0472
6	2	6	0.0512
7	4	6	0.0111
8	5	7	0.0399
9	6	7	0.0261
10	6	8	0.0149
11	6	9	0.077
12	6	10	0.2301
13	9	11	0.0852
14	9	10	0.041
15	4	12	0.1278
16	12	13	0.0666
17	12	14	0.1614
18	12	15	0.09
19	12	16	0.1426
20	14	15	0.2513
21	16	17	0.1456
22	15	18	0.1861
23	18	19	0.119
24	19	20	0.0666
25	10	20	0.1898
26	10	17	0.0623
27	10	21	0.0723
28	10	22	0.1541
29	21	22	0.025
30	15	23	0.2205
31	22	24	0.2351
32	23	24	0.3135

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33	24	25	0.4333
34	25	26	0.5743
35	25	27	0.2882
36	28	27	0.4557
37	27	29	0.6128
38	27	30	0.9216
39	29	30	0.7208
40	8	28	0.2517
41	6	28	0.0744

From the above table, it is evident that line number 38, i.e, line from bus number 27 to 30 is found to be the weakest bus. So, there are two locations to place a STATCOM, one is at bus 27, while other is bus number 30. STATCOM is placed at bus number 30, & optimal reactive power dispatch including STATCOM is performed on IEEE 30 bus system & table 4 shows the optimized values of control variables after PSO Optimization for above three said scenarios

Table 2: Optimized values of control variables for all Scenarios

Bus	Control variables	Optimized values		
		Scenario 1	Scenario 2	Scenario 3
1	Vg1 (pu)	1.0736	1.0602	1.0125
2	Vg2(pu)	0.9643	1.0111	1.0498
5	Vg5(pu)	0.9418	1.0274	1.101
8	Vg8(pu)	1.0548	1.0073	1.0058
11	Vg11(pu)	1.0127	1.0816	0.988
13	Vg13(pu)	1.1031	1.0642	1.0625
6-9	T1	1.0193	0.9859	0.9806
6-10	T2	1.0256	0.9802	0.9818
4-12	T3	1.0106	1.047	0.9904
27-28	T4	1.035	1.0606	1.0048
6-9	QC3 (MVAR)	18.7492	19.1845	19.3669
10	QC10(MVAR)	15.6332	14.8848	19.2533
24	QC24(MVAR)	13.5829	16.007	12.9662
30	STATCOM (MVAR)	11.9254	11.8957	16.9678

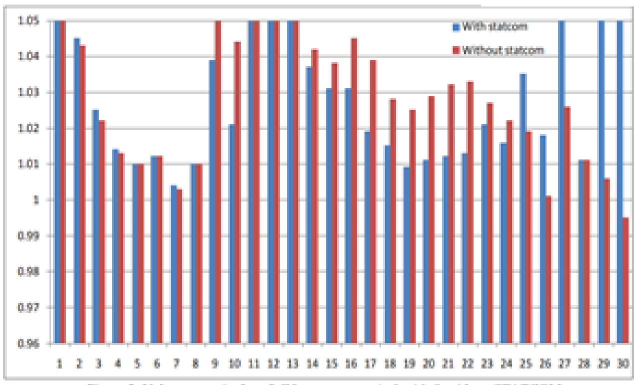

Figure 3: Voltage magnitudes of all buses at scenario 1 with & without STATCOM

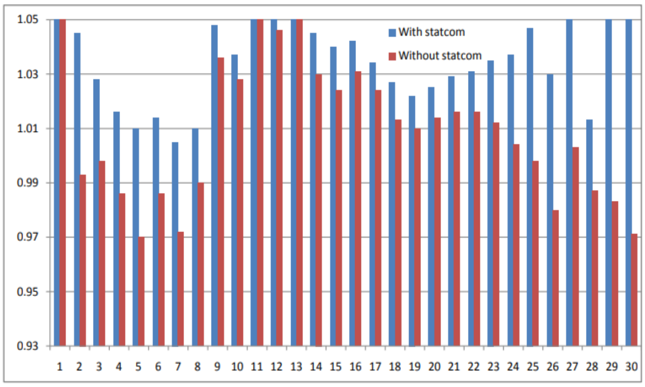

Figure 4: Voltage magnitudes of all buses at scenario 2 with & without STATCOM

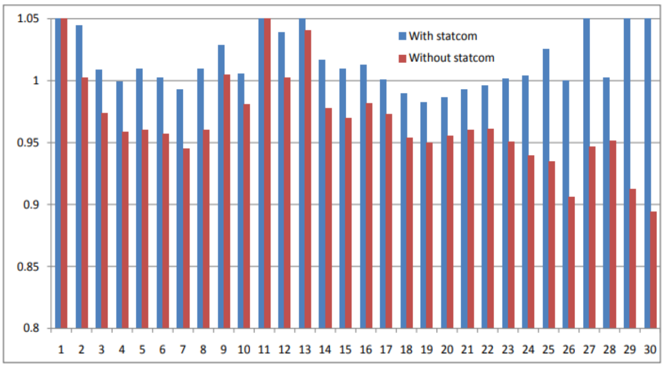

Figure 5: Voltage magnitudes of all buses at scenario 3 with & without STATCOM

Figure 3, 4 & 5 depicts the Voltage magnitudes of all buses at scenario 1, 2 & 3 with & without STATCOM respectively. From the figure, it clearly tells that the voltage magnitude at all the buses has been improved & it is within the limits.

VIII. CONCLUSION

In this paper, a novel mutated voltage stability index has been developed which is fast & accurate. It is a powerful index which is used to determine the weakest bus in the power system to place a STATCOM.MVSIhas been calculated for IEEE thirty bus system for base case & contingency scenarios. In all the cases, Bus number 30 is found to be the weakest bus & STATCOM has been placed at bus number 30. Reactive power has been dispatched optimally using PSO. Comparative analysis has been performed on voltages at all buses at different cases. The result shows the significantly voltage stability enhancement.

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