OPTIMAL PLACEMENT OF SVC AND STATCOM FOR VOLTAGE STABILITY ENHANCEMENT UNDER CONTINGENCY USING CAT SWARM OPTIMIZATION

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ABSTRACT

Due to continuous expansion of power system in accordance with the growing demand, stability studies have become a fascinated area for research in the modern day. The aim of this paper is to identify the optimal location and size of shunt FACTS controllers in an interconnected power system under N-1 contingency for voltage stability analysis. As the size and the cost of the FACTS devices are high, an optimal location of FACTS along with its size needs to be identified before they are actually installed. In this process, we are trying to improve the voltage profile and Maximum loading Parameter while maintaining the losses under control using FACTS controllers based upon Cat Swarm Optimization (CSO).

KEYWORDS: *SVC, STATCOM, voltage Stability, CSO, CPF.*

I. INTRODUCTION

Power system stability [1] is a very Complex subject that has been challenging the power system engineers in the past two decades. Due to the continuous expansion of power systems to cater the needs of growing population, power system stability problems also are a continuous and fascinating area of study. When a bulk power transmission network is operated close to the voltage stability limit, it becomes difficult to control the reactive power demand for that system. Voltage stability is of major concern in power systems stability [5]. Main reason for the cause of voltage instability is the sag in reactive power at various locations in an interconnected power system. Voltage stability is a problem in power systems which are heavily loaded, faulted or have a shortage of reactive power. The problem of voltage stability concerns the whole power system, although it usually has a large involvement in one critical area of the power system. Voltage stability is concerned with the ability of a power system to maintain steady voltages at all buses in the system under normal operating conditions, and after being subjected to a disturbance. Instability that may occurs in the form of a progressive fall or rise of voltage of some buses. The Possible outcome of voltage instability is loss of load in the area where voltages reach unacceptably low values, or a loss of integrity of the power system. A power system at a given operating state is small disturbance voltage stable if, following any small disturbance such as unbalanced loads and load variations, voltages near loads are identical or close to the pre-disturbance values. Large disturbance voltage stability [2] refers to the system's ability to maintain steady voltages following large disturbances such as system faults, loss of generation, or circuit contingencies. The voltages at various points after such a disturbance may reach the pre-disturbance values or not, leading to voltage sag at certain points.

Though in India, power transmission and distribution systems have been centralized and cause of power system instability is very minimal, the line outages caused due to weather conditions is still being considered a serious problem. Reactive power deficiency and voltage degradation is serious during such situations. There is a necessity to throw light in this area to assess the voltage stability of an interconnected power system affected by such a contingency.

Using FACTS controllers [3, 4] one can control the variables such as voltage magnitude and phase angle at chosen bus and line impedance where a voltage collapse is observed. Introducing FACTS devices is the most effective way for utilities to improve the voltage profile and voltage stability margin of the system. With the ongoing expansion and growth of the electric utility industry, including deregulation in many countries, numerous changes are continuously being introduced to a once predictable business. Although electricity is a highly engineered product, it is increasingly being considered and handled as a commodity. Flexible AC Transmission Systems (FACTS), provide proven technical solutions to address these new operating challenges being presented today. FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impact, and implementation time compared to the construction of new transmission lines. The potential benefits of FACTS equipment are now widely recognized by the power systems engineering and T&D communities.

The aim of this paper is to identify the optimal location and size of SVC and STATCOM in an interconnected power system under N-1 contingency for voltage stability analysis. As the size and the cost of the facts devices are high, an optimal location and size has to be identified before they are actually installed. We are trying to improve the voltage profile and Maximum loading Parameter while maintaining the losses under control using FACTS controllers. Optimization techniques find a variety of use in many fields. As Artificial intelligence techniques are improving day by day, the use of these techniques in power systems is playing an important role for the optimal location of FACTS devices. We are using Cat Swarm Optimization (CSO) [15, 16, and 17] to identify the optimal location and size of FACTS controllers. This is the first paper to introduce CSO for voltage stability analysis under contingency for optimal placement of FACTS.

The organization of this paper goes like this. Section 2 briefs out the problem statement. Section 3 defines the objective function. Section 4 gives the details of the test systems and the software's used. Section 5 details the CSO. Section 6 presents the details of the results. And finally sections 7 and 8 give the Conclusion and Future scope of the work.

II. PROBLEM STATEMENT

A contingency is the failure or loss of an element (e.g. generator, transformer, transmission line, etc.), or a change of state of a device (e.g. the unplanned opening of a circuit breaker in a transformer substation) in the power system. Contingency Analysis is essentially a "preview" analysis. It simulates and quantifies the results of problems that could occur in the power system in the immediate future. CA is used for the off-line analysis of contingency events, and show operators what would be the effects of future outages. This allows operators to be better prepared to react to outages by using pre-planned recovery scenarios. An "outage" is the removal of equipment from service. Line contingency refers to the removal of transmission line from the system. Whereas in the case of generator contingency we assume that the particular generator is no longer a part of the system and usually the voltage variation is high. Both line contingency and generator contingency come under large disturbances. In this paper we are doing (N-1) line outages contingency analysis and we are trying to improve the voltage profile and compensate reactive power losses through the use of FACTS devices. (N-1) contingency refers to removal of transmission lines individually for (N-1) cases. At any instant only one particular line can be removed. Exhaustive Search [10] and PSO [11] techniques have been investigated before the application of CSO to the present problem.

III. OBJECTIVE FUNCTION

The objective function which we have assumed is

$$F = \{F1, F2, F3\}$$

The functions F1, F2, F3 are defined and used in optimization process.

$$F = \omega 1F1 + \omega 2F2 + \cdot\cdot\cdot + \omega n\, Fn \text{ ……………………. } (1)$$

In our study, the fitness function is defined as a sum of three terms with individual criteria. The first part of the objective function concerns the voltages level. It is favorable that buses voltages be as close as possible to 1 p.u. Equation (2) shows the voltage deviation in all buses.

$$F_1=F_v= [\sum(V_i-1)^2]^{1/2} \qquad (2)$$

Where n_b is the number of buses and Vi is the voltage of bus i .

The second one is related to power system total loss and minimizing it in power systems that are given by

$$PL_k = P_{sending} - P_{recieving}$$

$$F_L = P_{L\_total} = F_{loss} =\sum P_{lk} \qquad (3)$$

Where P_{lk} indicates the loss in line ending to buses l and k, and $PL = F$loss represents the total loss of power network.

F3-This function represents minimum size of FACTS controller.

IV. TEST SYSTEMS & SOFTWARE USED

We are testing our algorithm here on two test systems: The 3-bus system and IEEE 14-bus system. The specifications of 3 bus system can be given as: Total Number of Buses used here are 3, total number of Lines used is 3, total Number of Generators is 1 and the total Number of Loads is 2. The specifications of IEEE 14 bus system can be given as: the number of buses being 14, the number of Lines being 16, the generator count is 5 (including slack bus) and the number of loads being 11. An MVA base of 100 is assumed for the two bus systems. All the analysis and testing here is being done in MATLAB [7].

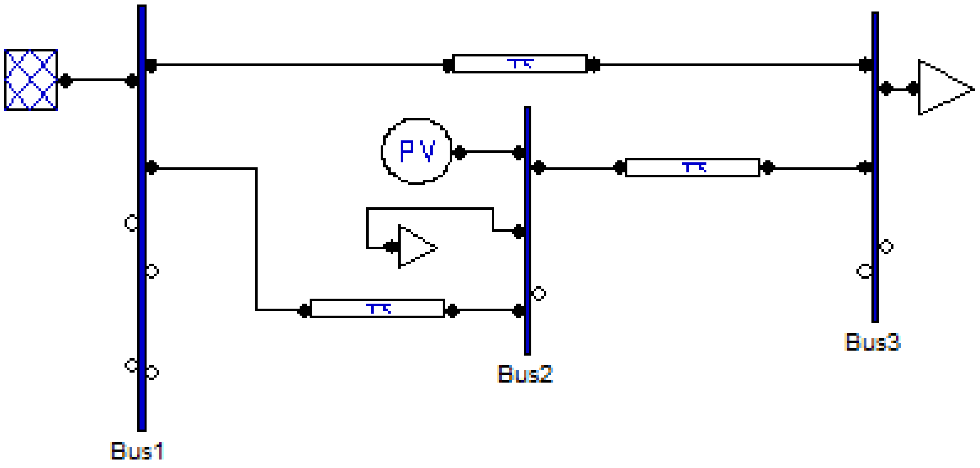

Fig 1: 3-bus power system

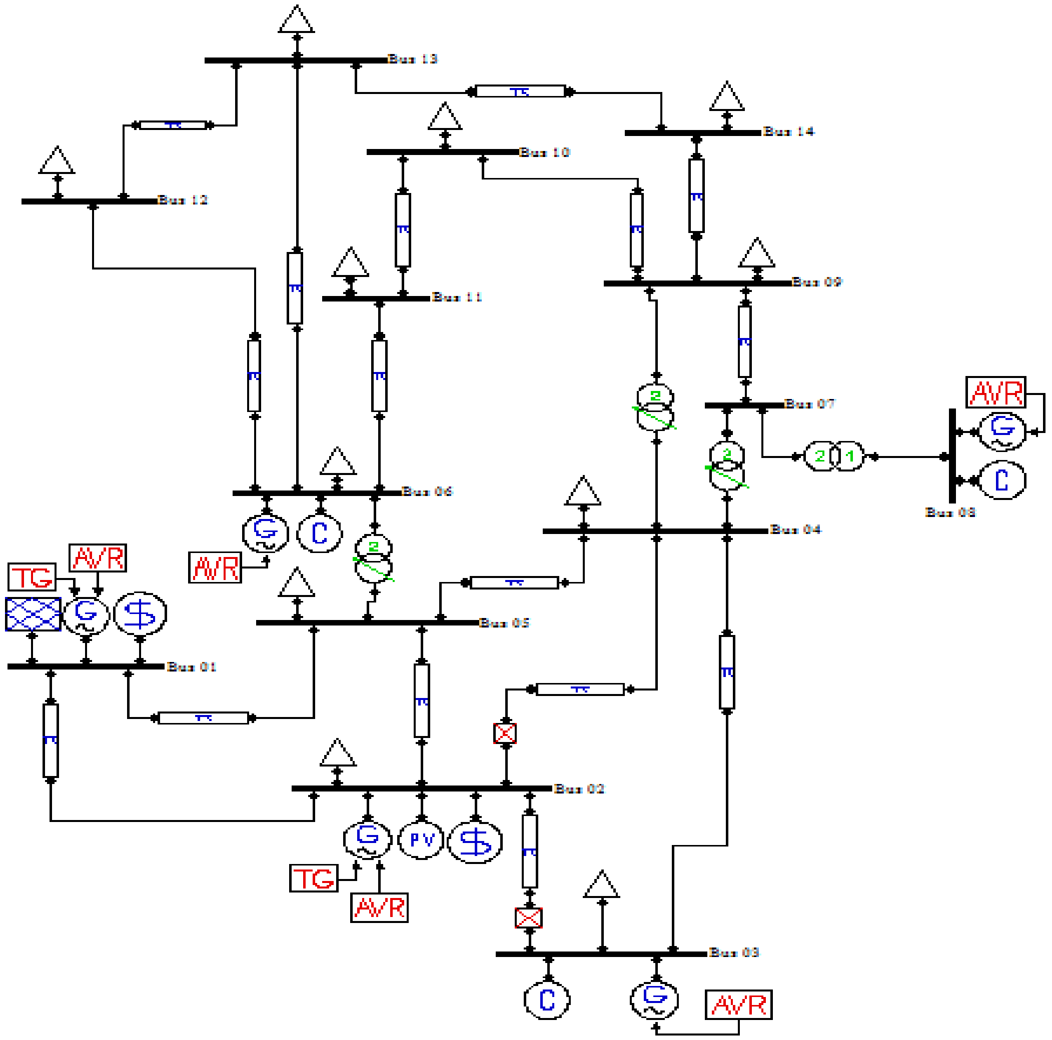

Fig 2: Standard IEEE 14-bus system

V. CAT SWARM OPTIMIZATION AND FACTS

5.1 INTRODUCTION TO CSO:

In the field of optimization, many algorithms were being proposed recent years, e.g. Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), and Simulated Annealing (SA) etc. Some of these optimization algorithms were developed based on swarm intelligence. Cat Swarm Optimization (CSO), the algorithm, is motivated from PSO and ACO. According to the literatures, PSO with weighting factor usually finds the better solution faster than the pure PSO, but according to the experimental results, Cat Swarm Optimization (CSO) [15, 16 and 17] presents even much better performance.

5.2 PROPOSED ALGORITHM

In Cat Swarm Optimization, we first model the major two behaviors of cats into two sub-models, namely, seeking mode and tracking mode [15].

5.2.1 THE SOLUTION SET IN THE MODEL -- CAT

Solution set must be represented in some manner. For example, GA uses chromosome to represent the solution set; ACO uses ant as the agent, and the paths made by the ants depict the solution sets; PSO uses the positions of particles to delineate the solution sets. We use cats and the model of behaviors of cats to solve the optimization problems, i.e. we use cats to portray the solution sets. In CSO, we first decide how many cats we would like to use, then we apply the Cats into CSO to solve the problems. Every cat has its own position composed of *M* dimensions, velocities for each dimension and a flag to identify whether the cat is in seeking mode or tracing mode. The final solution would be the best position in one of the cats due to CSO keeps the best solution till it reaches the end of iterations.

5.2.2 SEEKING MODE

This sub-model is used to model the situation of the cat, which is resting, looking around and seeking the next position to move to. In seeking mode, we define four essential factors: seeking range of the selected dimension (SRD), counts of dimension to change (CDC), and self-position considering (SPC). SMP is used to define the size of seeking memory for each cat, which indicates the points sought by the cat. The cat would pick a point from the memory pool according to the rules described .SRD declares the mutative ratio for the selected dimensions. These factors are all playing important roles in the seeking mode.SPC is a variable, which decides whether the point, where the cat is already Standing will be one of the candidates to move to.
How the seeking mode works can be described in 5 steps as follows:

Step1: select the total number cat that has to be considered.
Step2: for each cat a fixed range of velocities has to be assumed.
Step3: Calculate the fitness values (FS) of all candidate points.
Step4: Select how many cats to be available in seeking mode.
Step5: Randomly pick the cat from the total number of cats and apply to seeking mode.

5.2.3 TRACING MODE

Tracing mode is the sub-model for modeling the case of the cat in tracing some targets. Once a cat goes into tracing mode, it moves according to its' own velocities for every dimension. The action of tracing mode can be described in 3 steps as follows:

Step1: Update the velocities for every dimension (v_k, d) according to equation.

Step2: Check if the velocities are in the range of maximum velocity. In case the new velocity is over range, set it be equal to the limit.

Step3: Update the position of cat_k and again calculate the best fitness value. Proceed till the best fitness value is obtained and the corresponding cat location and velocity are the best values.

5.2.4 ALGORITHM FOR THE CAT SWARM OPTIMIZATION

As described in the above subsection, CSO includes two sub-models, the seeking mode and the tracing mode. To combine the two modes into the algorithm, we define mixture ratio (MR) of joining seeking mode together with tracing mode. While they are resting, they move their position carefully and slowly, sometimes even stay in the original position. The algorithmic flow routine for the CSO can be explained through the flow chart in figure 3.

5.3 FACTS

Flexible AC Transmission Systems (FACTS) [4] controllers have been used in power systems since the 1970s with the objective of improving system dynamic performance. Due to the environmental, right of- way, and cost problems in both bundled and unbundled power systems, many transmission lines have been forced to operate at almost their full capacities worldwide. FACTS controllers enhance the static performance viz. increased loading, congestion management, reduced system loss, economic operation, etc., and dynamic performance viz. increased stability limits, damping of power system oscillation, etc. The concept of FACTS involves a family of fast acting, high power, and electronic devices, with advanced **a**nd reliable controls. By using FACTS controllers' one can control the variables such as voltage magnitude and phase angle at chosen bus and line impedance. Flexible alternating-current transmission systems (FACTS) defined as "ac transmission systems incorporating power electronics based and other static controllers to enhance controllability and increase power transfer capability".

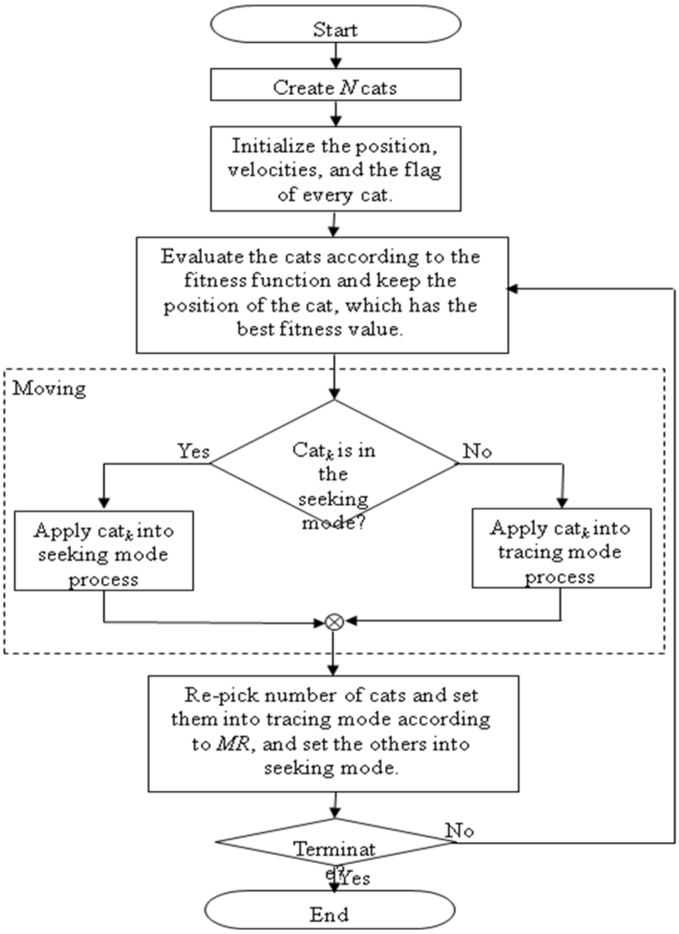

Fig 3: Flow chart for the CSO technique

5.3.1 SVC

A static VAR compensator [4] consists of a capacitor bank in parallel with a thyristor controlled reactor as shown in figure 4. It is used to stabilize a bus bar voltage and improve damping of the dynamic oscillation of power systems. In this model, a total reactance bSVC is assumed and the following is the differential equation. The model is completed by the algebraic equation expressing the reactive power injected at the SVC node.

$$\dot{b}_{SVC} = (K_r (V_{ref} + v_{POD} - V) - b_{SVC})/T_r$$
$$Q = -b_{SVC} * V_2 \qquad (4)$$

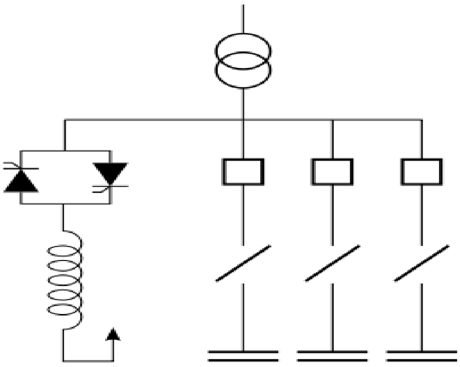

Fig 4: Structure of SVC

5.3.2 STACOM

A static synchronous compensator (STATCOM) [4] as shown in figure 6 is a regulating device used on alternating current electricity transmission networks. It is based on power electronic voltage source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. The mathematical model of the differential equation and the reactive power to be injected at the STATCOM node are given, respectively as follows.

$$\dot{i}_{SH} = (K_r\,(V_{ref} + v_{POD} - V) - i_{SH})/T_r$$

$$Q = -i_{SH}\,V \qquad (5)$$

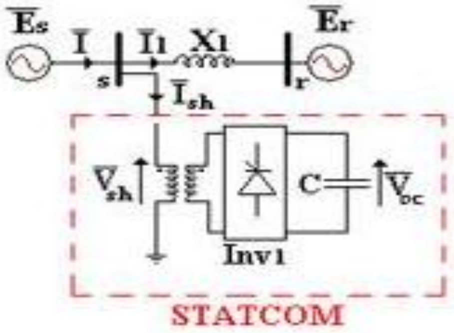

Fig 5: Structure of STATCOM

VI. IMPLEMENTATION, RESULTS AND DISCUSSIONS

The implementation of the present problem and its solution can be explained as follows. We run the CPF [14] for the base case that is the pre disturbance case and the voltages at various buses are noted. And now we introduce the contingency i.e., the line outage and rerun the CPF routine to know the deterioration of voltages. Similarly we continue this for N-1 cases and the maximum loading parameter and the voltages at the respective buses is noted. From the N-1 line contingency analysis we identify the three critical cases for which there is maximum deviation in the voltages. After identifying the worst locations for line contingencies, now, using the CSO technique, which has been described earlier, the two shunt FACTS controllers are introduced at appropriate places with chosen VAR ratings to improvise the maximum loading limit of the system and also to bring the system voltages back to the pre disturbance values (or) near pre-disturbance values.

6.1 RESULTS FOR 3-BUS SYSTEM

Three bus system: The theoretical and practical results of a 3-bus system without considering line outage are shown. The theoretical values were found out using Newton-Raphson method. In N-R method the active and reactive power equations are given as follows:

$$Pi=\Sigma\ ViVk\ Yik^{*}\cos\,(\delta i-\delta k-\theta ik) \qquad (6)$$

$$Qi=\Sigma\ ViVk\ Yik^{*}\sin\,(\delta i-\delta k-\theta ik) \qquad (7)$$

Using the above equations the voltages at their respective buses are obtained as follows

Table 1: 3-bus system values without line outage

Bus numbers	Theoretical Values V(p.u)	Practical Values V(p.u)
1	1.05 ∠ 0	1.05 ∠ 0
2	1.03 ∠ -0.2298	1.03 ∠ -0.23305
3	0.9475 ∠ -0.3202	0.93896 ∠ -0.3301

Table 2: 3-bus system values with line outage

Bus numbers	Theoretical Values V(p.u)	Practical Values V(p.u)
1	1.05∠0	1.05∠0
2	1.03 ∠-2.77916	1.03 ∠-2.8517
3	1.0248∠-1.9259	1.0248∠-1.946

For the line outage contingency case, we find the theoretical values using Newton-Raphson Method. We assume that for this case the transmission line between bus-1 and bus-3 is removed.
Now we place the FACTS controller between bus-3 and bus-2 and note down the respective voltages and line flows between the buses. The following tables show the voltage profile and power flow when SVC is incorporated between bus-3 and bus-2.

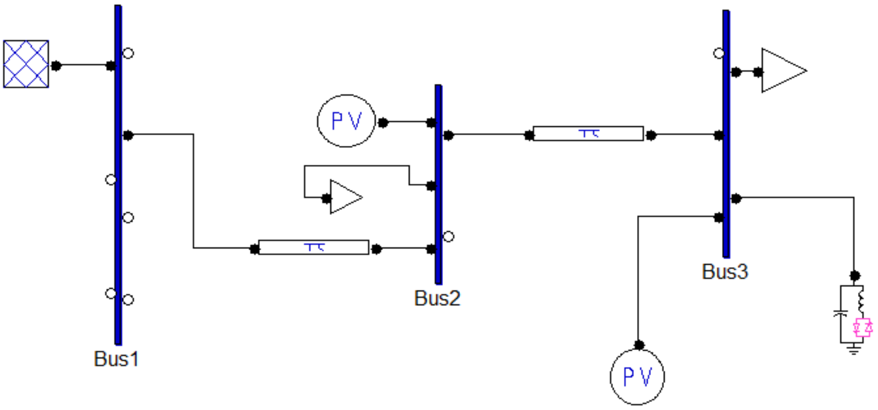

Fig 6: 3-bus system with SVC placed at bus3

Table 3: 3-bus system values with SVC placed at bus-3

Bus numbers	V(p.u) with SVC placed at bus-3
1	1.05∠0
2	1.03∠-0.17476
3	1.0256∠-0.25122

Similarly the reactive power flow between bus-3 and bus-2 for SVC and STATCOM is tabulated as shown below.

Table 4: Reactive Power Flow between bus-3 & bus-2(SVC)

Reactive Power Flow between bus-3 & bus-2	Q(p.u)
Theoretical	-1.65
Practical	-1.0037

Table 5: Reactive Power Flow between bus-3 & bus-2(STATCOM)

Reactive Power Flow between bus-3 & bus-2	Q(p.u)
Theoretical	≅ 1
Practical	0.91941

6.2 RESULTS FOR IEE 14-BUS SYSTEM FOR LINE 10 OUTAGE CONTINGENCY:

6.2.1 FACTS USED: SVC (FOR LINE 10 OUTAGE)

Using CPF routine [14] basing on the same NR method, voltage stability of the IEEE 14 bus test system is investigated. The behavior of the test system with and without FACTS devices under different loading conditions is studied. The critical buses are identified as buses 12, 13, 14 by performing a line outage contingency i.e., line 10 going out of service. Bus 13 has the weakest voltage profile and hence its profile is needed to be improved using Facts devices. The best location and optimal size of SVC'S for line 10 outage is identified using CSO at the locations 12, 13, and 14 with the FACTS size equal to 0.01kvar, 0.01kvar, and 0.05kvar respectively. The following table shows the improvement in voltage profile and maximum loading parameter for line 10 contingency before and after contingency when 3 SVC'S are placed at the locations 12, 13, and 14 using CSO technique.

Table 6: voltage profile before and after line 10 contingency

BUS NO	V(P.U) BEFORE CONTINGENCY (WITH OUT FACTS)	V(P.U) AFTER CONTINGENCY (line 10)	V(P.U) AFTER CONTINGENCY **(WITH 3 FACTS)**
01	1.0572	1.0577	1.0564
02	0.93179	0.94915	0.88829
03	0.85811	0.88577	0.77827
04	0.77903	0.80139	0.75435
05	0.79614	0.82107	0.77839
06	0.82196	0.8462	0.97179
07	0.79451	0.79031	0.8646
08	0.93818	0.93788	0.98203
09	0.72039	0.70069	0.86105
10	0.71231	0.70156	0.85587
11	0.75452	0.76107	0.90063
12	**0.7663**	**0.66922**	**1.045**
13	**0.74451**	**0.50774**	**1.045**
14	**0.66134**	**0.53445**	**1.045**
M L.P(λ_{max})	**2.375**	**2.1732**	**2.5799**
Q_{GEN}	**7.1003**	**6.463**	**7.2481**
Q_{LOSS}	**5.167**	**4.6955**	**7.2043**
%Q_{LOSS}	**72.77**	**72.65**	**99.39**

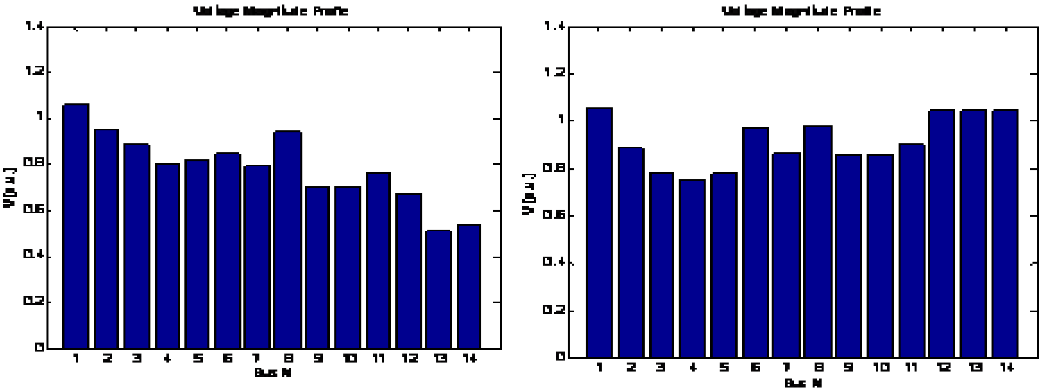

Fig 7: Voltage magnitude profile before and after placement of SVC'S for line 10 contingency

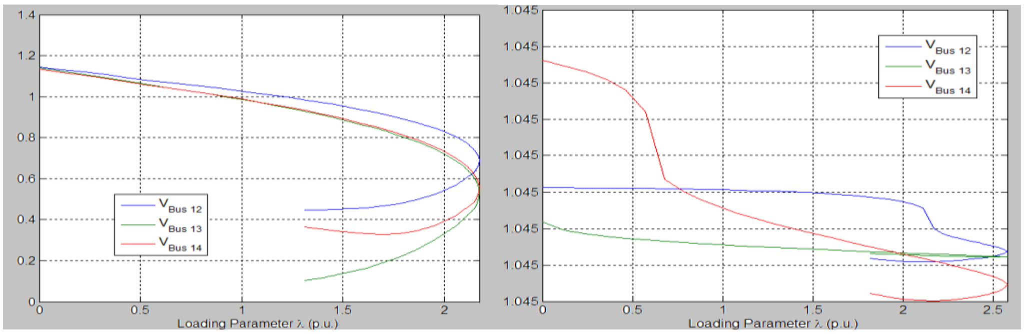

Fig 8: P-V curves before and after placement of SVC'S for line 10 contingency.

6.2.2 FACTS USED: STATCOM (FOR LINE 10 OUTAGE)

The best location and optimal size of STATCOM for line 10 contingency is between the locations 12-06, 13-12, and 14-13 with size equal to 0.01kvar, 0.01kvar, and 0.01kvar each as derived from CSO.

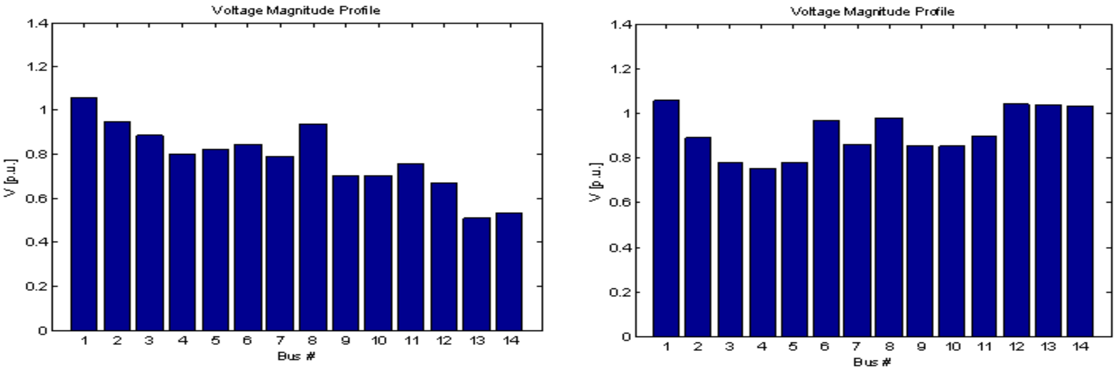

Fig 9: Voltage magnitude profile before and after placement of STATCOM'S for line 10 contingency

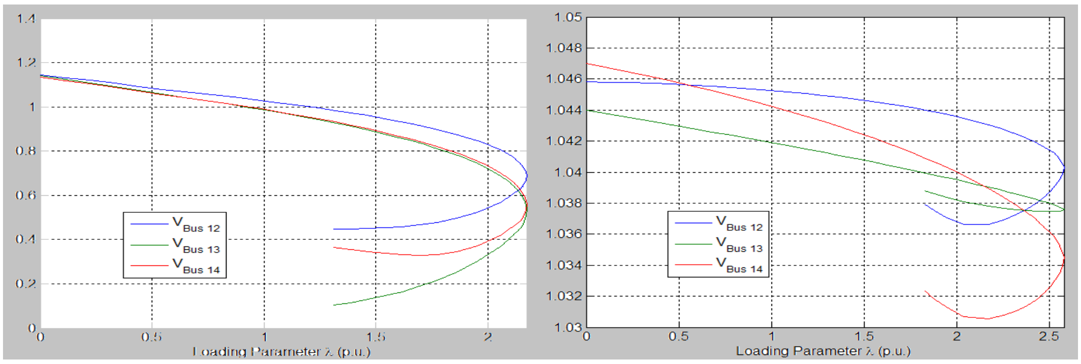

Fig 10: P-V curves before and after placement of STATCOM'S for line 10 contingency

Table 7: voltage profile before and after line 10 contingency

BUS NO	V(P.U) BEFORE CONTINGENCY (WITH OUT FACTS)	V(P.U) AFTER CONTINGENCY (line 10)	V(P.U) AFTER CONTINGENCY **(WITH 3 FACTS)**
01	1.0572	1.0577	1.0564
02	0.93179	0.94915	0.8891
03	0.85811	0.88577	0.77948
04	0.77903	0.80139	0.75471

05	0.79614	0.82107	0.77881
06	0.82196	0.8462	0.96988
07	0.79451	0.79031	0.86258
08	0.93818	0.93788	0.98081
09	0.72039	0.70069	0.8572
10	0.71231	0.70156	0.85229
11	0.75452	0.76107	0.89786
12	**0.7663**	**0.66922**	**1.0399**
13	**0.74451**	**0.50774**	**1.0375**
14	**0.66134**	**0.53445**	**1.0339**
M L.P(λ_{max})	**2.375**	**2.1732**	**2.578**
Q_{GEN}	**7.1003**	**6.463**	**7.247**
Q_{LOSS}	**5.167**	**4.6955**	**7.1477**
%Q_{LOSS}	**72.77**	**72.65**	**98.63**

VII. CONCLUSION

CSO was successfully implemented for a sample 3 bus and an IEEE 14 bus test systems. This latest AI technique which was never applied to voltage stability problems earlier produced the best results as compared to Exhaustive Search technique and PSO as can be seen from the above tables. From the results it is clear to state that the voltage magnitude profile, MLP have been improved as compared with Exhaustive Search technique [10] and PSO [11] keeping the losses under control.

VIII. FUTURE SCOPE

The future scope of this work includes the testing of this algorithm on an IEEE 30 bus and IEEE 118 bus test systems to find the optimal location for SVC and STATCOM and comparing it with PSO and Exhaustive search technique.

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