

Adaptive Facts Control For Voltage Instability Mitigation In Power Grids

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ABSTRACT

Now a day's voltage instability related problems in power system affects the system constraints and leads to voltage instability. Under normal operating conditions the Voltage instability problem is leads to interruptions in power system and this will reduces the system performance. The power system will require maintaining voltage stability during normal working condition to obtain better performance. It will go into instability state if a large interruption or increase in load requirement, or change in system condition causes a progressive and uncontrollable reduction in voltage. The unmanaged reactive power flow is the main reason for voltage instability in power system. A control of reactive power flow is done by means of Flexible AC Transmission System (FACTS) is a model of modern device. The effective management of reactive power flow is done by introducing FACTS device. The dynamic performance of the power system can be improved by providing automatic FACT Devices. This work deals with voltage instability prevention process in power system with the provision of automatic fact device. The design aims to reduce the voltage instability of power systems by means of providing automatic fact device. The outcome showed that the proposed technique reduced the voltage instability in IEEE system, and this method performed meta-heuristic optimization technique.

Keywords: Voltage instability Prevention; Automatic FACTS devices; Reactive Power flow

I. INTRODUCTION

In world economical system development the power system plays a major role. Currently, increasing power demand requires. Reactive power requirement is the main constraint involved in voltage instability related problem. The dynamic and efficient performance of the power system is improved by introducing FACTS devices in modern power system. FACTS devices provide effective reactive power compensation for voltage regulation [1]. In this research work the automatic fact device provision is initiated into the abnormal transmission line or bus bar of the power system. The faulted bus bar is identified and the reactive power compensation is provided by the FACTS devices for rectifying fault in source and load side.

In order to compensate reactive power in unstable system number methods are applied with automatic FACTS device provision [2-5]. In [6, 7, 8], to reduce voltage instability UPFC, TCSC, SVC, SVAR are the FACTS device is implemented with genetic algorithm for obtain reactive power flow equations and the reduction of Power loss. In the [9, 10, 11], the power system reliability is achieved through FACTS device allocation and system design parameter calculation. In [12], voltage and transient stability analysis of the power system is discussed for optimum power related research.

To obtain reactive power flow equation for calculating reactive power is a common matter in power system related problems. The most efficient method is (i.e.) EA (evolutionary algorithm) is discussed in this research work to obtain voltage instability. Classical optimization methods usually are local search based and have need of well-defined analytic functions. Evolutionary algorithm simply compares the quality of solutions.

This work deals with an automatic FACTS device provision method with an evolutionary algorithm. The proposed technique also adjusts other decision variables in order to reduce the voltage instability. The technique used an adaptive evolutionary algorithm to optimize the following stability indicators: the voltage profile, the reactive power flow losses, and the collapse in voltage margin. Some experiments were performed, and the outcome showed that the proposed method reduced the voltage instability in IEEE 14 and 57 bus bar systems, and the method also outperformed other Meta- heuristic optimization methods.

2. VOLTAGE STABILITY

In power system Voltage stability is achieved by means of reactive power compensation. The reactive power flow is the main constraint to maintain the system in suitable working condition. If the fault or interruption happens in the power system may leads to oscillation in bus voltage and the system goes under unstable operation. The stable operation of the system is achieved by means of allocating FACTS devices during abnormal condition. The oscillations in load voltage are occasionally called instability in load voltage.

According instability in load sometimes collapse the system performance. The poor performance in the system beyond the maximum acceptable range damages the appliances in customer side. Unstable voltage or collapse in voltage causes poor voltage profile and total or partial shutdown of the entire power system. The collapse in system voltage frequently named as voltage instability. To obtain stable operation of the power system the load voltage and system voltage should be maintained.

Equation 1 shows the voltage collapse index of the power system with n number of buses of transmission line which is mentioned below.

$$B_j = \left| 1 - \sum_{i=1}^{n_c} C_{ji} \frac{V_i}{V_j} \right| \quad (1)$$

Where,

B_j represents voltage collapse index,
 n_c represents the number of generation bus,
 V_i represents i^{th} generation bus voltage,
 V_j represents the j^{th} load bus voltage,
 C_{ji} represents the D matrix element.

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

Equation (2) shows the Y bus Submatrix.

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

This index B_j ranges from 0, stable system, to 1, which leads to collapse in voltage.

In Power system operation condition voltage instability categorized in to two mentioned below.

1. Short duration voltage instability
2. Long duration voltage instability

2.1. Short duration voltage instability

If the system has small interruptions under normal working condition the system operating state reaches unstable state for a short period of time which is known as short duration voltage instability. It may causes severe damages in the system on load side. The overloading of the power system also leads to this type of voltage instability.

2.2. Long duration Voltage instability

If the power system disturbed by interruption voltage for a long duration of time which is known as long duration voltage instability. The long duration voltage instability may occur in nonlinear types of loads. The voltage instability of the power system is happened by means of change in reactive power flow. The voltage stability limit is the maximum limit of power system to withstand normal working condition. Beyond the voltage stability limit the system performance is poor. By means of allocating FACTS devices the reactive power of the power system is compensated to maintain voltage stability limit.

2.3. Single Line Diagram

The single line diagram of IEEE 13 bus system is shown in fig 1. It is implemented in Matlab Platform.

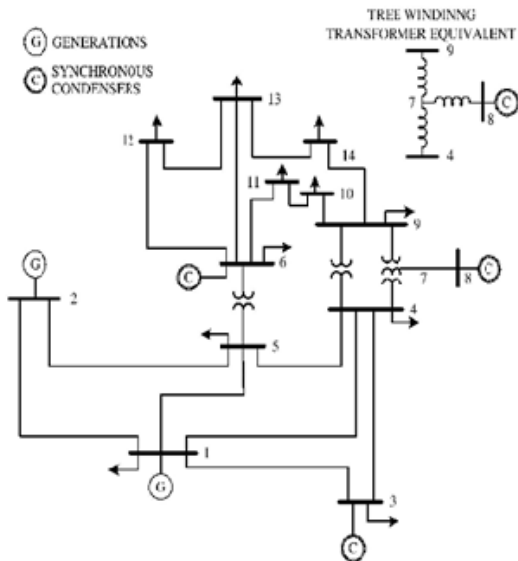


Fig 1: Single Line Diagram of IEEE 13 Bus Systems

Table 1 to 6 shows design and implementation of the IEEE 13 bus bar system for prevention of voltage instability in power systems.

No. runs	1
Minimum O.F.	8.094e+03
Maximum O.F	8.0940e+03
Mean O.F	8.0940e+03
Std.deviation O.F	0
Mean TOC(s)	17.7194

Table 1: Generator Statistics

Bus No	Pg(MW)
2	37.1345
2	34.9222
6	0
8	0

Table 2 : Generator Active Power

Table 3 shows the generator bus voltage of the IEEE 13 bus system.

Bus No	Vg.(p.)
1	1.0600
2	1.0400
3	1.0116
6	1.0600
8	1.0600

Table 3: Generator bus voltage

Bus no	V(p.u)	Teta(deg)	Pg(MW)	Qg(MVAr)	Qc(MVAr)	Pload(MW)	Cload(MVAr)
1	1.0600	0	196.6620	6.9880	0	0	0
2	1.0400	-4.0586	38.8979	38.8979	0	21.7000	12.7000
3	1.0116	-9.7341	25.7653	25.7653	0	94.2000	19
4	1.0008	-8.7244	0	0	0	47.2000	-3.9000
5	1.0031	-7.4640	0	0	0	7.6000	1.6000
6	1.0600	-12.9281	0	4.0571	0	11.2000	7.5000
7	1.0602	-11.7464	0	0	0	0	0
8	1.0600	-11.7464	0	-0.0950	0	0	0
9	1.0343	-13.4550	0	0	0	29.5000	16.60000
10	1.0313	-13.6510	0	0	0	3.5000	5.8000
11	1.0419	-13.4161	0	0	0	6.1000	1.8000
12	1.0442	-13.7940	0	0	0	13.5000	1.6000
13	1.0385	-13.8514	0	0	0	14.9000	5.8000
14	1.0178	-14.6607	0	0	0	29.5000	5

Table 4 Bus Voltage and Powers Under Optimum Control Variables;

Branch bus	From bus	To bus	T(p.u)
8	4	7	0.9000

9	4	9	1.1000
10	5	6	0.9000

Table 6: Branch Power Flow and Loss under Optimum Control Variables

From bus	To bus	P(MW)	Q(MVAr)	Ploss(MW)	Qloss(MVA)
1	2	13.0520	-5.4578	2.9634	9.047
1	5	65.6100	12.4458	2.1812	9.004
2	1	-128.0887	8.6835	2.9634	9.047
2	3	53.6986	2.4479	1.2627	5.319
2	4	50.7813	6.5437	1.4231	4.318
2	5	39.0433	8.5229	0.8595	2.624
3	2	-52.4358	-1.7378	1.2627	5.319
3	4	-6.8420	8.5031	0.0856	0.218
4	2	-49.3582	-5.7671	1.4231	4.318
4	3	6.9276	-9.5806	0.0856	0.218
4	5	-49.0409	10.7009	0.3358	1.059
4	7	26.7183	28.3332	0	3.441
4	9	13.9528	-19.7864	0	1.336
5	1	-63.4288	-8.6807	2.1812	9.004
5	2	-38.1838	-9.5107	0.8595	2.624
5	4	49.3768	-9.6415	0.3558	1.059
5	6	44.6359	26.2329	0	5.689
6	5	-44.6359	-20.7947	0	5.689
6	11	7.6086	6.0287	0.0797	0.166
6	12	7.8939	2.8211	0.0769	0.160
6	13	17.9334	8.5015	0.2319	0.456
7	4	-29.7186	-25.4818	0	3.441
7	8	0	0.0950	0	1.4151e-0
7	9	29.7188	25.3867	0	1.495

8	7	0	-0.0950	0	1.4151e-0
9	4	-13.9528	23.7252	0	1.336

Facts devices

The main aim of provision of FACTS device in power system to manages the parameter like, power flow in reactance, voltages in bus, and impedance of the transmission line. In this proposed technique consist of TCSC and SVC for FACT device allocation to maintain voltage stability to improve system performance.

Static VAR compensator

Static VAR Compensator (SVC) is parallel to a bus and provides a flexible reactance. A static VAR compensator is a parallel combination of controlled reactor and fixed shunt capacitor shown in the below fig 2. The thyristor switch assembly in the SVC controls the reactor. The firing angle of the thyristor controls the voltage across the inductor and thus the current flowing through the inductor. In this way, the reactive power draw by the inductor can be controlled.

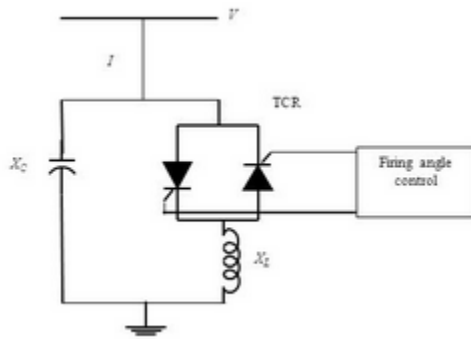


Fig 2: Static VAR compensator

The SVC is capable of step less adjustment of reactive power over an unlimited range without any time delay. It improves the system stability and system power factor.

Static VAR Compensator (SVC) is shunt connected to a bus and provides an adjustable reactance [15], [16]. The reactive power supplied by SVC in the j -th bus can be modeled as in Eq. (4)

$$Q_{svc} = -B_{svc} V_j^2 \quad (4)$$

Where V_j is the voltage magnitude at j^{th} bus and B_{SVC} is the SVC susceptance.

Advantage of Static VAR Compensator

- It increased the power transmission capability of the transmission lines.
- It improved the transient stability of the system.
- It controlled the steady state and temporary overvoltage's.

Thyristor controlled series compensator

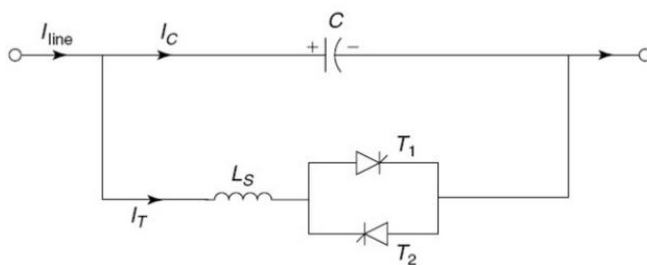


Fig 3: Thyristor Controlled Series Compensator

Thyristor Controlled Series Compensator (TCSC) is series connected to a transmission line in order to control its impedance. TCSC uses thyristor-controlled reactor in parallel to a capacitor bank. The series reactance is automatically adjusted to satisfy an amount of active power flow throughout the transmission line.

Thyristor Controlled Series Compensator (TCSC) is series connected to a transmission line in order to control its impedance [17]. TCSC uses thyristor-controlled reactor in parallel to a capacitor bank. The series reactance is automatically adjusted to satisfy an amount of active power flow throughout the transmission line. The modified admittance matrix, for addition of a TCSC, is expressed as

$$\Delta Y_{ij} = Y_{ij}^{\text{mod}} - Y_{ij} = (g_{ij}^{\text{mod}} + jb_{ij}^{\text{mod}}) - (g_{ij} + jb_{ij}) \quad (5)$$

$$g_{ij} = -\frac{v_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}} \quad (6)$$

$$b_{ij} = -\frac{x_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}} \quad (7)$$

$$g_{ij}^{\text{mod}} = -\frac{r_{ij}}{\sqrt{r_{ij}^2 + (x_{ij} + x_{TCSC})^2}} \quad (8)$$

$$b_{ij}^{\text{mod}} = \frac{x_{ij} + x_{TCSC}}{\sqrt{r_{ij}^2 + (x_{ij} + x_{TCSC})^2}} \quad (9)$$

III. AUTOMATIC ALLOCATION OF FACTS DEVICES;

This research study regards three indicators in order to enhance the voltage stability of power systems: L-index, voltage deviation, and reactive power losses. The proposed optimization method models three objective functions by using these indicators. The first objective function, which uses L index, is modeled as in Eq.

$$F_1(X) = \min(\max(L)) \quad (10)$$

where X is the vector of decision variables and $L \in [0;1]$ is the L-index. L equal to 0 means stability and L equals to 1 means suggest proximity to voltage collapse.

The second objective function, which uses the voltage deviation, is modeled as in Eq. (13)

$$F_2(X) = \sqrt{\sum_{i=1}^{N_L} (v_i - 1)^2} \quad (11)$$

Where V_i , in pu, is the voltage magnitude of i^{th} load bus and N_L is the number of load buses. The optimization algorithms based on the behavior of living beings has gained prominence in recent years because of the quality of these solutions and the ease of implementation, in addition to these are flexible to change in the objective function. The following subsections present the optimization algorithms used in the experimental study.

3.1. Adaptive Evolutionary Algorithm

Evolutionary algorithm is a efficient mechanism for search and optimization, and one of the best known evolutionary computation methods [18]. An important issue in an evolutionary algorithm is maintaining its variety to avoid the premature convergence. The diversity control aims to reduce the distinction between the population diversity and a reference value [19]. The proposed method uses an adaptive evolutionary algorithm (AEA) to control the population diversity, avoiding the premature convergence and maintaining the global search.

Decision Variable Coding

The individual of the population, which coded the vector of decision variable X, is formed by the voltage magnitude of the generator buses, the shunt capacitor bank, transformer tap settings, and the location and reactive power injection of TCSC and SVC devices.

DIVERSITY CONTROL

The population diversity means how different the individuals are from each other. Control of the population diversity of an EA, or minimizing its loss, may benefit the evolutionary process in several ways, such as, preventing premature convergence to a local optimum and considering different niches for solutions of multimodal problems [20].

In this work, the population diversity is calculated, at k^{th} generation, as follows

$$\Gamma(k) = 1 - \sum_{i=1}^{n_s} \rho_i^2 \quad (12)$$

Where n_s are the number of alleles and ρ_i is the i^{th} occurrence rate.

The diversity control is performed by changing the mutation rate, ρ_m , when there is a deviation between the population, G , and reference, G_r , diversities. The mutation rate is updated in order to vanish this deviation as follows

$$\rho_m(k+1) = \rho_m(k) + \eta(\Gamma_r - \Gamma(k)) \quad (13)$$

IV. Experimental studies

Proposed Model

The standard IEEE 14, 30 and 57 bus-bar power systems is used. In a PSO process, a swarm of particles of potential solutions browses the global optimal solution through the search space. During their trip with discrete-time iterations, the speed of each particle in the next iteration is calculated as a function of the best swarm position, the best particle position, and its previous Meta-heuristic-optimization(GSA), Simulated annealing (MSA, BSA) emulates the physical annealing process when applied to combinatorial optimization(PSO-GSA). Simulated annealing aims to find an ideal setting, or state with minimum energy, of a complex problem.

Experiments with Standard EA

For the IEEE 14, 30 busbar system the proposed EA-based reduced more than 30% in L-index, 20% in reactive power losses, and 90% in voltage deviation. For IEEE 57 busbar system. The proposed EA-based reduced more than 50% in L-index and voltage deviation. Table 7 shows the standard evolutionary algorithm results.

OBJ.FUNCTIONS	INITIAL	EA	PSO	SA
L.index	0.0768	0.0523	0.0523	0.0572
Voltage deviation	0.1424	0.0067	0.0083	0.0236
MVAR losses	54.54	42.26	42.86	46.93

Table 7: EXPERIMENTS WITH STANDARD

Experiments with Adaptive EA

The fittest individual for voltage deviation throughout the evolutionary process and at the load buses in IEEE 14, 30 busbar systems, respectively, for EA and AEA. AEA outperformed EA since the beginning of the evolutionary process, and the former reached a final fitness 50% better than the latter.

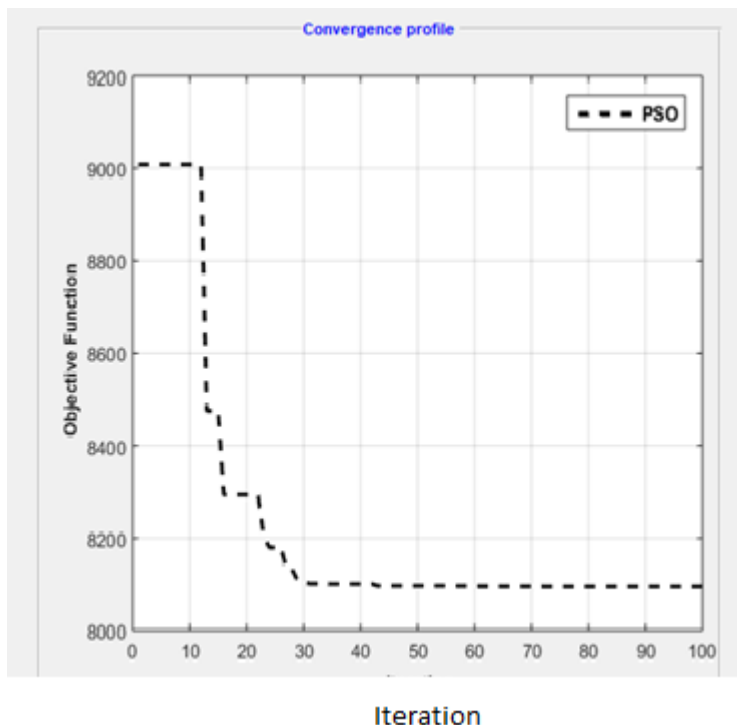


Fig 4: Experiments with Adaptive EA

Fig 4 experimental results of particle swarm optimization of Adaptive evolutionary algorithm. Table 8 shows the experiments with adaptive evolutionary algorithm results.

OBJ.FUNCTIONS	INITIAL	EA	PSO	SA
L.index	0.3099	0.1497	0.1561	0.1722
Voltage deviation	0.2043	0.0906	0.1471	0.1873
MVAR losses	121.67	75.60	87.23	114.05

Table 8: Experiments with Adaptive EA
NUMERICAL ASSESSMENT

In this work, comparison evaluation of the proposed research work is done to prove their performance improvement. The comparison is made between the General evolutionary algorithm PSO and the Adaptive evolutionary algorithm namely Adaptive PSO (APSO). In this research work, voltage stability index and transmission loss is considered for the comparison evaluation. Here the comparison is made in two cases. Those are with FACT devices and without FACT devices. Along with these, varying voltage profiles also shown in this research work.

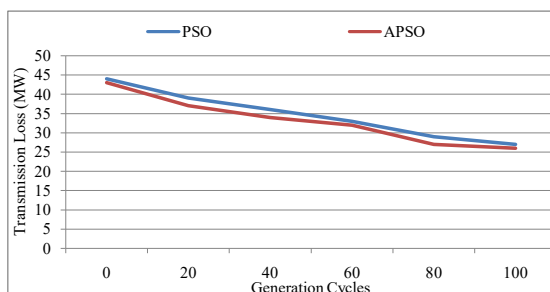


Figure 3. Transmission Loss comparison without FACT devices

The convergence characteristic of the proposed research technique is shown in the figure 3. From this comparison it is proved that the proposed method tends to have lesser transmission loss than the other research techniques. From this analysis it is confirmed that the proposed APSO shown 4.62% lesser transmission loss than the traditional PSO algorithm.

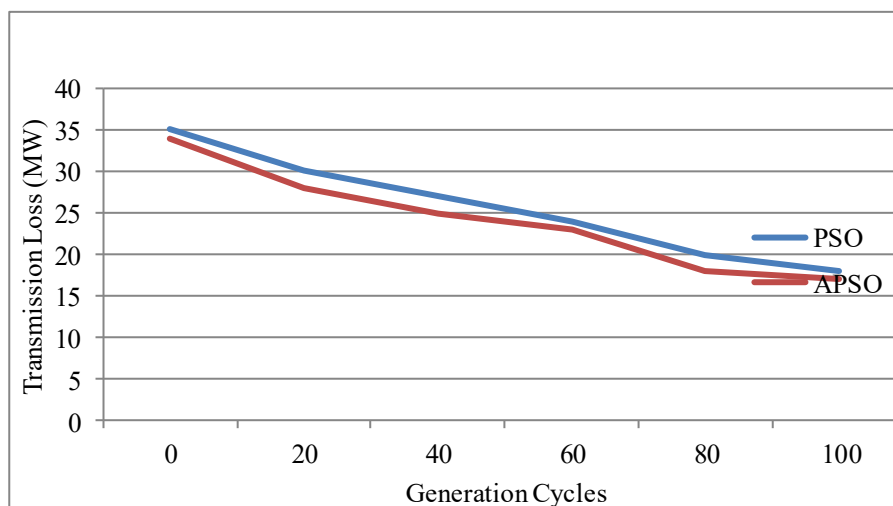


Figure 4. Transmission Loss comparison with FACT devices

The convergence characteristic of the proposed research technique is shown in the figure 4. From this comparison it is proved that the proposed method tends to have lesser transmission loss than the other research techniques. From this analysis it is confirmed that the proposed APSO shown 5.93% lesser transmission loss than the traditional PSO algorithm.

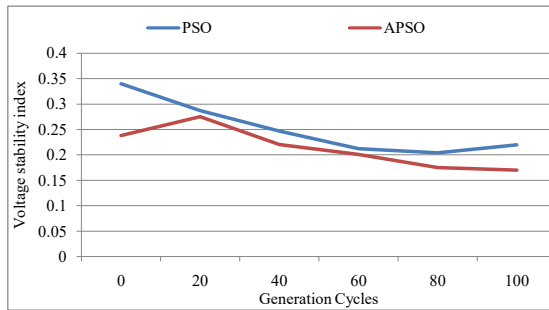


Figure 5. Voltage Stability Index Comparison without FACTS devices

The voltage stability index of the proposed research technique without FACTS devices is shown in the figure 5. From this comparison it is proved that the proposed method tends to have lesser stability index than the other research techniques. From this analysis it is confirmed that the proposed APSO shown 15.29% lesser voltage stability index than PSO.

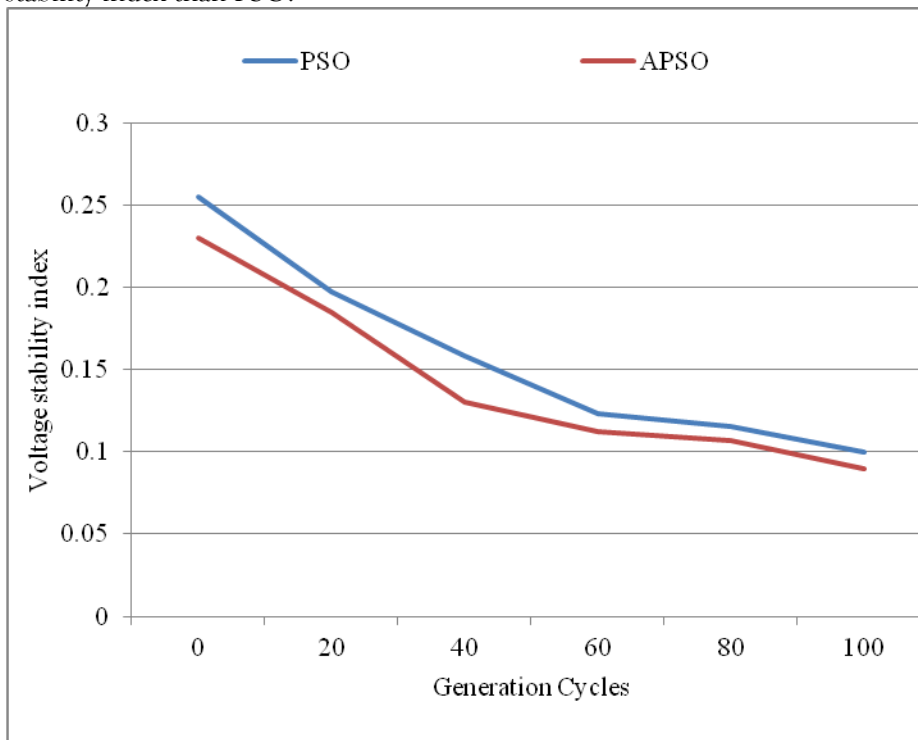


Figure 6. Voltage Stability Index Comparison with STATCOM

The voltage stability index of the proposed research technique with FACTS devices is shown in the figure 3. From this comparison it is proved that the proposed method tends to have lesser stability index than the other research techniques. From this analysis it is confirmed that the proposed APSO shown 9.9% lesser voltage stability index than PSO.

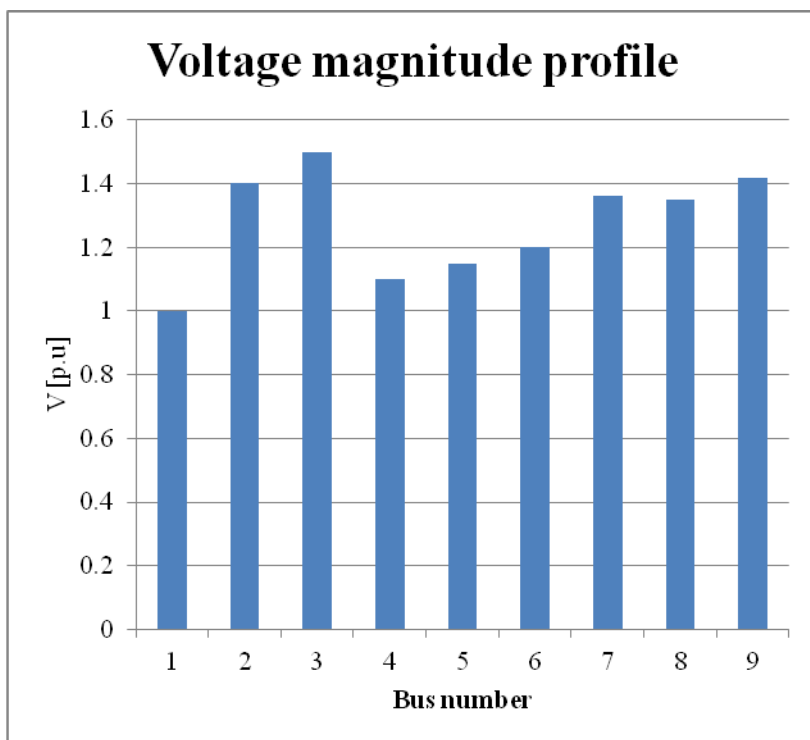


Figure 7. Voltage magnitude profile for system without FACT devices

Figure 7, shows the voltage magnitude profile observers in the environment where there are no fixed FACT devices. This figure illustrates, how voltage deviates in different buses without fixing any devices to control it. In the following figures voltage magnitude profile after fixing FACT devices are shown.

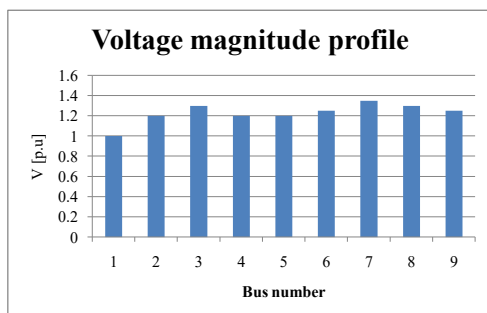


Figure 8. Voltage magnitude profile for system with Evolutionary PSO

Figure 8, shows the voltage magnitude profile observed in the environment where FACT devices are located using PSO algorithm. This figure illustrates, voltage deviation occurred in the different buses after fixing the FACT devices by using evolutionary PSO algorithm. When comparing it with figure 7, here voltage deviation is lesser than without having FACT devices. However it still shows considerable voltage deviation.

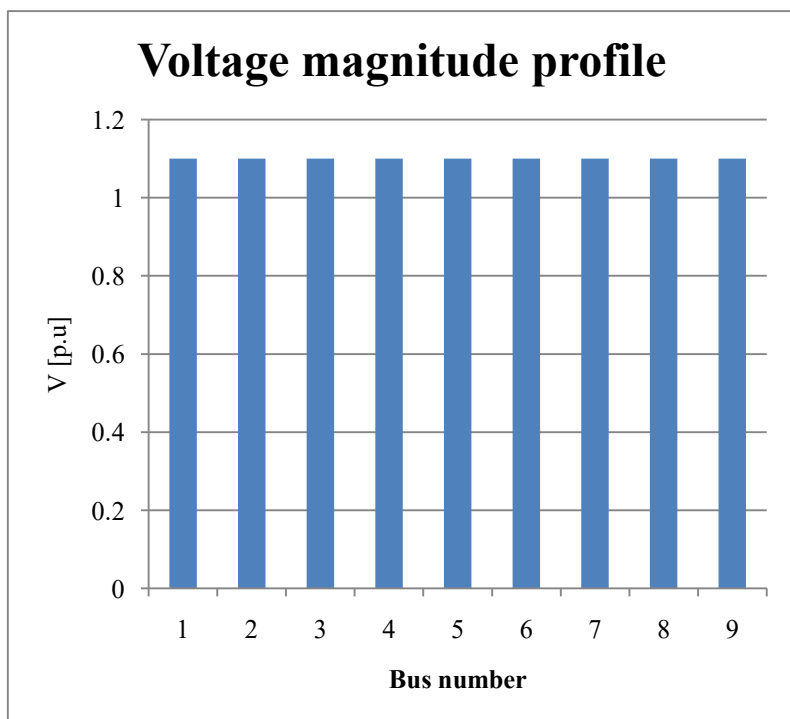


Figure 9. Voltage magnitude profile for system with Adaptive PSO

Figure *, shows the voltage magnitude profile observed in the environment where FACT devices are located using APSO algorithm. This figure illustrates, voltage deviation occurred in the different buses after fixing the FACT devices by using adaptive PSO algorithm. When comparing it with figure 7 and 8, here voltage deviation is lesser than without having FACT devices. It is proved that by using adaptive algorithm voltage stability can be controlled in great.

CONCLUSION

This paper deals with the reduction voltage instability through an optimization process. The method projected an automatic provision of FACTS devices and adjustments of choice variables by using an adaptive evolutionary algorithm. Three objective functions were designed by using performance indicator of power systems: L-index for voltage collapse margin, voltage divergence at load buses, and reactive power losses. The method was validated in investigational studies with two standard IEEE power systems by comparing the performance of various optimization techniques PSO, SA, EA, and the proposed adaptive EA. The results showed that the EA-based methods outperformed the other ones, particularly in IEEE 57 busbar system. In IEEE 14 busbar system, all technique reached similar results in experiments with the objective functions based on L-index and reactive power losses. In experiments with the intention based on voltage deviations, EA outperformed the other ones. On the other hand, in experiments with IEEE 57 busbar system, a bigger dimension system, EA outperformed the other technique in all experiments. In experiments that EA and adaptive EA were compared, the final had better performance than the standard EA in all aspects. Several new studies can be happened from this research, such as control multiplicity analysis and a multi objective approach concerning two or more objective functions used in this research.

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