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Genetically Tuned STATCOM for Voltage Control and Reactive Power Compensation

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***Abstract*—In this paper Static Synchronous Compensator (STATCOM) is used for voltage stability and the compensation of reactive power. The STATCOM contains an Insulated Gate Bipolar Transistor (IGBT) based voltage source converter for voltage control and reactive power compensation. The STATCOM is used to control the reactive power with the voltage source converter in combination with a DC voltage source. The values of the DC link capacitor and battery source were optimized using the Genetic Algorithm technique and the simulations results for the same were observed under the inductive as well as capacitive load conditions. The comparison of voltage compensation for various conditions show that the performance of STATCOM tuned with GA was the best and closest to the nominal value of voltage. The simulation is done in MATLAB for STATCOM and Voltage Source Converter (VSC).**

***Index Terms*—Genetic algorithm, Optimization, Reactive power compensation, STATCOM, Voltage source converter.**

I. Introduction

The generation of bulk power at remote locations necessitates the use of transmission lines to connect generation sites to load centers. Furthermore, in order to enhance system reliability multiple lines that connect load centers to several sources, interlink neighboring utilities and build the needed levels of redundancy. This phenomenon has gradually led to the evolution of complex interconnected electrical transmission networks. These networks now exist in all continents. An electrical power transmission network comprises mostly 3-phase alternating-current (ac) transmission lines operating at different transmission voltages (generally at 230 kV and higher). With increasing requirement of power-transmission capacity and for longer transmission distances, the transmission voltage continues to increase and hence the transmission losses are reduced. In a complex interconnected ac transmission network, the source to load power flow has multiple transmission paths. For a system comprising multiple sources and numerous loads, a load-flow study must be performed to determine the levels of active and reactive power flows on all lines, impedance and the terminals voltages. The line loading cannot be controlled, hence for increasing the reliability of transmission network's power supply the line impedance can be modified by using series and/or shunt circuit elements.

A flexible ac transmission system (FACTS) is used for generating or absorbing reactive power. Static synchronous Compensator (STATCOM) is a FACTS controller operated as a shunt connected static VAR compensator based on a voltage source or current source converter whose capacitive or inductive output current can be controlled independent of the ac system voltage. A lot of work has been accomplished in the field of reactive power compensation. The STATCOM has a special characteristic that it does not depend on the ac system voltage [1]-[4] and yet compensates for any deviation in system voltage. The STATCOM is composed of a voltage source inverter with a dc capacitor, coupling transformer, and signal generator and control circuit [5], [6]. Due to its versatile nature and speedy response, STATCOM finds a wide application in the field, both as a reactive power compensating device and harmonic absorber [7], [8].

There has been a lot of research in the recent past in order to improve the characteristic and response time of STATCOM. The application of artificial intelligence techniques is relatively newer addition in the field [9]-[11]. A non-linear fuzzy logic controller is used to overcome the problems generated by different uncertainties that exist in power systems. Different input variables are used to design the controller. Parameters of the proposed controllers are adjusted by means of Neural Network techniques to improve the performance of the system. Artificial Neural Network (ANN) is also introduced in the coordination of controllers, which substitute for the tap changing mechanism [12]. ANN is utilized as a classifier with an integer value as the output, which is a tap position [13].

Modern Power Systems are large, complex, widely distributed and highly non linear systems. Power Systems operation conditions and topologies are time varying and the disturbances are unforeseeable. These uncertainties make it very difficult to effectively deal with power system stability problems through conventional controller that is based on a linearized system model. Therefore, fuzzy logic control has been emerging in recent years as a complement to the conventional approach. The fuzzy logic controller is

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designed by A. Ajami and S.H. Hoiseini for STATCOM to enhance the transient stability in AC power systems [14].

In a conventional scheme, a STATCOM is controlled by PI and PID controllers. The Genetic Algorithm (GA) finds its application in obtaining the best values for PI and PID controller gains. With GA, we can obtain a precise solution with good computation efficiency. This method has robust stability and efficiency to solve the tuning problem of PI and PID controller parameters more easily and quickly than any other method. The use of GA for the calculation of optimum parameters in the design of PI and PID controller can bring about optimum dynamic response, in a very short time [15]-[20].

II. Reactive Power Compensating Devices

Synchronous condensers, Static VAR compensators (such as TCR, TSC, TSR, FC, and Harmonic filter), STATCOM, series capacitors and reactors, shunt capacitors and shunt reactors are some of the reactive power compensating devices.

VSC are often preferred over current sourced converters for FACTS applications. Since the direct current in VSC flows in either direction, the converter valves have to be bi-directional [18]. The dc voltage is unidirectional; the turn off devices need not have reverse voltage capability, such turns off devices are known as asymmetric turn off devices. Thus a VSC valve is made up of an asymmetric turn off device such as GTO with a parallel diode connected in reverse. Some turn off devices, such as the IGBTs etc., may have a parallel reverse diode built in as part of a complete integrated device suitable for voltage sourced converters. For high power converters, provision of separate diodes is advantageous. Basically a VSC generates ac voltage from a dc voltage [10]. It is often referred to as inverter, even though it has the capability to transfer power in either direction. VSC can control the magnitude, the phase angle & the frequency of the output voltage.

III. Simulation of the VSC

The VSC is modeled in MATLAB as shown in Fig. 1. The current and voltage waveforms are shown in Figs. 2 and 3.VSC are often preferred over Current Source Converters (CSC) for FACTS applications. Since the direct current in VSC flow in either direction, the converter valves have to be bidirectional and as the dc voltage does not reverse, the turnoff devices need not have reverse voltage capability. The VSC may be classified as 6, 12, 24 and 48 pulse converters. According to the type of converter there are different transformer connections.

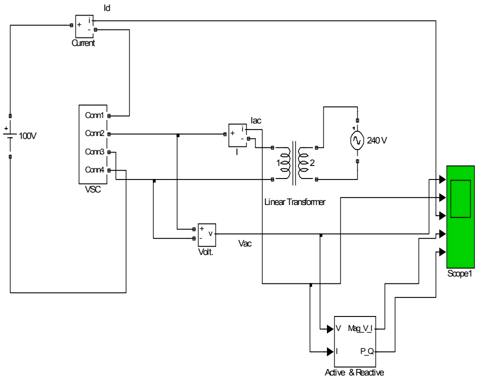
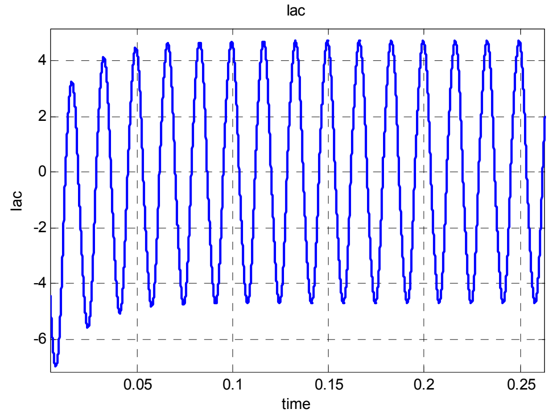
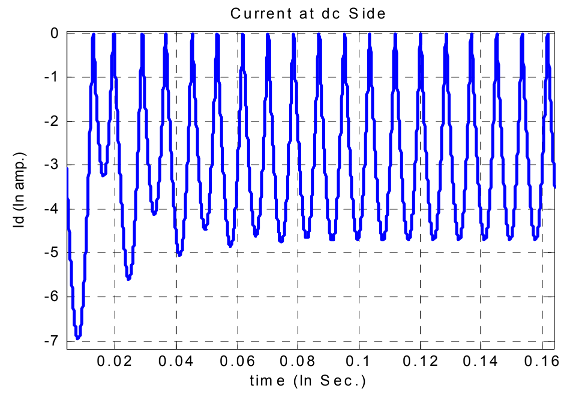


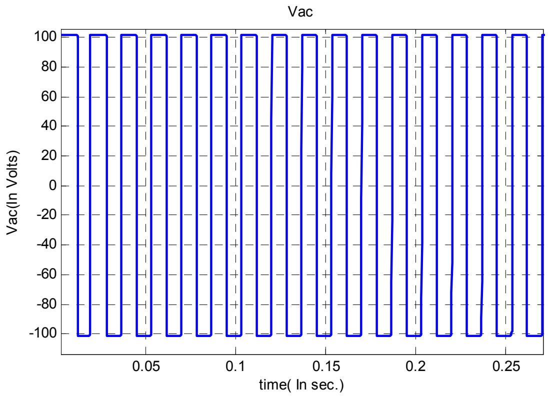
Fig. 1: Simulation model of single phase VSC with AC supply & DC constant voltage source



(a): Current through AC system



(b): Current of capacitor in VSC



(c): Voltage of System in VSC

Fig 2: Simulation results of single phase VSC with AC supply and DC constant voltage source

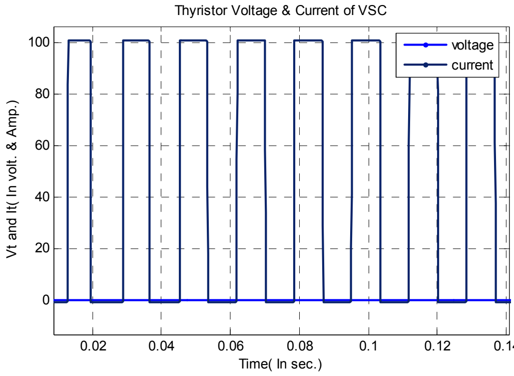


Fig. 3: Simulation result of single phase VSC

IV. Working Principle of STATCOM

Static Synchronous Compensator (STATCOM) is a primary shunt device of the FACTS family, which uses power electronics to control power flow and improve transient stability on power grids. The STATCOM regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system.

The variation of reactive power is performed by means of a voltage source convertor (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced commuted power electronics devices (CTO's or IGBT's) to synthesize the voltage from a dc voltage source. The operating principle of STATACOM is explained in Fig. 4. It can be seen that if Es> Et then current Iq flows from the counter to ac system through reactance and converter generates capacitive reactive power for ac system. On the other hand, if Es< Et then current Iq flows from ac system to the converter and converter absorbs inductive reactive power from ac system. Finally, if Es= Et then there is no exchange of reactive power.

For computation purposes, we assume that the active and reactive power is transferred between two sources V1 and V2. V1 represents the system voltage to be controlled and V2 is the voltage generated by the VSC. In steady state operation, the voltage V2 generated by the VSC is in phase with V1 (∂=0, angle of V1 w.r.t. V2) so that only the reactive power is flowing from V1 to V2; i.e. STATCOM is observing reactive power. In contrary, if V2 is higher than V1, reactive power is flowing from V1 to V2 i.e. STATCOM is generating the reactive power. The amount of reactive power is given by:

$$Q = \frac{V1.(V1 - V2)}{x}$$

A capacitor connected on the DC side of the VSC acts as a dc voltage source. In order to compensate for transformer and VSC bases and to keep the capacitor charges, the following two VSC technologies can be used:

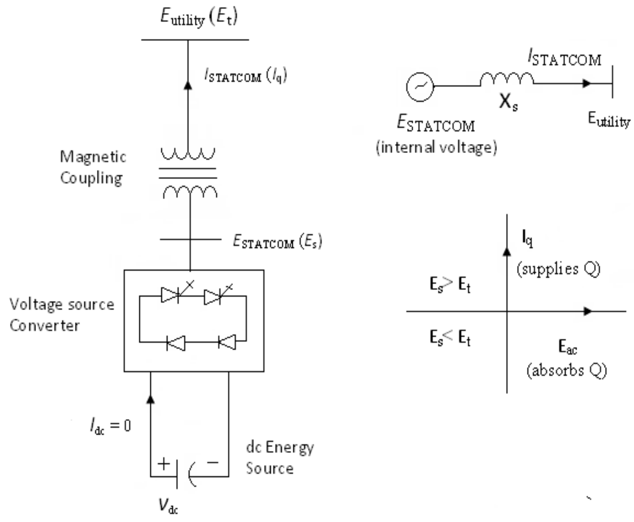


Fig. 4: STATCOM working concept

- VSC using GTO based square wave inverters and special interconnection transformers typically with three level inverters are used to build a 48 step voltage wave form.
- VSC using IGBT based PWM inverters use PWM technique to synthesize a sinusoidal waveform from a dc voltage source with a typical chopping frequency of a few kilo-hertz.

V. Genetic Algorithm As Optimization Tool

The basic purpose of Genetic Algorithm is Optimization. It is very useful for a great variety of tasks. In all optimization problems, there is a problem of maximizing and minimizing an objective functions f(x) for a given space x of arbitrary dimension. A brute force which would consist in examining every possible x in order to determine the element for which f(x) is optimal is clearly infeasible. GA gives a heuristic way of searching the input space for optimal x, that approximates brute force without enumerating all the elements and therefore bypass performance issues specific to exhaustive search [10].

An elementary unit of a GA is called a chromosome, which carries the information about the set of parameters representing a particular instance of a discriminated function. The appropriate two chromosomes are combined to form a new one using a single point crossover. A random point in the chromosome is picked. All the information from parent A is copied from the start up to the crossover point, then all the information from parent B is copied from the cross over point to the end of the chromosome. The new chromosome thus gets the head of one parent chromosome combined with the tail of the other. Mutations are a crucial part of the algorithm as they allow creation of radically new solutions.

A 'colony' is a collection of chromosomes, which evolve as the algorithm progresses. It is created by providing two random chromosomes and is then propagated through epochs. Colony size is kept bound to speed up the algorithm convergence. Each chromosome has a number of 'genes' equal to the number of parameters used in the objective function. Thus, a gene is a binary representation of the value of the parameters. It is a sequence of bits (0 and 1) and its length (which is pre-determined) reflects the precision of parameter values. A fitness function of a chromosome is a measure of its performance and it is a quantity that the algorithm is trying to maximize/minimize. The process of optimization by GA is shown in brief in Fig. 5.

VI. RESULTS AND DISCUSSIONS

Fig. 6 shows the test system implemented in MATLAB to carry out simulations for the STATCOM. The system has a 230 KV transmission system with 100 MVA feeding into the primary of a three winding transformer. A varying load is connected to the 11 KV secondary side of transformer. A two level STATCOM is connected to the 11 KV tertiary winding of the transformer. A 13.3 micro Farad capacitor provides the STATCOM energy storage capabilities.

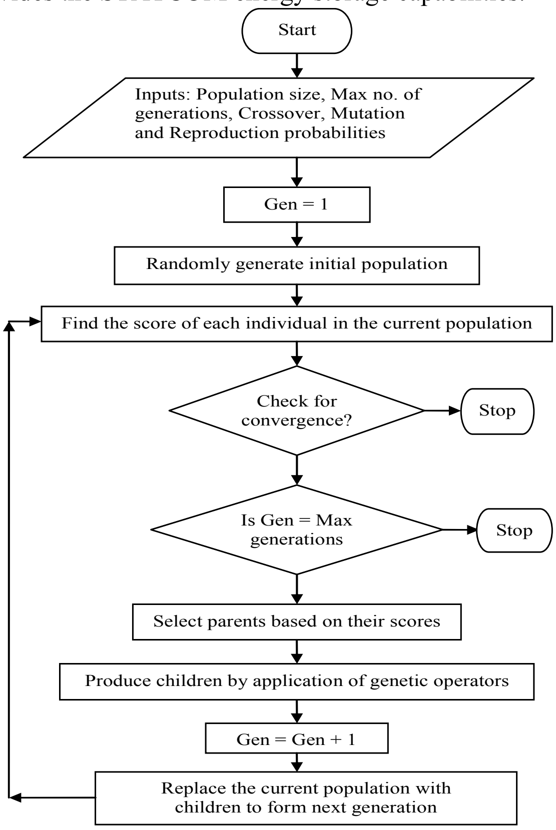


Fig. 5. Optimization process with GA

The circuit breakers (CB's) are provided on the different points as shown in Fig. 6, in order to connect and disconnect the different loads such as load B, load C, load D and STATCOM at different times. In order to show the effectiveness of this controller in providing continuous voltage regulation and reactive power, simulations were carried out with and without STATCOM connected to the system. A set of simulations were carried out on the test system for a time period of 0.9 sec.

A. *Simulation Results without STATCOM*

The STATCOM is disconnected from the system using circuit breaker CB4. At 0.1 sec., an RL load is connected through CB1. From the simulation results as shown in Fig.7, it is observed that there is dip in the system voltage level and it drops from its nominal value of 1.0 pu to 0.7 pu and at 0.2 sec. a further drop in voltage is seen due to addition of another RL load through CB2. A capacitor bank load is connected to the system at 0.6 sec through CB3 and it is observed that there is a swell in system voltage level. The voltage rises to 1.2 pu from its nominal value.

The reactive power variation is shown in Fig. 8. It is thus concluded that due to addition of Rl load at 0.1 and 0.2 sec., there is absorption of reactive power and is shown by the negative Q in the test results as shown in Fig. 8, whereas at 0.6 sec. due to addition of capacitive load, there is generation of reactive power. The addition of capacitive load makes the nature of overall load connected to the system capacitive in nature and it is seen from the figure that Q is positive for this period.

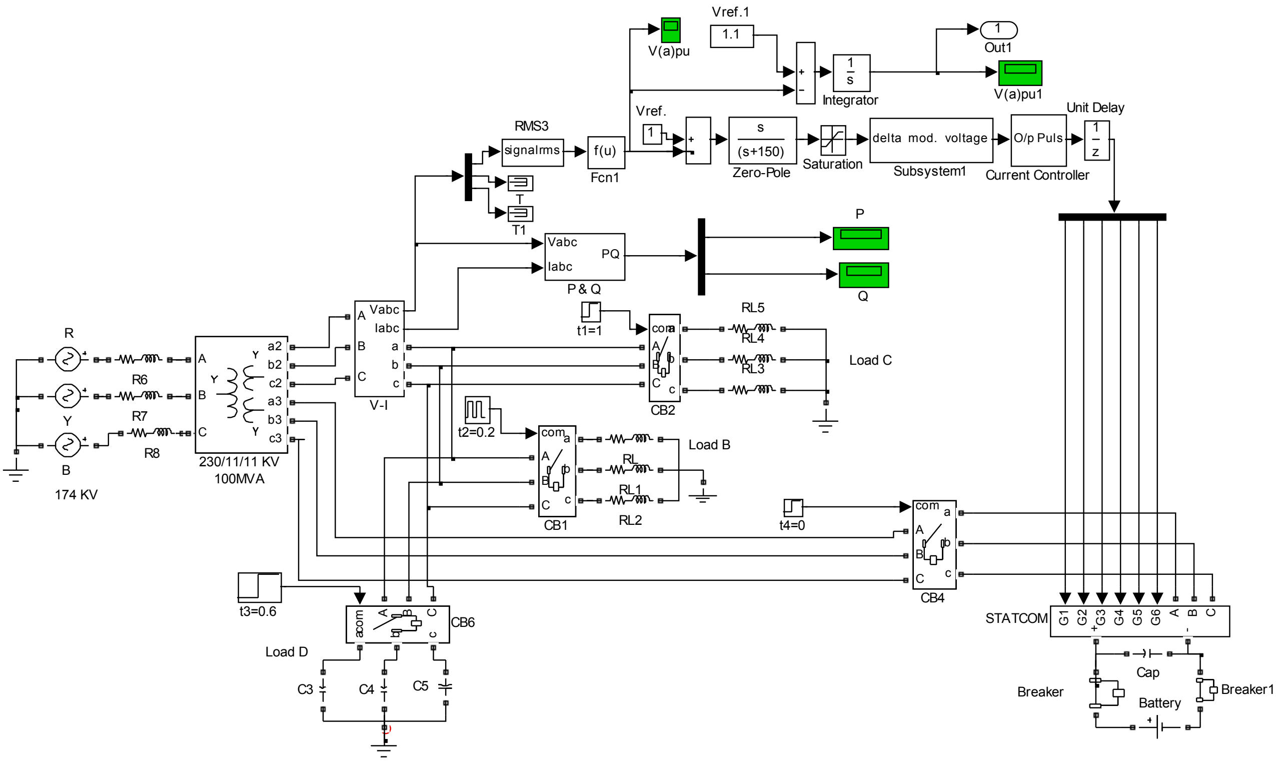


Fig. 6. Control and test system implemented in MATLAB to carry out the STATCOM simulation

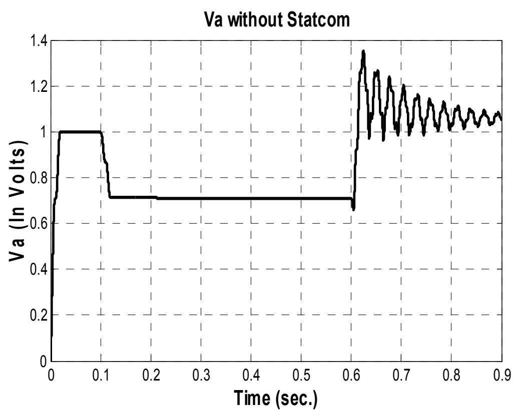


Fig. 7: Voltage without compensation

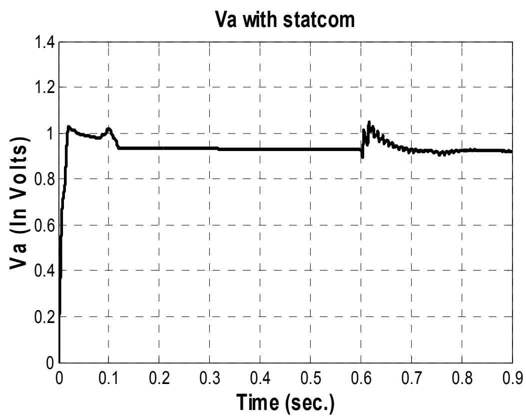


Fig. 9: Voltage with STATCOM compensation

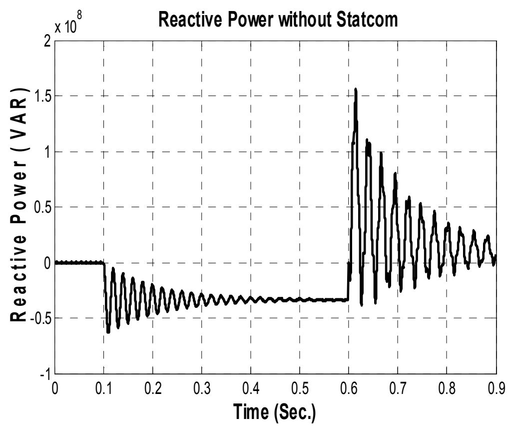


Fig. 8: Reactive power without compensation

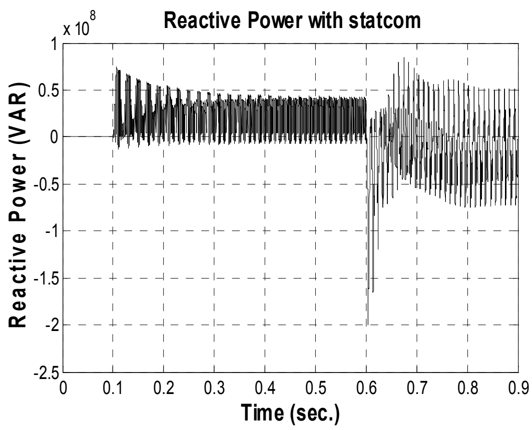


Fig. 10: Reactive power with STATCOM

B. Simulation Results with STATCOM and without Parameter Optimization

The simulation is now carried out with STATCOM connected through CB4. The simulation results for system voltage level and reactive power compensation are shown in Figs. 9 and 10. It is clear from Fig. 9 that the severity of voltage drop as observed due to addition of RL load at 0.1 sec and at 0.2 sec has been subsequently reduced. The voltage dip which was to the extent of 40% has almost come down to 10 to 15%. Similarly, at 0.6 sec. due to introduction of capacitive load, the voltage swell, which was observed in Fig. 7 without STATCOM has been overcome. It is seen that the system voltage level is now maintained in between 0.9 to 0.95 pu. As for observation of Fig. 10, it is inherent that with the introduction of STATCOM, the reactive power absorption (i.e. negative Q), which was observed from 0.1 to 0.6 sec. due to RL load, has been compensated. The STATCOM device fulfills the reactive power requirement of load during the above mention period which was previously drawn from the source and vice versa from 0.6 sec. onwards on connection of capacitive load.

C. Simulation Results with STATCOM and with GA

The simulations are now carried out with STATCOM connected and parameter optimization of STATCOM and voltage source converter. The GA tool is used for fine tuning of the system parameters. The values of the DC link capacitance and battery source were optimized using the techniques and the simulations results for the same as for system voltage profile and reactive power compensation are shown in Figs. 11 and 12 respectively. It is very clear from Fig. 11 that the system voltage level is maintained constant at 1.0 pu during the steady state condition even when there is addition of inductive as well as capacitive load. The comparison of voltage compensation for all three conditions has been shown in Fig. 13. The performance of STATCOM tuned with GA, was the best and closest to the nominal value of voltage i.e. 1 pu. The optimization was done with the fitness function as the total integral error, as below:

$$J = \int_0^T \left| V_{ref} - V_a \right| .dt$$

Where,
Vref = Nominal value of voltage (i.e. 1 pu)
V_a = The actual voltage (in pu), and
T = Total period for which compensation is desired

Fig. 14 shows the optimized parameter values with GA. The total number of iterations selected was 100. The optimized values of capacitor and battery source were found to be 50e-03 Farad and 16e3 Volts respectively. The first parameter value is not evident from Fig. 14 due to uneven scaling of the graph for the two parameters. The other parameters used in simulation are given in Appendix. With the ever increasing requirement of quality supply for sensitive loads, the application of STATCOM is expected to increase and use of genetic algorithm as an optimization tool can improve its performance significantly.

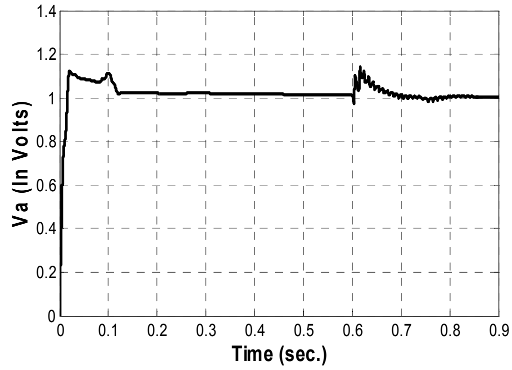


Fig. 11: rms voltage with STATCOM and GA

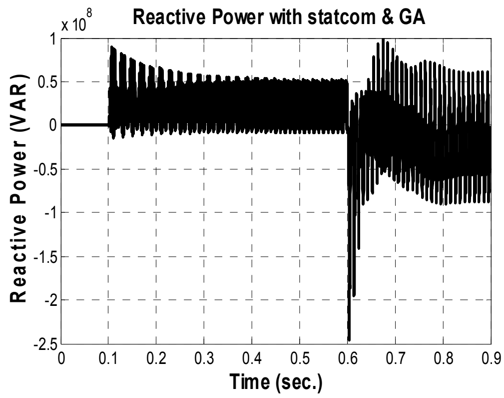


Fig. 12: Reactive power with STATCOM & GA

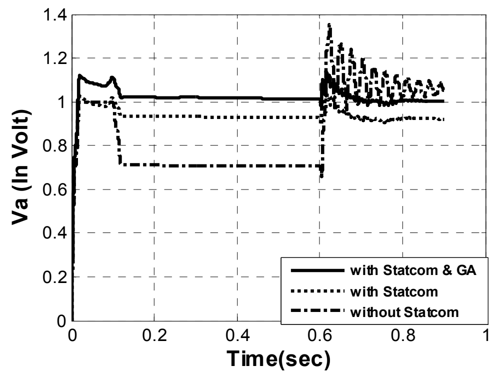


Fig. 13: Compensation of voltage profiles

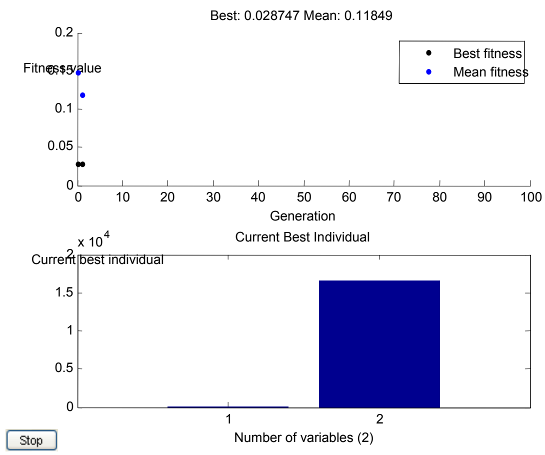


Fig. 14: Optimized parameter values with GA

VII. Conclusions

A STATCOM model has been developed with all the necessary components and controllers in order to demonstrate its effectiveness in maintaining simple and fast voltage regulation at any point in the transmission line. The values of the DC link capacitor and battery source were optimized using the Genetic Algorithm and the simulations results were compared with that of the system without compensation and with STATCOM, under both optimized and un-optimized conditions. The comparison of voltage compensation for inductive as well as capacitive load conditions show that the performance of STATCOM tuned with GA was the best and closest to the nominal value of voltage of 1 per unit.

Appendix

***Line Parameters**:*

Supply System = 132KV,

Transformer: 100MVA, Primary Voltage = 132 KV, Secondary Voltage = 11 KV, Tertiary Voltage = 11KV

STATCOM specifications: Capacitor = 50e-03F, Battery=16e3 Volt

Loads:

Loads B: R=0.05 Ω, L=0.0059 H

Loads C: R=12.1 Ω, L=0.1926 H

Loads D: C= 3μF

References

[1] N.G. Hingorani and Gyagyi, Understanding FACTS, IEEE Press, 2000.

[2] C.K. Lee, Joseph S.K. Leung, S.Y. Ron Hui and Henry Shu-Hung chung, "Circuit level comparison of STATCOM technologies," IEEE Trans. Power Electronics, vol. 18, July 2003, pp.1084-1092.

[3] C.J. Hatziaduniu and F.E. Chalkiadakis, "A transformer less high pulse static synchronous compensator based on the 3 level GTO inverter," IEEE Trans. Power delivery, vol. 13, July 1998, pp. 883-888.

[4] Byoung-Kuk Lee and Mehrdad Ehsant, "A simplified functional simulation model for three phase voltage source inverter using switching function concept," IEEE Trans. Industrial Electronics, vol. 48, April 2001, pp. 309-321.

[5] S. Panda and R. N. Patel, "Improving Power System Transient Stability with an Off–Centre Location Of Shunt FACTS Devices", Journal of Electrical Engineering, vol. 57, No. 6, 2006, pp. 365-368.

[6] S. Panda and R. N. Patel, "Optimal Location of Shunt FACTS Controllers for Transient Stability Improvement Employing Genetic Algorithm", Electric Power Components and Systems, vol. 35, No. 2, Feb. 2007, pp. 189-203.

[7] C. Schauder, M. Gernhardt, E. Staccey, T. Lemak, L. Gyugyi, T.W. Cease and A.Edris, "Development of a ± 100 MVAR static condenser for voltage control of transmission systems," IEEE Trans. Power Delivery, vol.106, July 1995, pp. 1486-149.

[8] C. Schauder, E. Staccey, M. Lund, L. Gyugyi, L. Kovalsky, A. Keri, A. Mehraban, and A. Edris, "AEP UPFC Project: installation, commissioning and operation of the ± 160 MVA STATCOM (Phase I)," IEEE Trans. Power Delivery, vol.13, Oct. 1998, pp. 1530-1535.

[9] R. N. Patel, S. K. Sinha, and R. Prasad, "Design of a Robust Controller for AGC with Combined Intelligence Techniques", International Journal of Electrical Power and Energy Systems Engineering, vol. 1, No. 2, Spring 2008, pp. 95-101.

[10] S. Panda, N. P. Padhy, R. N. Patel, "Application of Genetic Algorithm for FACTS-based Controller Design," International Journal of Computer, Information, and Systems Science, and Engineering, vol. 1, No. 1, 2007, pp. 40-47.

[11] Jyh-Shing Roger Jang, "ANFIS: adaptive network based fuzzy inference system," IEEE Transaction on Power System, MAN, AND CYBERNETICS, vol. 23, No.3, May/June-1993.

[12] Gwang Won Kim and Kwang Y. Lee, "Coordination control of ULTC transformer and STATCOM based on an artificial neural network," IEEE Transaction on Power System, vol. 20, No. 2, May-2005, pp. 580-586.

[13] B. Kasztenny, E. Rosolowshi, J. lzykowshi, M.M. Saha and B. Hillstrom, "Fuzzy logic controller for on-load transformer tap changer," IEEE Trans. Power Sys. vol. 13, No.1, Jan. 1998, pp. 164-170.

[14] Ajami and S.H. Hosseini, "Application of fuzzy controller for transient stability enhancement of ac transmission system by STATCOM," SICE-ICASE International Joint Conference 2006, Oct. 18-21, Bexco, Busan, Korea, pp. 6059-6063, 2006.

[15] R. N. Patel, "Application of Artificial Intelligence for Tuning the Parameters of an AGC", International Journal of Mathematical, Physical and Engineering Sciences, World Academy of Science, Engineering and Technology (WASET), Vol. 1, No. 1, 2007, pp. 34-39.

[16] P.Rao, M.L. Crow, Z.Young, "STATCOM control for power system voltage control application," IEEE Trans. Power Delivery, No. 15, 2000, pp. 1311-1317.

[17] P.S. Sensarma, K.R. Padiyar, V. Ramnarayan, "Analysis and performance evaluation of a distribution STATCOM for compensating voltage fluctuation," IEEE Trans. Power Delivery, vol. 16, 2001, pp. 259-264.

[18] S. Panda, R. N. Patel, N. P. Padhy, "Power System Stability Improvement by TCSC Controller Employing a Multi-Objective Genetic Algorithm Approach", International Journal of Intelligent Technology, vol. 1, No. 4, 2006, pp. 266-273.

[19] P.W.D.S. Lehn, "Modeling analysis and control of current source inverter based STATCOM," IEEE Trans. Power Delivery, No.17, 2002, pp. 248-253.

[20] H. Chen, R. Zhou, Y. Wang, "Analysis of voltage stability enhancement by robust non linear STATCOM control," Proceedings of IEEE PES Summer Meeting, vol. 3, 2000, pp. 1924-1929.