Optimal Location and Parameter Setting of FACTS Devices to Improve the Performance of Power System using Genetic Algorithm Technique

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ABSTRACT:
The Flexible AC Transmission System (FACTS) is a system for improving the operation of electrical power systems. It is very important to know that their implementation is very difficult and imposes a particular location that must be mandatory optimal. In this paper one of the heuristics methods based on genetics has been implemented for determining the optimal locations of FACTS devices in the electrical network. The standard 14-node IEEE network has been used for testing and validating the proposed method it in the MATLAB environment.

KEYWORDS: FACTS, Genetic Algorithm, Performance, Stability.

1. INTRODUCTION

In the present time, the world's electric power systems are widely interconnected. This is done mainly for economic considerations, to reduce the cost of electricity and to improve reliability of power supply. As power transfers grow, the power system becomes increasingly more complex to operate and the system can become less secure for riding through the major outages [1].

The flexible alternating current transmission systems FACTS technology can be used to overcome many the lacks mentioned above. The devices is a system for improving the operation of electrical power systems such as voltage stability, transient stability, system loadability and other [2, 3]. Hence it is very important to know that their implementation is very difficult and imposes a particular location that must be mandatory optimal. In this context, several researches have been developed in order to install these devices in an suitable location and with the best parameters to optimize the technical performances of power system such as; Optimal location of phase shifters in the French network by Genetic Algorithm developed by paterni in [4], Optimal placement of multiple-type FACTS devices to maximize power system loadability using a Generic Graphical user interface by Ghahremani in [5], Multiobjective optimal location of FACTS shunt-series controllers for power system operation planning presented by laskhar [6], Genetic Algorithm for Solving Optimal Power Flow Problem with UPFC [7]. Unfortunately these researches were partial and didn't touch all the performances such as voltage profile, line losses, transient and dynamic stability. However, only some devices were used in their research paper namely UPFC or other.

In our study we will integrate various FACTS Devices such as SVC (or STATCOM), TCSC (or SSSC), TCVR, TCPST and UPFC. In the other hand, the FACTS parameter's must be seriously taken into account so that the device plays it's own role in electrical network, this is the case study of Jigar, Yang and Husam respectively in [8], [9] and [10]. However the optimized parameters of FACTS devices must be studied taken in consideration various IEEE standard power system 09, 14, 30, 57 and 118 BUS systems; this is our case study in this paper. Finally, the majority of cases study based on programs codes and calculation but not practices, because of the impossibility brings to researchers and engineers. We will implement the obtained placements and parameters in IEEE 14 BUS power system using Power System Analysis Toolbox (PSAT) to validate some solutions given by GA technique.

The mentioned lacks forced us to think how to combine different views, therefore we developed a MATLAB programs to give better placements and parameters of various FACTS devices to improve the performances of the system and overcome the lacks mentioned above. We used the Genetic Algorithm as an optimization technique then a graphical interface was developed to facilitate the use of this technique, in sum and according to the obtained data, we used the PSAT to project and test the obtained placements and parameters, especially in IEEE 14 BUS Power System. The results given by this technique of optimization are presented later in this paper.

2. FACTS DEVICES MODELLING

The mathematical model of the FACTS devices must be given in order to be able to make a better analysis in steady state. For our study, we used FACTS devices: SVC (or STATCOM), TCSC (or SSSC), TCVR, TCPST, UPFC and STATCOM with SMES.

2.1. Static Var Compensator

SVC is used as an inductive or capacitive compensator. Its mathematical model is characterized by two ideal elements switched in parallel; one capacitive and the other inductive [14], [15]. The principle of SVC is therefore to inject or absorb reactive power at the node where it is connected.

$$-\text{QSVC max} \leq \text{QSVC} \leq \text{QSVC max} \quad (1)$$

With a typical parameter of QSVC max = 300 MVar.

2.2. Thyristor Controlled Serie Compensator

The modification of the line reactance allows the TCSC to behave as an inductive or capacitive compensator [17]. For the capacitive mode, it is set at -0.8 XL and 0.2 XL is the maximum parameter of the inductive mode, where XL is the reactance of the line.

$$K_{TCSCmin} \leq K_{TCSC} \leq K_{TCSCmax} \quad (2)$$

The maximum compensation parameters are set at: $K_{TCSCmin}$ = - 80% in capacitive mode; $K_{TCSCmax}$ = 20% in inductive mode

2.3. Thyristor Controlled Voltage Regulator

To modify the node voltage level, Thyristor voltage regulators (TCVR) are used [19]. This latter is represented by an ideal tap-changer transformer without series impedance as follows

$$V_{TCVR} = K_{TCVR} V_i$$
$$-K_{TCVR\,max} \leq K_{TCVR} \leq K_{TCVR\,max}$$
$$V_{i'} = (1+K_{TCVR})\, V_i$$
$$0.85\, V_i \leq V_{i'} \leq 1.15\, V_i \quad (3)$$

With typical parameter of $K_{TCVR\,max}$ *=0.15.*

2.4. Thyristor Control Phase Shifting Transformer

To regulate the voltage angle between the end of the source and the end of the transmission line, the Thyristor Controlled Phase Shift (TCPST) transformer is used. It is represented by an ideal phase shifter [8].

$$-\delta_{TCPST\,max} \leq \delta_{TCPST} \leq \delta_{TCPST\,max} \quad (4)$$

With a typical parameter of $\delta_{TCPST\,max} = 20°$. The angle δ_{TCPST} is the phase of the TCPST used to regulate the angle between bus i and bus k.

2.5. Unified Power Flow Controller

The UPFC is a device consisting of two FACTS, one series and the other parallel. It is the most powerful device because it ensures both a dual function of the FACTS series and shunt. It is the most powerful FACTS device [17], [19], [20]. The three controllable parameters of the UPFC are Vse, θse and Ish. Where Vse is the amplitude of the voltage injected in series with the transmission line at intervals [Vse min = 0, Vse max = 0.3], θse is the phase angle of this voltage at intervals [θse min = 0 ° , θse max = 360 °] and Ish is the bypass current of a reactive source of the UPFC in the intervals [Ish min = - 0,15, Ish max = 0,15]. The reactive power can take a discrete number of parameters in the range: -Qmax ≤ Q ≤ Qmax; where: Qmax = 200 MVar and corresponds to the maximum reactive power that can be absorbed or supplied.

3. GENETIC ALGORITHM

John Holland and colleagues at the University of Michigan [7] have proposed the genetic algorithm whose initial concept was first studied by JD Bagley in 1967: "The behavior of adaptive systems that use genetic and correlative algorithms" [8]. Other independent studies on evolutionary algorithms include [12]. The genetic algorithm is a search-based optimization technique that evolves in a search space of the candidate population to identify the best individual in the population.

4. PROBLEM FORMULATION

The aim of optimization is to perform the most effective utilization of a transmission lines, in this context, the best locations of FACTS devices is to maximizing loadability of electrical network while the thermal and voltage constraints are also respected; that is, in terms of branch loading and the voltage levels, the holding power system is in a security state to maximize the power that is transmitted by the electrical network to the customers.

The objective function is designed to penalize the configurations of FACTS devices that lead to overloaded transmissions lines and over or under-voltage at buses.

4.1. Penality Factor

In our case study, the load factor λ of the network was increased in an iterative optimization process in accordance with the description of this subsection.

First, the modification of the generating power in the generation buses according to, Eq. (5).

$$P_{Gi} = \lambda * P_{Goi} \quad (5)$$

Where,

P_{Goi}, P_{Gi} are respectively the initial power generation at bus i and the modified power

For the load buses the active and reactive power were modified according to, Eq. (6).

$$P_{Li} = \lambda * P_{Loi} \quad \text{and} \quad Q_{li} = \lambda * Q_{Loi} \quad (6)$$

4.2. Objective Function

The corresponding objective function to maximize the power system loadability could be formalized as follows:

$$F = max\{\lambda\} \quad (7)$$

To simplify the enforcement of the process constraints while the FACTS devices are placed at random locations, let us define a fitness function F_t so that the two terms that are targeted separately the first term in line overloading Ove_l and the second term is related to bus voltage violations Vio_B are included as follows:

$$F_t = 2 - \{\prod_{Line} Ove_L + \prod_{Bus} Vio_B\} \quad (8)$$

4.3. Optimisation Strategy Using GA

The number of individuals is calculated for a population according to the following equation:

$$n_{Ind} = 3 * n_{FACTS} * n_{Placement} \quad (9)$$

Where,

n_{FACTS}: The number of simulated FACTS devices and $n_{Placement}$ is the total number of locations of the FACTS devices.

The real value of the FACTS devices is calculated by the following relation:

$$v_{RealFACTS} = v_{min} + (v_{max} - v_{min}) * v_{FACT} \quad (10)$$

Where: V_{min} and V_{max} are the minimum and maximum setting values of the FACTS devices, respectively, and V_{FACTS} is its normalized value. The initial load factor is equal to 1.

5. GENETIC ALGORITHM PARAMETERS

In the Table 1, we present the Genetic Algorithm parameters used in the simulation

Table 1. The value of each parameter of (GA).

Genetic Algorithm Parameter	values
generations	120
Population size	15
elite count	4
Crossover fraction	0.8
Fitness limit	$1e^{-6}$
Time limit	inf

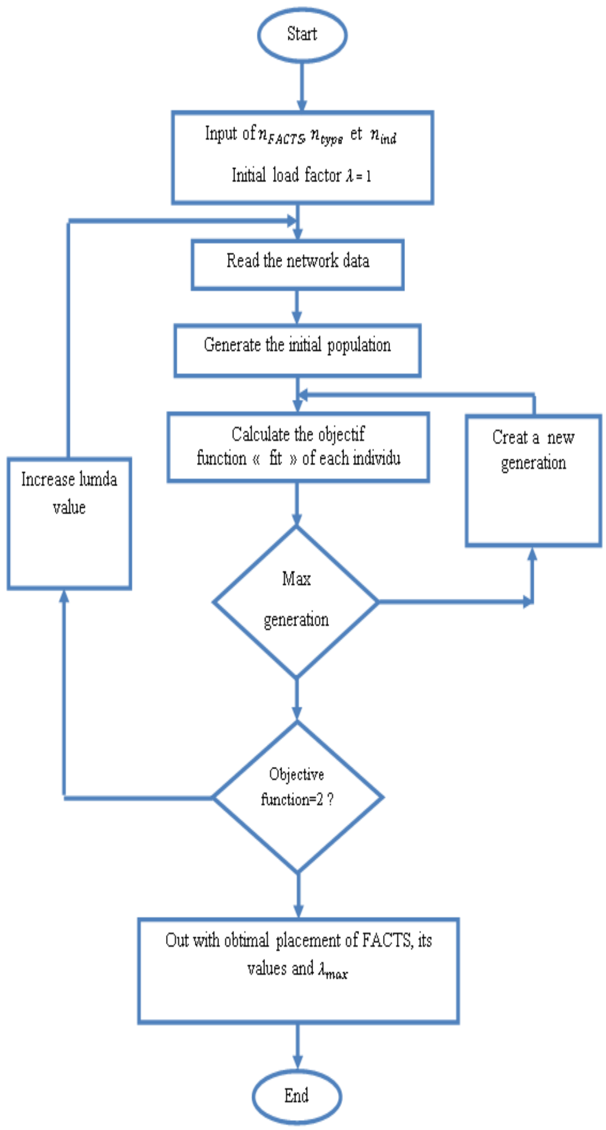

Fig. 1. Flowchart of optimization according to GA.

6. SIMULATION RESULTS

Table 2: The location of FACTS devices, its parameters and total line losses, illustrated on the various IEEE –power systems model.

In order to validate our method proposed in this paper, we used the Matlab environment to simulate the different IEEE test networks 09, 14, 30, 57 and 118 bus. The simulation results obtained are presented for the different cases, with different types of FACTS such as TCSC, SVC, STATCOM, SSSC, TCVR, TCPST and UPFC. All possibilities are studied with AG techniques. Namely, the effect of the optimal placement of the FACTS device and its best parameters on the system performance: system load capacity, voltage deviation, line losses and overall stability.

Table 2. Optimal placement of FACTS devices with their best parameters in various test systems.

System test	Type of FACTS device	Location of FACTS	Device parameters	Total losses	
				Without FACTS	With FACTS
09 BUS	SVC	BUS 09	-29.418 MVAr	14 MW	13 MW
	TCSC	Branch 07	-0.211 Reactance		
14 BUS	TCVR	Branch 07	1.033 Ratio	50 MW	49 MW
	TCVR	Branch 02	1.073 Ratio		
30 BUS	SVC	BUS 04	-110.494 MVAr	10MW	8MW
	SVC	Branch 21	-176.159 MVAr		
	TCSC	Branch 15	-0.363 Reactance		
	TCSC	Branch 01	-0.463 Reactance		
	TCSC	Branch 05	-0.102 Reactance		
	TCSC	Branch 22	-0.119 Reactance		
57 BUS	SVC	BUS 23	-38.203 Mvar	139MW	123MW
	SVC	Branch 37	298.070 Mvar		
	TCSC	Branch 67	0.066 Reactance		
	TCSC	Branch 50	-0.698 Reactance		
	TCSC	Branch 01	-0.294 Reactance		
	TCVR	Branch 47	0.901 Ratio		
	TCPST	Branch 61	-8.388 Degree		
	UPFC	Branch 77	0.121 p.u.		
			318.873 Degree		
			-0.020 p.u.		
118 BUS	SVC	BUS 53	0.51809 p.u	262 MW	249MW
	SVC	BUS 113	0.90306 p.u		
	SVC	BUS 1	0.75209 p.u		
	TCSC	Branch 69	0.88364 p.u		
	TCSC	Branch 89	0.96301 p.u		
	TCSC	Branch 161	0.87917 p.u		
	TCVR	Branch 99	0.58953 p.u		
	TCVR	Branch 41	0.49612 p.u		
	TCPST	Branch 110	0.22395 p.u		
	TCPST	Branch 65	0.055579 p.u		
	UPFC	Branch 70	0.78, 0.84, 0.20 p.u		

In the 09 and 14 Bus test systems the total line losses difference with and without FACTS is 1 MW; in 57 Bus we have 16 MW; and in the 118 Bus we can compensate until 13 MW when use the optimal placements of FACTS Devices.

7. THE SIMULATION ACCORDING TO THE SCENARIOS PRESENTED IN THE TABLE 2

To validate our approach, after choosing the type and the number of FACTS; the program is run for determining optimal placement and parameters and we saved the results in the Table 1. In the other hand, a graphical representation of voltage deviation and total line losses were exposed in the Figs. 2- 9.

Case 1-IEEE 09 BUS system

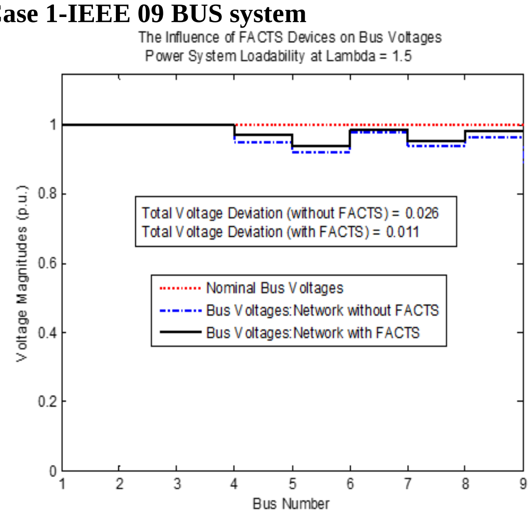

Fig. 2. Voltage deviation of 09 BUS system.

Case 2-IEEE 14 BUS system

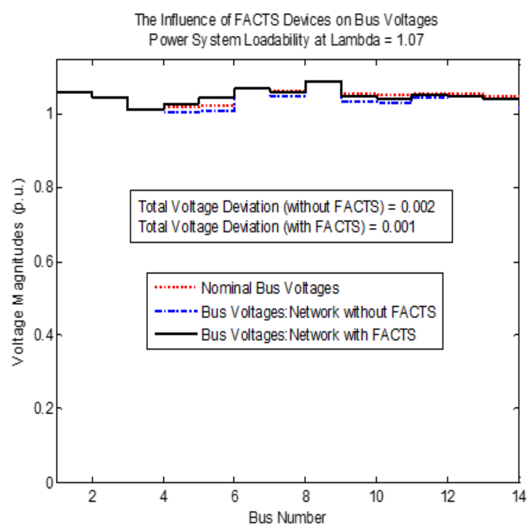

Fig. 3. Voltage deviation of 14 BUS system.

Figs. 2, 3, 4 and 5 show the Bus voltages deviation without FACTS and with optimal placements of FACTS. For example in the 57 BUS test system we have TVD = 0.3 instead of 2.04 without FACTS.

Case 3-IEEE 30 BUS system

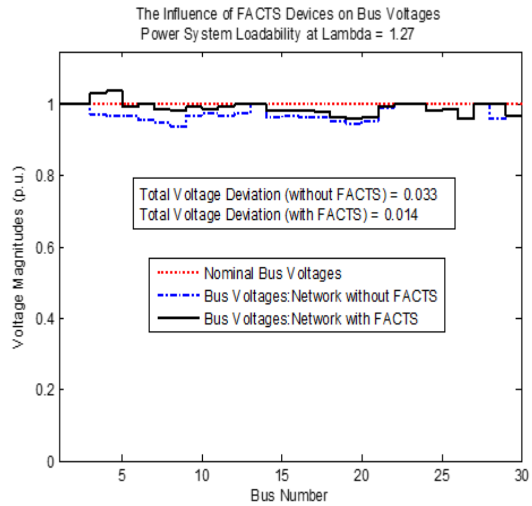

Fig. 4. Voltage deviation of 30 BUS system.

Case 4-IEEE 57 BUS system

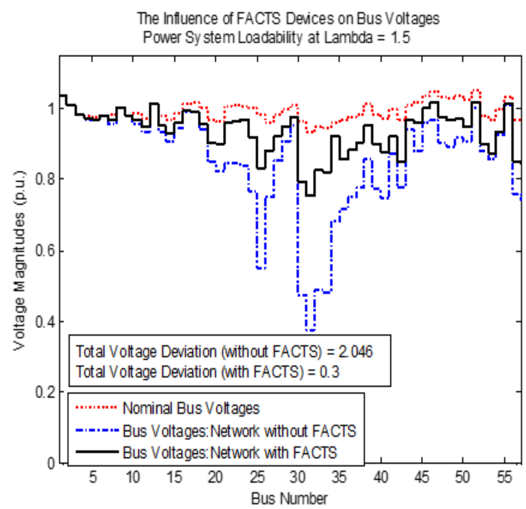

Fig. 5. Voltage deviation of 57 BUS system.

8. THE INFLUENCE OF FACTS DEVICES ON LINE LOSSES FOR VARIOUS NETWORKS

Figs. 6, 7, 8, and 9 present the total line losses in the lines. With optimal placement of FACTS and without FACTS; in 57 Bus test we have 16 MW benefit.

Case 1-IEEE 09 BUS system

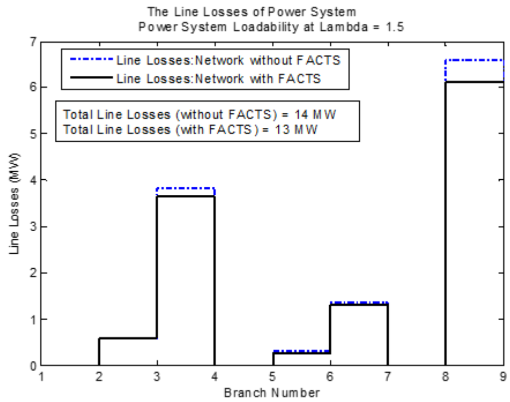

Fig. 6. Total line losses of 09 BUS system.

Case 2-IEEE 14 BUS system

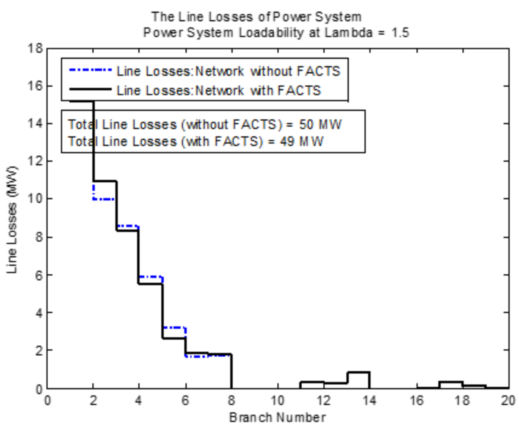

Fig. 7. Total line losses of 14 BUS system.

Case 3-IEEE 30 BUS system

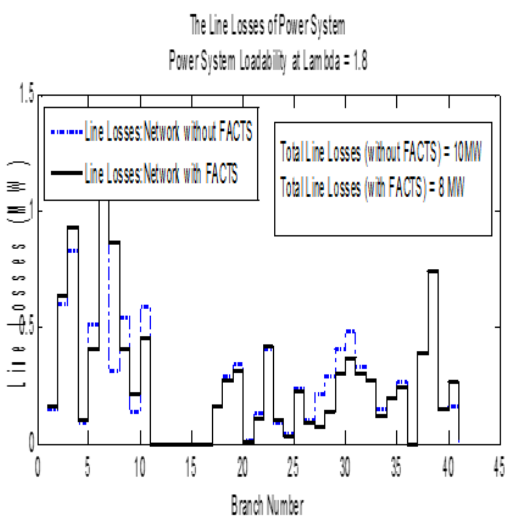

Fig. 8. Total line losses of 30 BUS system.

Case 4-IEEE 57 BUS system

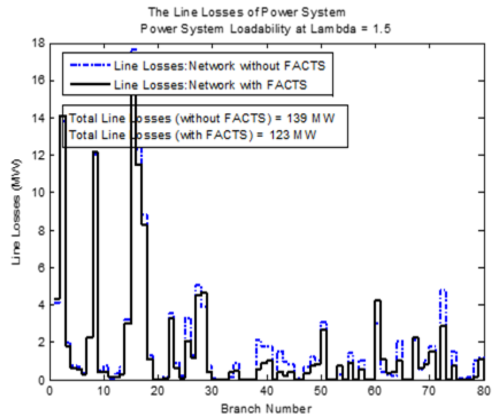

Fig. 9. Total line losses of 57 BUS system.

9. INVESTIGATION OF ONE SOLUSTION OF GENETIC ALGORITHM USING PSAT (APPLICATION IN IEEE 14 BUS TEST SYSTEM)

Case study in Table 3.

Table 3. Case study

System test	FACTS number	FACTS type	FACTS placement
IEEE14-BUS	3	SVC	BUS 6
		STATCOM	BUS 2
		TCSC	Branch 9-10

10. THE SIMULATION SCHEME DEVELOPED IN PSAT

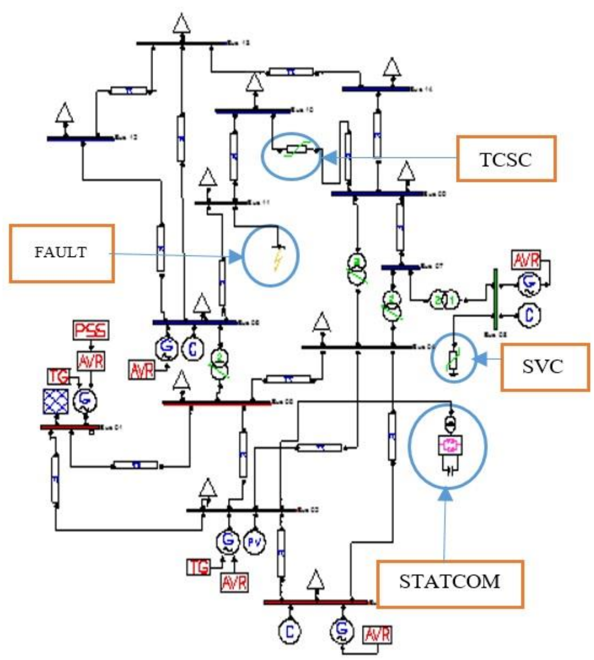

Fig. 10. IEEE 14 BUS system developed in PSAT.

11. THE EFFECT OF OPTIMAL PLACEMENT ON SYSTEM STABILITY

In the scheme presented in Fig.10 we will implant the FACTS devices according to the suitable location given by GA technique, the optimal placements were indicated in Table 3; In this example case, we used the proposed locations to validate our approach in order to test the behavior of synchronous machines in IEEE 14 BUS test. The effect of optimal placements in the stability of power system is presented in Figs. 11 and 12.

11.1. Dynamic stability

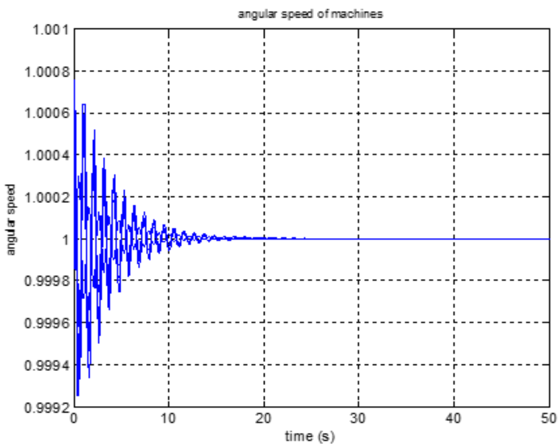

Fig. 11. Angular velocity of the machines.

11.2. Transient stability (Fault created at Bus 11)

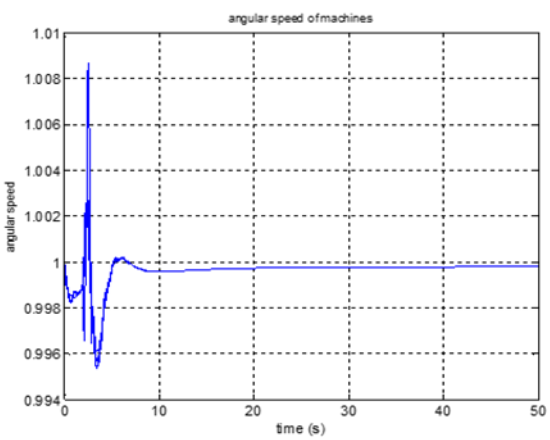

Fig. 12. Angular velocity of the machines.

12. DISCUSSION

According to the results presented in Figs. (3 - 13), it could be seen that the voltage deviation has greatly decreased, the total losses in the lines have also decreased, especially after the test of a solution obtained by the GA technique in the IEEE bus system using the PSAT.

Figs. 3, 4, 5 and 6 show the effects of the optimal location of the FACTS devices in the voltage deviation of the IEEE-09, IEEE-14, IEEE-30 and IEEE-57 bus systems using the GA technique. The figures reveal that the voltage profile improves significantly with the optimal location of the various FACTS devices. This shows a significant improvement in system safety under abnormal loading conditions with the optimal location of FACTS devices.

13. CONCLUSION

The method presented in this paper has helped us to make the right choice of optimal positioning and parameters: This approach is based on the genetic algorithms method which has allowed locating the optimal location of the FACTS devices in the different systems, as well as, IEEE standard power supply. We noted the increase in the load capacity of the power system and the minimization of transmission losses and thus overall stability of the electrical system. Different types of FACTS devices have been taken into account in this study. It is clear from the simulation results that the efficient placement of FACTS devices in appropriate locations with optimal settings can significantly improve system performance. This approach could serve as a new technique for the installation of FACTS devices in the large electrical system.

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