K.Karthikeyan[1,*],
P.K.Dhal[2]

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Regular paper

Investigation of optimal location and tuning of STATCOM by genetic algorithm based transient stability improvement

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The power electronics device plays an important role in power system operation and control. The voltage instability and voltage collapse have been considered in present power system scenario due to over load condition. So transient stability development via optimal location and tuning of STATCOM (Static synchronous Compensator) is systematically investigated in this paper. The performance analysis of STATCOM has been implemented for Western Science Coordinated Council (WSCC) 9 bus system for the development of transient stability using Power System Analysis tool box (PSAT) software. The system has analyzed through various working conditions like Without STATCOM, with STATCOM (untuned) and with STATCOM (tuned) when the system undergoes a three phase fault. The effectiveness of STATCOM is shown through the nonlinear time-domain simulation. The results are compared with the Genetic Algorithm based tuned STATCOM and shows successful performance of the tuned system.

Keywords: STATCOM, PSAT, transient stability, genetic algorithm, optimal location

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1. Introduction

In our modern day, the power system network is structured with lots of buses and numerous generating stations being interconnected via power transmission lines. In the power system scenario, the low frequency oscillations are formed due sudden change of load or faults. A suitable damping of the power system oscillations is an important issue when facing with stability of the power system [1] [2]. To improve the stability of the system, FACTS (Flexible AC Transmission Systems) are designed and used in recent years. FACTS devices are employed to inject or absorb the reactive power [3] [4]. FACTS are utilized to improve power system operation control and power transfer capability.

The voltage control and reactive power compensation using STATCOM by genetic algorithm & particle swarm optimization is proposed in some papers. In some papers coordinated design of PSS and STATCOM papers are presented [5]. In some papers, the effect of power system stabilizer is explained. The optimal location and tuning of STATCOM has an essential role to enhance the stability [6] [7]. This paper presents the investigation of best location and tuning of STATCOM through genetic algorithm to enhance the transient stability [8] [9] [10] for three phase fault conditions. Genetic algorithm is initially developed by John Holland during 1970's. It is an iterative procedure which maintains constant size population solutions. During each iteration step, there are three genetic operators such as reproduction, crossover and mutation. It is performed to generate new populations and the chromosomes of the new populations are evaluated through fitness value. Based on these genetic operators and its evaluation the new population of population solution formed. If the search goal has not been achieved, again genetic algorithm creates offspring strings through three operators. This process is

* Corresponding author: [1] K.Karthikeyan, Research Scholar, Department of Electrical and Electronics Engineering, Veltech Dr.RR & Dr.SR University, Chennai, India, Email: karthi_3050@yahoo.com

[2] P.K.Dhal, Professor, Department of Electrical and Electronics Engineering, Veltech Dr.RR & Dr.SR University, Chennai, India, Email: Pradyumna.dhal@rediffmail.com

continued until the search goal is achieved.The performance of the proposed controller is carried out by the time domain simulation.

2. Notation

The notation used throughout the paper is stated below.

Indexes:

K_r	Regulator gain of STATCOM
T_r	Regulator time constant of STATCOM
σ_i	Real part of the eigen value in i
ω_i	Imaginary part of eigen value in i
λ_i	Eigen value in i
ξ_i	Damping ratio in i
J_1, J_2	Objective function
λ	Constant
P	Real power in generation side and load side p.u
Q	Reactive power in generation side and load side p.u
V	Bus voltage magnitude in p.u

3. Genetic algorithm procedure

Step 1: create a random population from the solution space & initialize the values of K_r, T_r.

Step 2: Evaluate the fitness of each solution.

Step 3: selection or reproduction based on the fitness.

Step 4: Cross over the selected solutions.

Step 5: mutate the selected solutions.

Step 6: Replace the old solution with new one.

Step 7: test the problem criterion.

Step 8: continue steps 2-7 until the criterion is satisfied.

The fitness function can be varied depends upon the problem occur in the system. STATCOM parameters K_r, T_r are selected to tune as per algorithmic procedure.

4. Objective function

The design of STATCOM parameters has been formulated as an eigen value based objective function. Here, two sub objective functions are used. One is minimization of the real part of the eigen value and the other one is maximization of the damping ratio.

The damping ratio of the i th critical mode

$$\xi_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}} \tag{1}$$

Where the eigen value $\lambda_i = \sigma_i \pm j\omega_i$. The objective functions are represented as,

$$J_1 = \sum_i^n (\sigma_0 - \sigma_i)^2 \tag{2}$$

$$J_2 = \sum_i^n (\xi_0 - \xi_i)^2 \tag{3}$$

Where $\sigma_i \le \sigma_0$, $\zeta_i \ge \zeta_0$ for i = 1,2 ……,n. The combined objective function $J = J_1 + \alpha J_2$ is used to have a closed loop eigen values .The value of α is considered as 7.The fitness function can be varied depends upon the problem occur in the system. STATCOM parameters K_r , T_r are selected to tune as per algorithmic procedure. The convergence of GA is given in Fig. 1.

Table 1: Boundaries condition in 9-bus system

Population size	100
Lower bound (K_r)	0.01
Upper bound (K_r)	100
Lower bound (T_r)	0.1
Upper bound (T_r)	10

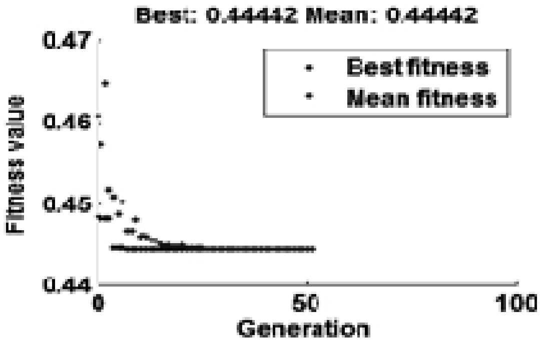

Fig.1 Convergence of GA

5. **Study system of WSCC- 9 bus system**

The time domain simulations are done in PSAT software which is used to compute and plot the graphs of the system. The performance of the STATCOM can be evaluated through the system which is selected to work out and the case studies [11] [12]. A 9 bus system (WSCC -Western Science Coordinated Council) with 6 transmission lines, 3 generators, 3 loads and a local load D is considered to study. It is shown in Fig.2.

6. Case study of 9-bus system

The system performance has been studied by applying a 3-phase fault. The fault has been applied at the bus 6 of the system. The value of assumption is taken as follows

(a) Fault time at 1.05s and clearing time 1.15s.

(b) Fault time at 3.15s and clearing time 3.50s.

Table 2: Loading conditions for the system (per unit)

Load	P	Q
Load A	2.00	0.90
Load B	1.80	0.60
Load C	1.60	0.65
Load D	1.60	0.65

7. Case 1

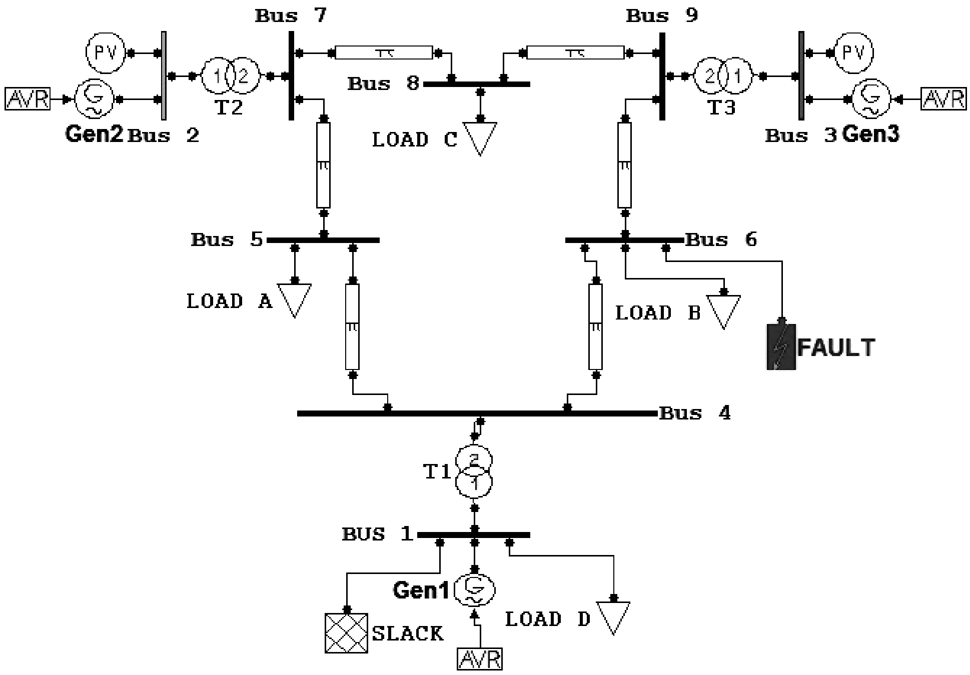

Fig.2 WSCC System with fault

In the first case, the bus 5 and bus 6 have been affected severely and the system has low voltage profile because of the fault as shown in Fig. 3 and table 3. According to this case, the optimal location of STATCOM is bus 5 and bus 6. Here, STATCOM has been applied at bus 6 to improve the system stability. The parameters of untuned STATCOM are 50 for K_r and 0.001 for T_r. The voltage profile of the system in case 1 is shown in Fig.3.The bus voltage 5 & 6 is shown in Fig.4 & 5 after the fault. The real &reactive power profiles in generation of the system without STATCOM are shown in Fig. 6 &8.The system has the stability after the fault.

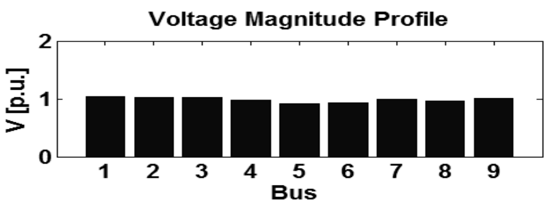

Fig.3 Voltage profile of the system without STATCOM

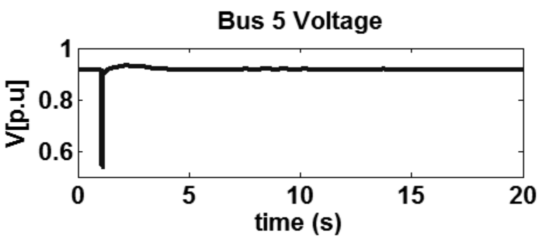

Fig.4 Bus 5 voltage without STATCOM

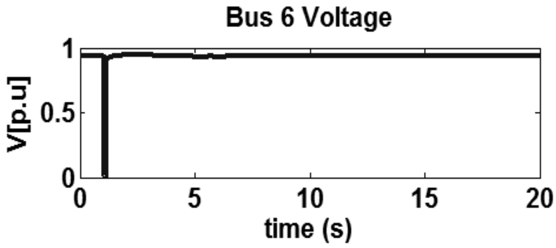

Fig.5 Bus 6 voltage without STATCOM

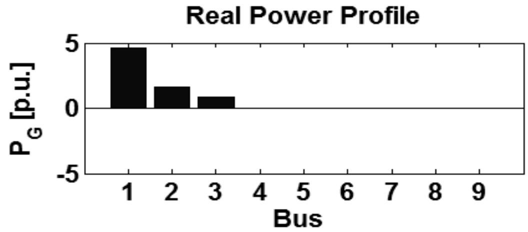

Fig.6 Real power profile in generation without STATCOM

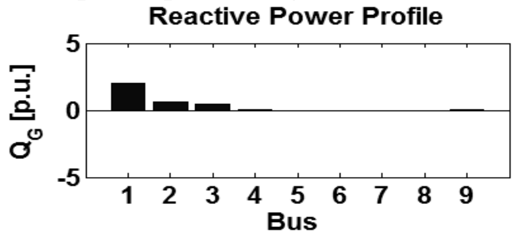

Fig.7 Reactive power profile in generation without STATCOM

The parameters of the voltage, phase, real & reactive power of the system without STATCOM are given in Table 3.

Table 3 : Parameters without STATCOM (case 1)

Bus	V [p.u.]	Phase [deg.]	P gen [p.u]	Q gen [p.u]	P load [p.u]	Q load [p.u]
Bus 1	1.04006	60.25	4.62488	2.01569	1.6	0.65
Bus 2	1.02504	59.48	1.63	0.62432	0	0
Bus 3	1.02505	59.08	0.85	0.42558	0	0
Bus 4	0.97888	59.39	0	0	0	0
Bus 5	**0.91728**	58.66	0	0	2	0.9
Bus 6	**0.93421**	58.70	0	0	1.6	0.65
Bus 7	0.99197	58.97	0	0	0	0
Bus 8	0.965	58.53	0	0	1.8	0.6
Bus 9	1.00191	58.84	0	0	0	0

8. System with STATCOM in 9-bus

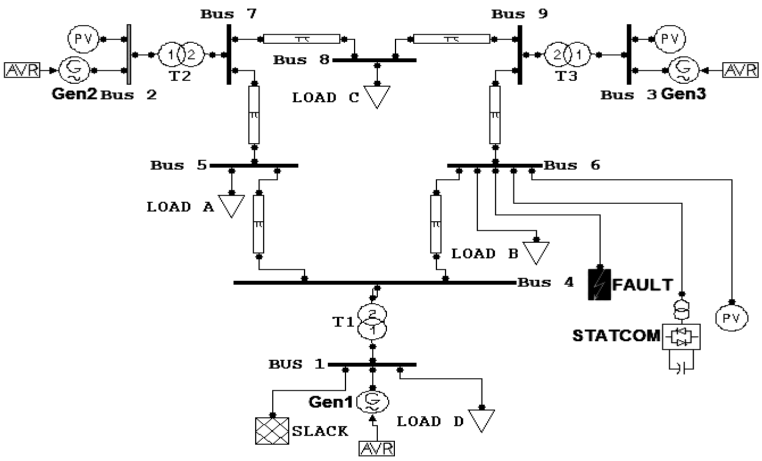

Fig.8 WSCC System with STATCOM

The voltage profile of the system is improved when it compared to system with STATCOM in Fig.9. The bus voltage 5 &6 of the system with STATCOM is shown in Fig.10 & 11 after the fault. The system is in stability condition. The real &reactive power profile in generation of the system with STATCOM (untuned) are shown in Fig. 12 & 13.The parameters of the voltage, phase, real & reactive power are given in Table 4.

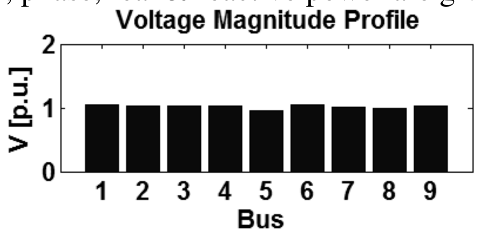

Fig.9 Voltage profile with STATCOM

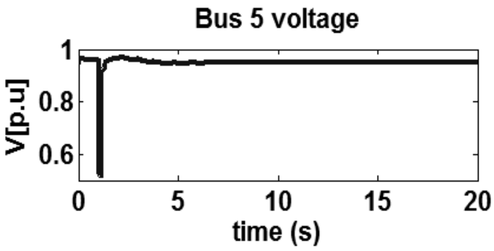

Fig.10 Bus 5 voltage with STATCOM

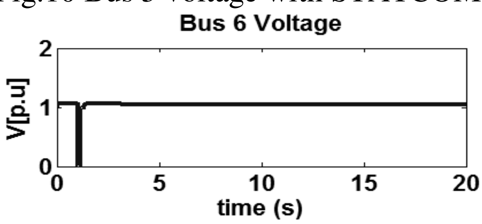

Fig.11 Bus 6 voltage with STATCOM

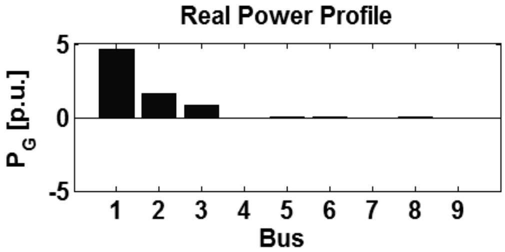

Fig.12 Real power profile in generation with STATCOM

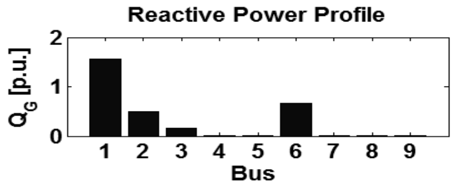

Fig.13 Reactive power profile in generation with STATCOM

Table 4 : Parameters of the system with STATCOM in case 1

Bus	V [p.u]	Phase [deg.]	P gen [p.u]	Q gen [p.u]	P load [p.u]	Q load [p.u]
Bus 1	1.04098	-36.62	4.61375	1.56254	1.6	0.65
Bus 2	1.0262	-36.64	1.63	0.48664	0	0
Bus 3	1.03123	-36.65	0.85	0.15559	0	0
Bus 4	1.01896	-36.64	0	0	0	0
Bus 5	**0.95011**	-36.67	0	0	2	0.9
Bus 6	**1.04451**	-36.67	0	0.65749	1.6	0.65
Bus 7	1.00626	-36.66	0	0	0	0
Bus 8	0.98593	-36.67	0	0	1.8	0.6
Bus 9	1.03137	-36.66	0	0	0	0

The STATCOM parameters K_r and T_r have been tuned by genetic algorithm and the voltage profile, bus 5 voltage, bus 6 voltage have been plotted. Genetic algorithm based tuned parameters are K_r= 0.424, T_r =1.418.The voltage profile, bus 5 voltage, bus 6 voltage have been plotted below after the STATCOM parameters tuned Fig.14, 15 &16.

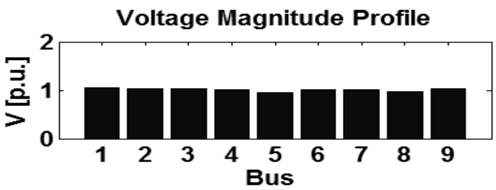

Fig.14 Voltage profile with STATCOM tuned by GA

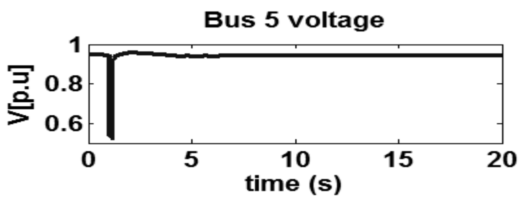

Fig.15 Bus 5 voltage with STATCOM tuned by GA

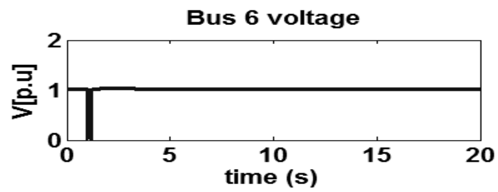

Fig.16 Bus 6 voltage with STATCOM tuned by GA

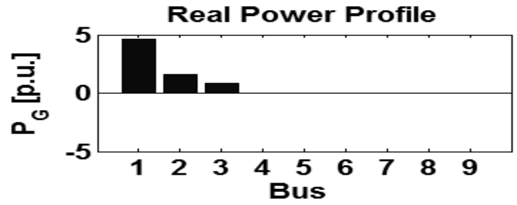

Fig.17 Real power profile in generation with STATCOM tuned by GA

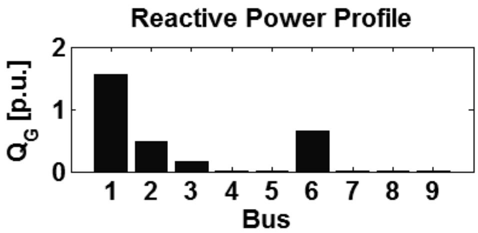

Fig.18 Reactive power profile in generation with STATCOM tuned by GA

The system is achieved stability after the fault. The voltage profile of the system is improved when compared to the system without STATCOM. The real &reactive power profiles in generation of the system with STATCOM (tuned) are shown in Fig. 17 & 18.The parameters of the voltage, phase, real & reactive power are given in Table 5. The comparison of the voltage profile is shown in Table 6.

Table 5 : Parameters of the system with STATCOM tuned by GA

Bus	V	phase	P gen	Q gen	P load	Q load
	[p.u.]	[rad]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 1	1.04029	-8.60	4.61375	1.56254	1.6	0.65
Bus 2	1.02541	-8.63	1.63	0.48664	0	0
Bus 3	1.02681	-8.64	0.85	0.15559	0	0
Bus 4	1.00772	-8.63	0	0	0	0
Bus 5	**0.94183**	**-8.65**	**0**	**0**	**2**	**0.9**
Bus 6	**1.01219**	**-8.65**	**0**	**0.65749**	**1.6**	**0.65**
Bus 7	1.00199	-8.64	0	0	0	0
Bus 8	0.97943	-8.66	0	0	1.8	0.6
Bus 9	1.02121	-8.65	0	0	0	0

Table 6 : Comparison of voltage profile in case 1

Bus	Without STATCOM(p.u)	With STATCOM-Untuned(p.u)	With STATCOM Tuned by GA(p.u)
Bus 1	1.04006	1.04098	1.04029
Bus 2	1.02504	1.0262	1.02541
Bus 3	1.02505	1.03123	1.02681
Bus 4	0.97888	1.01896	1.00772
Bus 5	**0.91728**	**0.95011**	**0.94183**
Bus 6	**0.93421**	**1.04451**	**1.01219**
Bus 7	0.99197	1.00626	1.00199
Bus 8	0.965	0.98593	0.97943
Bus 9	1.00191	1.03137	1.02121

9. Case 2

In the second case, the voltage profile of the system becomes very low. The bus 6 and bus 9 are identified as weak buses.

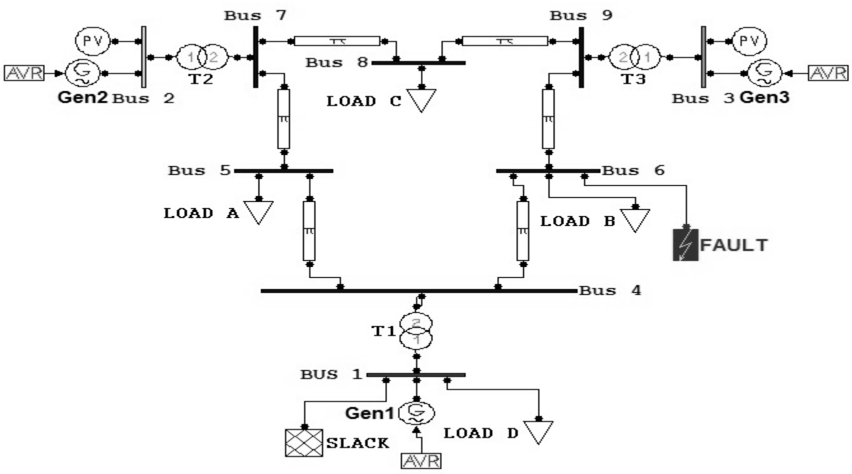

Fig.19 WSCC System with fault

The generation of the system without STATCOM in case 2 is shown in Fig. 19. The voltage profile of the system is collapsed during a fault as shown Fig. 20. The bus voltage 6 & 9 of the system without STATCOM is shown in Fig.21 &22 after a fault in case 2. The system has lost the stability. The real &reactive power profiles in generation of the system without STATCOM in case 2 in Fig. 23&24. The parameters of the voltage, phase, real & reactive power of the system without STATCOM in case 2 are given in Table 7.

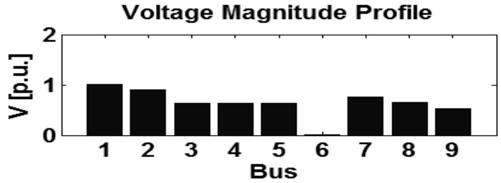

Fig. 20 Voltage profile without STATCOM

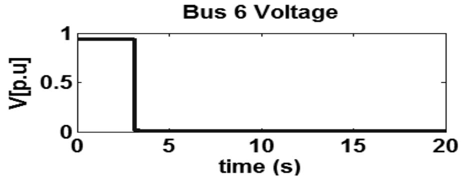

Fig.21 Bus 6 voltage without STATCOM

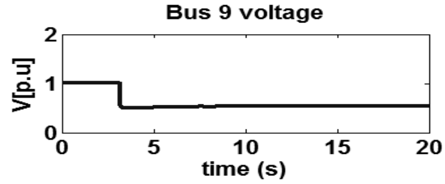

Fig.22 Bus 9 voltage without STATCOM

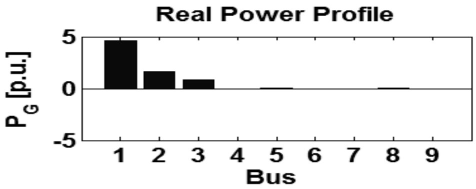

Fig.23 Real power profile in generation without STATCOM

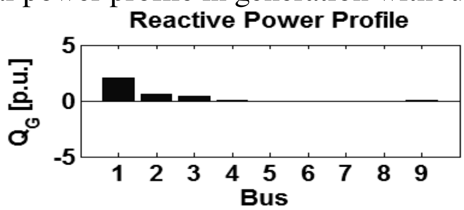

Fig.24 Reactive power profile in generation without STATCOM

The parameters of the voltage, phase, real & reactive power of the system without STATCOM in case 2 are given in Table 7.

Table 7 : Parameters of the system without STATCOM in case 2

Bus	*V*	*phase*	*P gen*	*Q gen*	*P load*	*Q load*
	[p.u.]	[deg]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 1	1.00119	311.37	4.62488	2.01569	1.6	0.65
Bus 2	0.90289	311.38	1.63	0.62432	0	0
Bus 3	0.63087	311.38	0.85	0.42558	0	0
Bus 4	0.62573	311.35	0	0	0	0
Bus 5	0.62698	311.34	0	0	2	0.9
Bus 6	**0**	**311.26**	**0**	**0**	**1.6**	**0.65**
Bus 7	0.76412	311.36	0	0	0	0
Bus 8	0.64609	311.35	0	0	1.8	0.6
Bus 9	**0.53083**	**311.36**	**0**	**0**	**0**	**0**

10. System with STATCOM in 9-bus

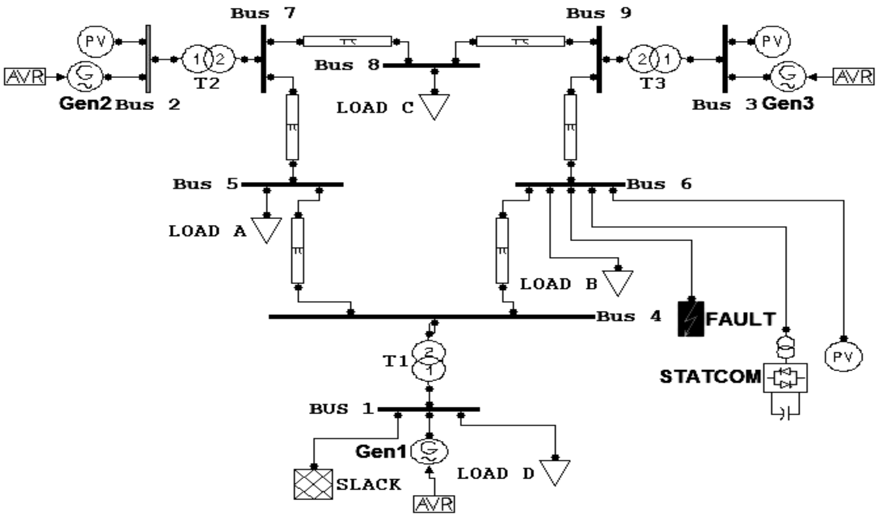

Fig.25 WSCC System with STATCOM

The STATCOM has been applied at bus 6 of the system. The STATCOM is used to improve the stability of the system. Now, voltage profiles of bus 6 and bus 9 voltages are plotted. The voltage profile of the system with STATCOM (Case 2) is shown Fig.26.The bus voltage 6 & 9 of the system with STATCOM is shown in Fig.27 &28 after the fault in case 2. The STATCOM (untuned) don't improve the stability. It works 3.6 s only. The real &reactive power profiles in generation of the system with STATCOM (case 2) are shown in Fig. 29 &30.

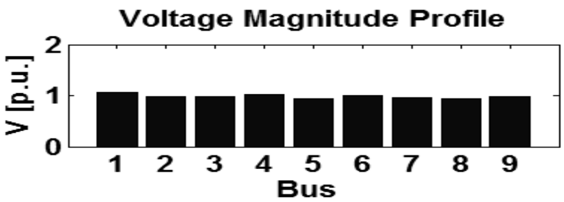

Fig. 26 Voltage profile with STATCOM

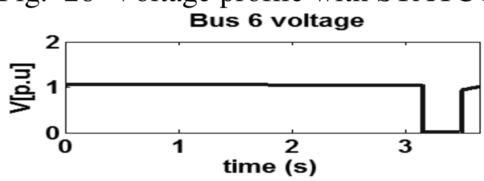

Fig .27 Bus 6 voltage with STATCOM

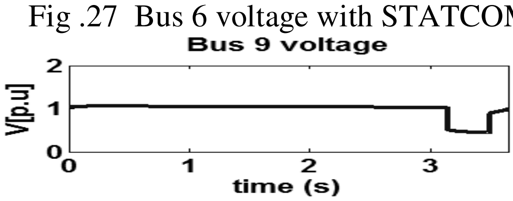

Fig . 28 Bus 9 voltage with STATCOM

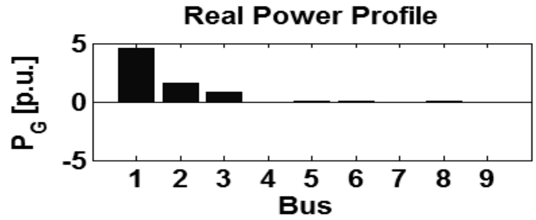

Fig.29 Real power profile in generation with STATCOM

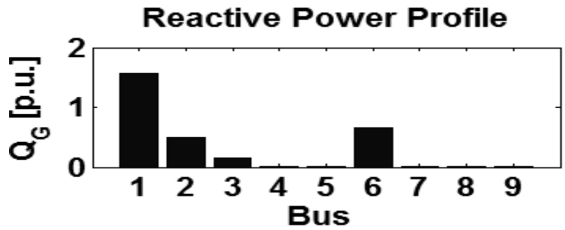

Fig.30 Reactive power profile in generation with STATCOM

Table 8 : Parameters of the system with STATCOM in Case 2

Bus	V	phase	P gen	Q gen	P load	Q load
	[p.u.]	[rad]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 1	1.06101	-8.3518	4.61375	1.56254	1.6	0.65
Bus 2	0.97774	-8.2964	1.63	0.48664	0	0
Bus 3	0.96985	-8.3813	0.85	0.15559	0	0
Bus 4	1.01259	-8.4716	0	0	0	0
Bus 5	0.9307	-8.5698	0	0	2.0	0.9
Bus 6	**0.99962**	**-8.566**	**0**	**0.65749**	**1.6**	**0.65**
Bus 7	0.96302	-8.4251	0	0	0	0
Bus 8	0.93992	-8.5117	0	0	1.8	0.6
Bus 9	**0.97799**	**-8.4533**	**0**	**0**	**0**	**0**

11. System with STATCOM in 9-bus tuned by GA

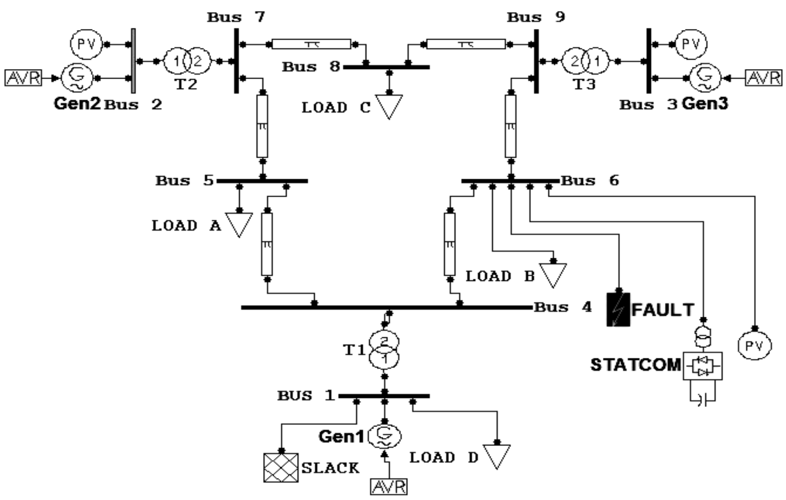

Fig.31 WSCC System with STATCOM tuned by GA

According to GA tuned system, STATCOM is applied to bus 6 to improve the transient stability (by using the GA tuned STATCOM parameters). The voltage profile of the system with STATCOM (Tuned by GA) is shown Fig. 32. The bus voltage 6 & 9 of the system with STATCOM is shown in Fig.33 &34 after the fault (case 2).The system has achieved stability. The real &reactive power profile (generation) of the system with STATCOM (Tuned by GA) are shown in Fig. 35 &36.

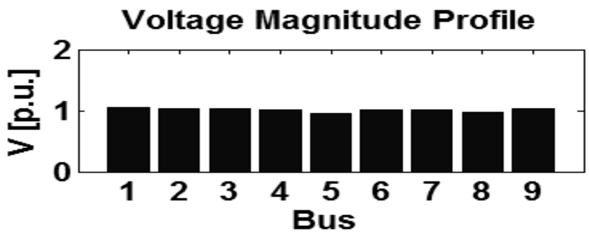

Fig. 32 Voltage profile with STATCOM tuned by GA

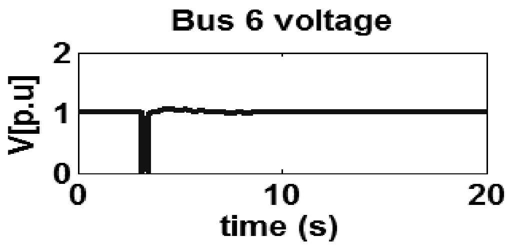

Fig.33 Bus 6 voltage with STATCOM tuned by GA

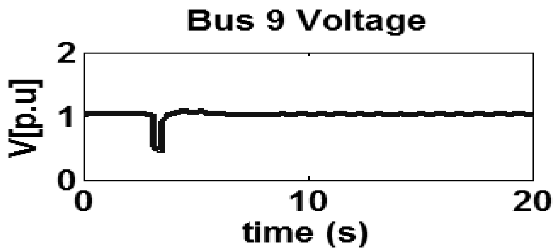

Fig.34 Bus 9 voltage with STATCOM tuned by GA

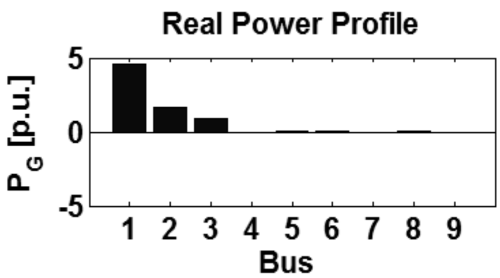

Fig.35 Real power profile in generation with STATCOM

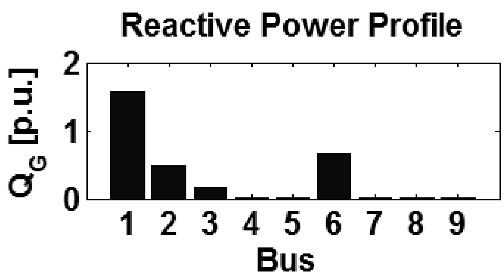

Fig.36 Reactive power profile in generation with STATCOM

The parameters of the voltage, phase, real & reactive power of the system with STATCOM (Tuned by GA) are given in Table 9. The comparison of voltage profile is shown in Table 10. The system with tuned STATCOM has given better voltage profile than untuned system and without STATCOM.

Table 9 : Parameters of the system with STATCOM tuned by GA

Bus	V	phase	P gen	Q gen	P load	Q load
	[p.u.]	[rad]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 1	1.04005	-14.967	4.61375	1.56254	1.6	0.65
Bus 2	1.02475	-15.108	1.63	0.48664	0	0
Bus 3	1.02625	-15.187	0.85	0.15559	0	0
Bus 4	1.00736	-15.136	0	0	0	0
Bus 5	0.94142	-15.273	0	0	2	0.9
Bus 6	**1.01177**	**-15.271**	**0**	**0.65749**	**1.6**	**0.65**
Bus 7	1.00141	-15.208	0	0	0	0
Bus 8	0.97888	-15.294	0	0	1.8	0.6
Bus 9	**1.02066**	**-15.235**	**0**	**0**	**0**	**0**

Table 10: Comparison of the voltage profile(in p.u)

Bus	Without STATCOM	With STATCOM (Untuned)	With one STATCOM (Tuned by GA)
Bus 1	1.00119	1.06101	1.04005
Bus 2	0.90289	0.97774	1.02475
Bus 3	0.63087	0.96985	1.02625
Bus 4	0.62573	1.01259	1.00736
Bus 5	0.62698	0.9307	0.94142
Bus 6	**0**	**0.99962**	**1.01177**
Bus 7	0.76412	0.96302	1.00141
Bus 8	0.64609	0.93992	0.97888
Bus 9	**0.53083**	**0.97799**	**1.02066**

Table 11 : power values of the system (Case 1)

Total Generation,Load & Loss			
Power in p.u	System Without STATCOM(p.u)	System with STATCOM(p.u)	System with Tuned STATCOM by GA(p.u)
Real power (Generation)	7.1049	7.0938	7.0938
Reactive power (Generation)	3.0656	2.8623	2.8623
Real power (Load)	7	7	7
Reactive power (Load)	2.8	2.8	2.8
Real power (Loss)	0.1049	0.0938	0.0938
Reactive power (Loss)	0.2656	0.0623	0.0623

The losses of the system are reduced when the system have STATCOM. It is shown in Table 11 and Table 12.

Table 12 : power values of the system (Case 2)

Total Generation,Load & Loss			
Power in p.u	System Without STATCOM(p.u)	System with STATCOM(p.u)	System with Tuned STATCOM by GA(p.u)
Real power (Generation)	7.1049	7.0972	7.0972
Reactive power (Generation)	3.0656	2.8612	2.8612
Real power (Load)	7	7	7
Reactive power (Load)	2.8	2.8	2.8
Real power (Loss)	0.1049	0.0972	0.0972
Reactive power (Loss)	0.2656	0.0612	0.0612

12. Conclusion

The stabilisation of the multi machine system is analysed by various operational conditions. The modified design of STATCOM is utilized in dissimilar conditions and used to achieve the stability. The instability of voltage wave forms is corrected and it is improved .The real and reactive power losses are minimized when STATCOM is used. The total voltage profile of the system is improved when compared to the system without STATCOM and untuned conditions. The Genetic algorithmic procedure has given the best results when fault clearing time is increased. The case 2 is producing best result compare to case1. It is proved in various conditions.

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