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Genetic Based Optimal Location of STATCOM Compensator

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Abstract

Heuristic approaches such as the Genetic Algorithm (GA) are traditionally used to find the optimal size and position of flexible alternating current transmission systems (FACTS) in power system. GA was used to solve engeering power optimization problems to achieve better and faster results than traditional methods. In This study shows the use of GA to select the optimal sizing and location of a static compensator (STATCOM) in a power system and compares the results to the classical method results when depending on the power factor correction limits. STATCOM devices used to riase transmission system capacity and enhence voltage profile by controlling the voltages at their connection through controlling the quantity of reactive power that injected into the power system. To verify the effectiveness of the proposed algorithm, studies are being applied on IEEE 5 bus, IEEE 30 bus test systems and the Iraqi national grid. The results show that the proposed method of STATCOM placement effectively to reduce the reactive power loss.

INTRODUCTION

FACTS devices are power electronic digital converters that may have the capability to control various electric power parameters in transmission brake lines, both in steady state condition power flow and dynamic stability control. They may have the capability to improve voltage profile, electric power transmission capacity, enhance electric power system stability, minimize transmission line losses, improve power factor, etc. With the quick development in the field of power electronics, FACTS devices have been recommended to be used in the operation, and control on the power systems. FACTS remotes such as SVC, STATCOM, and UPFC are being used to improve the performance power systems [1, 2]. They are able to control the reactive power (Q) which they supply or absorb rapidly and efficiently by controlling the firing delay angles of the thyristors. They can be used in transmission and distribution systems for managing and bettering many guidelines such as electric reactive power and voltage profile. STATCOM use power electronics to control its electric reactive power output to regulate profile buses voltages. Compared with mechanical means switched capacitor banks, STATCOM can react fast and has an improved reliability. Genetic algorithm can be used for the optimization of various process parameters associated with FACTS devices in a power system.

In [3] the GA used to choose the perfect location of STATCOM device in electric power system network to improve the voltage stability and reduce losses. In [4] some of the advanced techniques (Heuristic techniques) like Genetic (GA), and Particle Swarm Optimization (PSO) are presented to find the optimum location of STATCOM device in IEEE 14, 30, 57 bus systems in order to better the voltage profile and reduce the loss in power transmission system. In [5] the proposed work (Optimal Power Flow) OPF resolved by including a STATCOM to increase the system performance also to decrease the generating cost. In [6] and by using the STASCOM device which correct the power quality and increase the quality of the provision voltage.

This kind of paper presents a genetic based solution to seek rating and optimal location of STATCOM FACTS controllers to maximize the overall electric power flow and reducing the general system losses.

STATIC SYNCHROUNES COMPENSATOR (STATCOM)

IEEE as "a self-commutated switching power converter, provided from an appropriate electric energy source, and controlled to produce a variable rate multiphase voltage that can be coupled to an AC power system for exchanging independently controllable real and reactive power defines the STATCOM.

STATCOM is a shunt connected reactive compensation device that is capable of producing or absorbing reactive power, and whose result can be vary in order to maintain control of specific parameter of the electric power system. The STATCOM provides operating characteristics that are similar to a rotating synchronous compensator, but without mechanical inertia. For the reason that STATCOM employs solid electric power switching devices it can offer rapid controllability of the three-phase voltage, in magnitude and phase angle. STATCOM provides the support to modulate bus voltages during dynamic disturbances in order to provide better transitive characteristics, enhance the transient balance margins also to damp the actual system oscillations during disruptions [7].

STATCOM controllers based on solid state Voltage Source Converter (VSC) have been developed and commercially put in procedure for controlling system dynamics under various working conditions.

The advent of VSC technology has brought in a new family of FACTS controllers such as STATCOM and UPFC. The self-commutating VSC, also called DC-to-AC converter, is the backbone of these controllers being employed for controlling the reactive current by generation and absorption of controllable reactive power with assorted solid-state switching techniques. [8]

BASIC CIRICUT CONFIGURATION OF STATCOM

The STATCOM has been define as every CIGRE/IEEE with following:

1. Static based on solid-state switching devices with no rotating components.
2. Synchronous is similar to an ideal synchronous machine with 3-phase sinusoidal voltages at fundamental frequency.
3. Compensator means supplied with reactive compensation.

The typical connection of STATCOM to AC bus shown in Figure 1. That involves of the coupling transformer, input filter, voltage source converter and a control (VSC) [9].

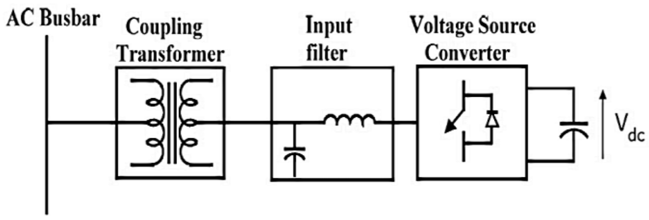

Figure 1. Connection of STATCOM with AC bus

The STATCOM is a static compensator consisting of inverters with a capacitor on its DC side, coupling transformers and a control system. The inverters are switched in conventional STATCOMs with a single pulse per period, and the transformers are connected to achieve harmonic minimization. The device response is provided by the continuous and rapid control of the capacitive or inductive reactive power.Its yield voltage is a waveform made out of pulses those methodologies a sinusoidal wave.

POWER FLOW MODEL

The power flow equations for the STATCOM are derived below from first principles and assuming the following voltage source representation:

$$E_{vR} = V_{vR}(\cos\delta_{vR} + j\sin\delta_{vR}) \ldots\ldots\ldots\ldots (1)$$

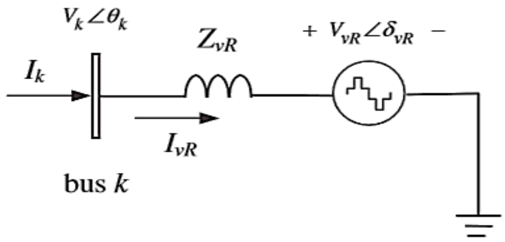

Figure 2. STATCOM equivalent circuit

Based on the shunt connection shown in Figure 2, the following may be writing:

$$S_{vR} = V_{vR}I_{vR}^* = V_{vR}Y_{vR}^*(V_{vR}^* - V_k^*) \ldots\ldots\ldots\ldots (2)$$

After performing some complex operations, the following active and reactive power equations are obtain for the converter and bus k, respectively:

$$P_{vR} = V_{vR}^2 G_{vR} + V_{vR}V_k[G_{vR}\cos(\delta_{vR} - \theta_k) + B_{vR}\sin(\delta_{vR} - \theta_k)] \ldots\ldots (3)$$

$$Q_{vR} = -V_{vR}^2 G_{vR} + V_{vR}V_k[G_{vR}\sin(\delta_{vR} - \theta_k) - B_{vR}\cos(\delta_{vR} - \theta_k)] \ldots (4)$$

$$P_k = V_k^2 G_{vR} + V_{vR}V_k[G_{vR}\cos(\theta_k - \delta_{vR}) + B_{vR}\sin(\theta_k - \delta_{vR})] \ldots\ldots (5)$$

$$Q_k = -V_k^2 G_{vR} + V_{vR}V_k[G_{vR}\sin(\theta_k - \delta_{vR}) - B_{vR}\cos(\theta_k - \delta_{vR})] \ldots\ldots (6)$$

Using these power equations, the linearized STATCOM model is give below, where the voltage magnitude V_{vR} and phase angle δ_{vR} are taken to be the state variables [7].

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_{vR} \\ \Delta Q_{vR} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k}V_k & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}}V_{vR} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k}V_k & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k}{\partial V_{vR}}V_{vR} \\ \frac{\partial P_{vR}}{\partial \theta_k} & \frac{\partial P_{vR}}{\partial V_k}V_k & \frac{\partial P_{vR}}{\partial \delta_{vR}} & \frac{\partial P_{vR}}{\partial V_{vR}}V_{vR} \\ \frac{\partial Q_{vR}}{\partial \theta_k} & \frac{\partial Q_{vR}}{\partial V_k}V_k & \frac{\partial Q_{vR}}{\partial \delta_{vR}} & \frac{\partial Q_{vR}}{\partial V_{vR}}V_{vR} \end{bmatrix} \begin{bmatrix} \Delta\theta_k \\ \frac{\Delta V_k}{V_k} \\ \Delta\delta_{vR} \\ \frac{\Delta V_{vR}}{V_{vR}} \end{bmatrix} \ldots\ldots (7)$$

RESEARCH METHOD

In order to optimize and to obtain the maximum benefits from their use, the main issues to be consider are the type of FACTS devices, the settings of FACTS devices and their optimal location.

a. Mean Power Factor (MPF)

Power factor (PF) can be used to determine the weakest bus in a power system. When a load bus or line has low PF, FACTS devices can be installed at this point. Improvement of PF of a power system can be achieved by locating FACTS device at a point in the power system, this device can adjust the reactive power injected or absorbed, so that PF is increasing [10].

The optimal location of STATCOM has been select based on MPF, for improvement of power factor of all power system. This power factor index considers both active and apparent powers to evaluate power factor, which provides information about the weakest bus or line in the system.

$$\boldsymbol{MPF} = \frac{\sum_{n=1}^{n} PF_n}{n} \qquad \textbf{(8)}$$

$\boldsymbol{where}\ PF_n: -$ *is the power factor of the nth bus.*

$n: -$ *number of load bus (PQ bus).*

b. Genetic Algorithm (GA)

Genetic algorithm (GA) is one of the evolutionary Algorithms search technique based on mechanism of natural selection and genetics. It searches several possible solutions simultaneously and do not require prior knowledge or special properties of the objective function [11]. GA begin with the initial random generation of a population of a binary string, calculates fitness values from the initial population, next it perform by the operation selection, crossover, and mutation. These operations are continuous until the best population obtained. Genetic algorithm encodes the variables of the optimization function and work a checking process that explores the searching space in parallel. Searching mechanism begin with an initial set of solutions generated randomly and called "Population". These initials set up solutions satisfies the equality and inequality limitations of the problem. Every individual solution in the population called "Chromosome". The algorithm can be direct by fitness function towards the global point. GA uses the standards of natural selection to improve the chromosomes during sequential iterations called "Generations". Crossover and / or mutation operators create new chromosomes (offspring). From the continuous evaluation of every chromosome through each generation, and by using selection techniques, a new generation is create. Typically, GA consists of three phases, Generation, Evaluation and Genetic operation.

Selection Operator:-

The selection operator is use to give preference to better individuals, to allow them to pass on their genes to the next generation. The goodness of an individual depends on its fitness, which may be determine by an objective function or a subjective judgment.

Crossover Operator:-

It is effectively a prime distinguished factor of GA as compared to other optimization techniques. Two individuals are chose randomly from the population using the selection operator, and a crossover site along the bit strings is randomly chose. The values of the two strings are to be exchange up to this point. If $S_1 = 111111$ and $S_2 = 000000$ and the crossover point is (4) then $S_1' = 111100$ and$S_2' = 000011$. The two new offspring resulted from this mating are passed to the next generation. The process of recombining portions of good individuals is likely to create even better individuals.

Mutation Operator:-

A portion of the new individuals will have some of their bits flipped with some low probability. The purpose of this mutation is to maintain diversity within the population, so that premature convergence is inhibited. Mutation alone induces a random walk throughout the search space.

Fitness calculation:-

In this paper, the fitness function chosen is MPF.

$$\boldsymbol{fitness\ functin\ f(n)} = \sum_{n=1}^{n} \frac{P_n}{S_n} \qquad \textbf{(9)}$$

$\boldsymbol{Where}\ P_n: -$ *real power of the* n_{th} *bus.*

$S_n: -$ *appearnt power of the* n_{th} *bus.*

Algorithm for the proposed work

Step 1: Network data collected for the buses of the power system.

Step 2: FACTS device data is collected.

Step 3: Newton Raphson load flow carried out for all buses with the FACTS device attached to one load bus, to determine the value of nodal voltage, real power & reactive power flows.

Step 4: The initialize values for the genetic algorithm, population size considered is 10 & number of generations is 100 with cross over & mutation probability of 0.8 & 0.001 respectively.

Step 5: Step 3 and step 4 are repeat to include all load buses for the number of generations specified.

The output of GA at the end of the last generation is the best location for the FACT device in the power system.

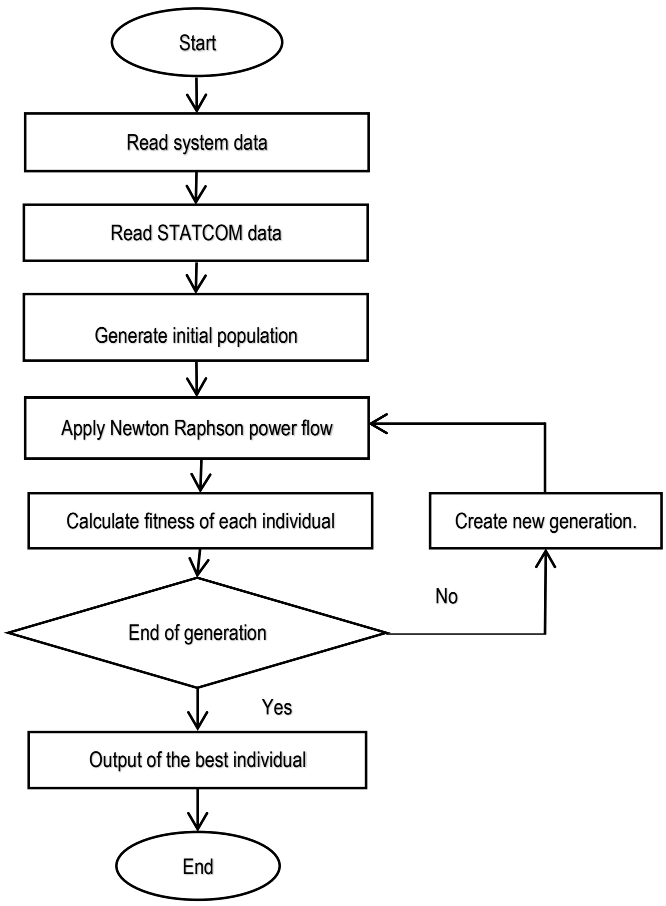

Figure 3. Flowchart of power flow system with GA.

RESULTS AND ANALYSIS

Classical method

Application of the classical method (Newton Raphson load flow method) on the IEEE 5-bus, IEEE 30-bus and Iraqi National Grid to select the best location of STATCOM as far as power factor of all load buses is concerned was performed, and load flow solution with and without STATCOM using MATLAB was obtained as shown in Tables (1, 2).

Table 1. IEEE 5-bus system without STATCOM

Bus No.	Voltage Mag.	Angle Degree	Load		Generation	
			MW	Mvar	MW	Mvar
1	1.060	0.000	0.000	0.000	131.141	90.801
2	1.000	-2.063	10.000	10.000	40.000	-61.662
3	0.987	-4.639	45.000	15.000	0.000	0.000
4	0.984	-4.960	40.000	5.000	0.000	0.000
5	0.972	-5.765	60.000	10.000	0.000	0.000
Total			165.000	40.000	171.141	29.139

Table 2. IEEE 5-bus system with STATCOM in Bus-4

Bus No.	Voltage Mag.	Angle Degree	Load		Generation	
			MW	Mvar	MW	Mvar
1	1.060	0.000	0.000	0.000	131.088	85.513
2	1.000	-2.055	20.000	10.000	40.000	-81.458
3	1.000	-4.829	45.000	15.000	0.000	0.000
4	1.000	-5.211	40.000	5.000	0.000	0.000
5	0.977	-5.827	60.000	10.000	0.000	0.000
Total			165.000	40.000	171.088	4.055

As per the Table 1. bus no. 1 is the slack bus with real power generation of 131.141 MW and 90.801 of reactive power. Through using STATCOM in bus-4 for IEEE 5-bus system, it is observed from Table 2. that a decrease in generation of both real and reactive power. Reactive power generation has declined to 85.513 Mvar because the STATCOM is injecting the reactive power into the fourth bus to compensate for the power absorbed by load.

A comparison of real power losses for the three different power systems considered outlined in Table .3 with and without a STATCOM connected.

Table 3. Real Power Losses

System	Power Losses Without STATCOM/MW	Power Losses With STATCOM/MW
IEEE 5-bus	6.1222	6.0684
IEEE 30-bus	17.5985	17.5579
Iraqi Grid	1.6246	0.9206

Placement of a STATCOM in a power system has shown an improvement of the over-all power factor of the power system, and this improvement was found to be dependent on location of STATCOM.

Figure.4 shows the value of the MPF when a STATCOM is connected to each of the three load buses (one at a time) of IEEE5-bus, with bus-4 having the highest MPF. Therefore, it is concluded that bus-4 is the best location for the STATCOM device to be connected to with a value of MPF = one.

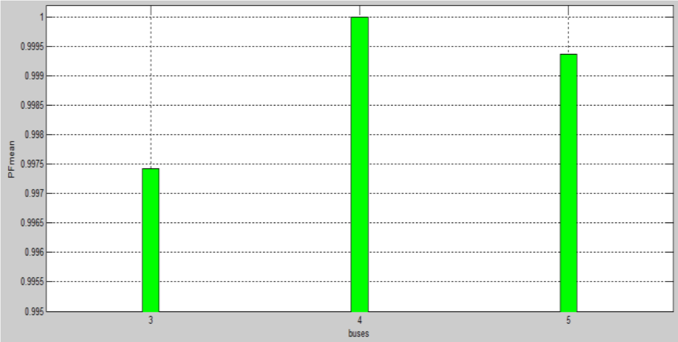

Figure 4. MPF of IEEE 5-bus with STATCOM connected.

In the IEEE 30-bus (No. of PQ buses in this system is 24), bus-7 was found to be the best location with MPF = 0.9983, as shown in Figure 5.

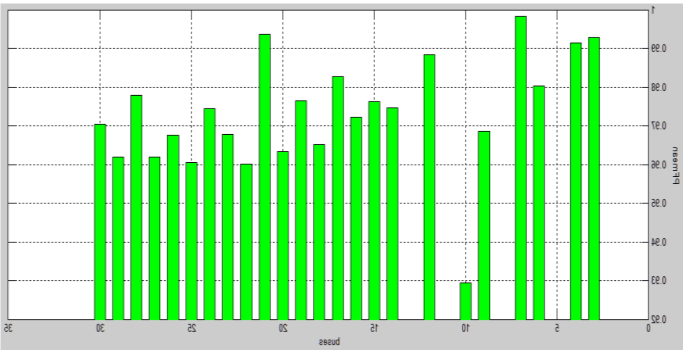

Figure 5. MPF of IEEE 30-bus with STATCOM connected.

For the Iraqi National Grid 24-bus (No. of PQ buses in this system = 14), bus-6 was found to be the best location with MPF = one as shown in Figure 6.

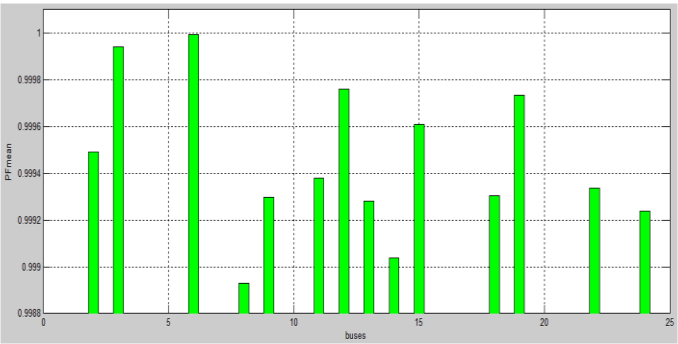

Figure 6. MPF of Iraqi National Grid with STATCOM connected.

Genetic algorithm method

A MATLAB coding is developed for genetic algorithm. In order to verify the effectiveness of the proposed algorithm, case studies are carried out on IEEE 5-bus, IEEE 30-bus systems and Iraqi National grid. For GA, number of generation considered is 100 & population size is 10. With cross over & mutation probability of 0.8 & 0.001 respectively. Figure.7 shows the application of the GA on the IEEE 5-bus system. After 17 generations, the best location of STATCOM was bus-4.

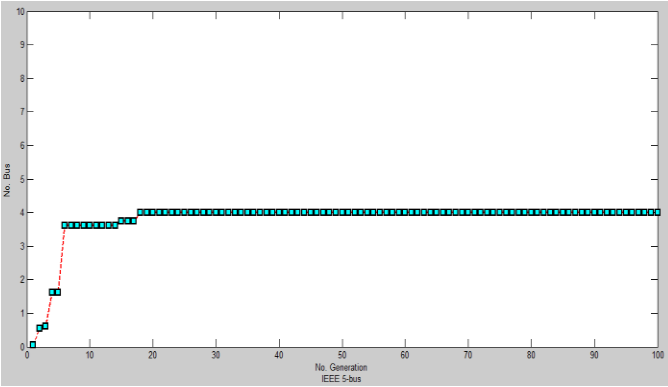

Figure 7. Optimal location of STATCOM device by GA for IEEE 5-bus.

Application of the GA on the IEEE 30-bus system in Figure.8, shows the best location of STATCOM is bus-7, and after the 21 generations.

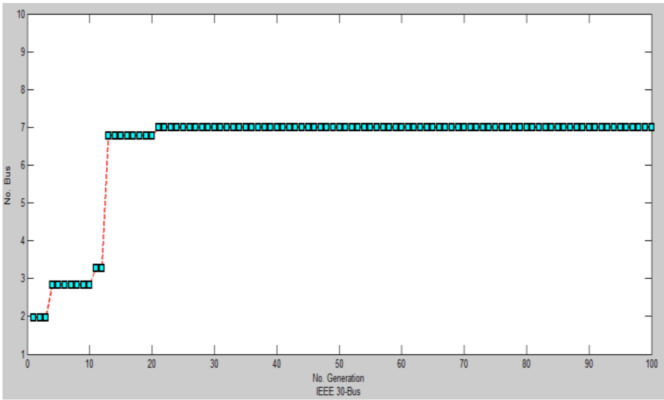

Figure 8. Optimal location of STATCOM device by GA for IEEE 30-bus.

Figure 9. shows the results of the GA on the Iraqi National Grid system. Bus-6 was found to be the best location of STATCOM after the 20 generations.

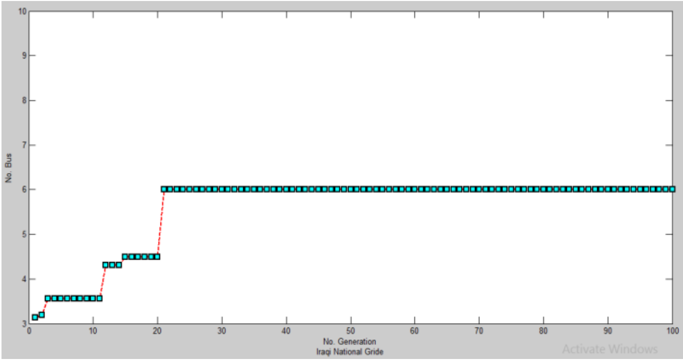

Figure 9. Optimal location of STATCOM device by GA for Iraqi national grid.

A comparison for the three power systems considered, with and without a STATCOM at the optimal location, as far as the mean power factor is concerned outlined in Table.4.

Table 4. Comparison MPF results with and without STATCOM.

Objective / Result	MPF Without STATCOM	MPF With Optimum Location Of STATCOM	No. of Bus That Optimum Location Of STATCOM
IEEE 5-Bus	0.9991	1.0000	Bus-4
IEEE 30-Bus	0.9710	0.9983	Bus-7
Iraqi Grid	0.9993	1.0000	Bus-6

It can be seen that the MPF is improved when using a STATCOM in the optimal location in the power system, which in turn means less power losses and a better over-all voltage profile.

CONCLUSION

In this paper, power flow solution was carried out using MATLAB on three different power systems, to find a value for the MPF with STATCOM connected to load buses, each one at a time to determine the best location for the STATCOM. The same goal was then achieved using GA to verify the results obtained earlier. It was found that a STATCOM device did increase the value of MPF, and choosing the right point for connecting the device raise the MPF even more.

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