Research Journal of Applied Sciences, Engineering and Technology 4(14): 2105-2109, 2012
ISSN: 2040-7467

Submitted: January 30, 2012 Accepted: February 22, 2012 Published: July 15, 2012

Identification of Optimum Location of STATCOM in Transmission Line Employing RCGA Optimization Technique

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Abstract: This study inspects the optimum location of STATCOM device in long transmission line to acquire the maximum power system transient stability improvement. STATCOM is a kind of prominent and effective shunt FACTS device which is used in power system to enhance the power system stability and to regulate the line voltage. When it has been placed at the center point of a transmission line, play a key role in controlling the reactive power flow and enhancing the power system transient stability. The active power losses caused by transmission line resistance alter the neutral position or optimum location of STATCOM in transmission line. RCGA optimization due to have high ability to solve non-linear objective function has been implanted to identify the optimum location of STATCOM. The results of non-linear simulation under severe disturbance approve that the optimum location of STATCOM in order to access the maximum power system transient stability by reducing the active power losses approaches to midpoint of transmission line.

Key words: Optimum location, power system transient stability, RCGA technique, STATCOM

INTRODUCTION

Recent advances in the field of Power Electronics provide an appropriate bed in order to using of Flexible AC Transmission System (FACTS) devices in power system. FACTS devices have ability to control the network status affected by very rapid and severe disturbances and this particular feature increases the power system transient stability (Hingorani Gyugyi, 2000; Enrique *et al*., 2004). Static synchronous compensator (STATCOM) is member of shunt FACTS family that can inject/absorb active power from the network in order to increase both the performance dynamic and the transient stability of power system (Falehi *et al*., 2011). STATCOM gives the maximum stabilized voltage support consequently maximum power system transient stability improvement when it has been placed at the midpoint of transmission line (Haque, 2000). The power system response with considering the actual model of long transmission line maybe has a somewhat deviation as compared to simplified model of transmission line. The main reason of this deviation is the neglect of transmission line resistance. To acquire the optimum location of STATCOM in actual model of transmission line, employing an intelligent algorithm is essential.

Many different conventional techniques have been implemented to tune the controller parameters. Most of these techniques are based on the pole placement method (Shrikant Rao and Sen, 2000; Abido, 2000a, b), eigenvalues sensitivities (Pal, 2002; Rouco and Pagola, 1997), residue compensation (About-Ela *et al*., 1996) and also the current control theory. Unfortunately, the conventional methods are time consuming and repetitive, also need heavy computation burden and slow convergence. In addition, process is sensitive to be trapped in local minima and the obtained response may not be optimal (Panda and Padhy, 2008).

The progressive methods develop a technique to search for the optimum solutions via some sort of directed random search processes (Haupt and Haupt, 2004). A suitable trait of the evolutionary methods is that they search the solutions without the prior problem perception. In recent years, a number of various ingenious computation techniques namely: Simulated Annealing (SA) algorithm, Evolutionary Programming (EP), Genetic Algorithm (GA), Differential Evolution (DE) and Particle Swarm Optimization (PSO) have been employed by scholars to solve the different optimization problems of electrical engineering (Wang *et al*., 2006; Gaing, 2004; Abido, 2000a, b; Christober, 2010; Yuryevich and Wong., 1999; Wu and Ma, 1995; Wang, 2009). The high performance of GA technique to solve the non-linear objectives has been approved in many literatures. In this study, RCGA optimization technique is selected to detect the optimum location of STATCOM in long transmission line in order to acquire the maximum power system transient stability.

The results of non-linear simulation under severe disturbance approve that the optimum location of STATCOM in order to access the maximum power system transient stability by reducing the active power losses approaches to midpoint of transmission line.

METHODOLOGY

Description of the implemented real coded genetic algorithm technique: Genetic Algorithm is a kind of random search optimization technique based on the mechanism of natural evolution and the survival of the best chromosome. A genetic algorithm is founded by a cycle of three stages, namely: assessment of each chromosome, selection of chromosome, creation of a new population. GA maintains and controls a population of solutions and enhances performance of fitness function in their search for better solutions. Reproducing the generation and keeping the best individuals for next generation, the best gens will be obtained. The RCGA optimization process can be described as below (Falehi and Rostami, 2011):

Initialization: To commence the RCGA optimization process, initial population shall be specified. An initial population can randomly be generated or obtain from other methods (Haupt and Haupt, 2004). The length limitation of variables should determine for optimization problem:

$$p = (p_{hi}-p_{lo})p_{norm}+p_{lo} \tag{1}$$

Objective function: Each individual represents a possible solution to optimize the fitness function. The fitness for each individual in the population is evaluated by taking objective function. Eliminating the worst individuals, a new population is created, while the most highly fit members in a population are selected to pass information to the next generation:

$$\text{Chromosome(var iables)} = [P_1, P_2, \ldots, P_N] \tag{2}$$

$$\text{Cost} = f(\text{chromosome}) = f(P_1, P_2, \ldots, P_{Nvar}) \tag{3}$$

Selection function: The selection function attempts to implement pressure on the population like natural biological systems. The selection function decides which of the individuals can survive and transfer genetic characteristic to the next generation. The selection function specifies which individuals are selected for crossover. Several methods exist that parents are chosen according to efficiency of their fitness. In this study, roulette wheel selection method is considered and is described in details in (Goldberg, 1989).

Genetic operator: There are two main operators in GA optimization process which are basic search mechanism of the GA techniques: crossover and mutation. They are used to create new population based on acquirement the best solution.

Crossover: Crossover is the core of genetic operation, which helps to achieve the new regions in the search space. Conceptually, pairs of individuals are chosen randomly from the population and fit of each pair is allowed to mate. Thus, parameter where crossover occurs expressed as:

$$\alpha = roundup\{random * N_{var}\} \tag{4}$$

Each pair of mates creates a child bearing some mix of the two parents:

$$parent\ 1 = [p_{m1}\, p_{m2} \cdots p_{m\alpha} \cdots p_{mNvar}] \tag{5}$$

$$parent\ 2 = [p_{d1}\, p_{d2} \cdots p_{d\alpha} \cdots p_{dNvar}] \tag{6}$$

Then the selected variables are combined to form new variables that will appear in the children:

$$p_{new1} = p_{m\alpha} - \beta[p_{m\alpha} - p_{d\alpha}] \tag{7}$$

$$p_{new2} = p_{d\alpha} + \beta[p_{m\alpha} - p_{d\alpha}] \tag{8}$$

where, β is also a random value between 0 and 1. The final step is to complete the crossover with the rest of the chromosome as before:

$$\text{Offspring\_1} = [p_{m1}p_{m2} \cdots p_{new1} \cdots p_{dNvar}] \tag{9}$$

$$\text{Offspring\_2} = [p_{d1}p_{d2} \cdots p_{new2} \cdots p_{mNvar}] \tag{10}$$

Mutation: The mutation process is used to avoid missing significant information at a special situation in the decisions. Mutation is usually considered as an auxiliary operator to extend the search space and cause release from a local optimum when used cautiously with the selection and crossover systems. With added a normally distributed random number to the variable, uniform mutation will be obtained:

$$p'_n = p_n + \sigma N_n(0, 1) \tag{11}$$

Stopping criterion: The stopping scale can be considered as: the maximum number of generation, population convergence criteria, lack of improvement in the best solution over a specified number of generations or target value for the objective function.

STATCOM model: The STATCOM is based on a solid state synchronous voltage source which injects a balanced set of three-phase sinusoidal currents to the network at the fundamental frequency with quickly controllable amplitude and phase angle (Falehi *et al*., 2011). The output current has been adjusted to control either the nodal voltage magnitude or the reactive power injected at the bus (Enrique *et al*., 2004). Substantially, it comprises of a VSC, a DC capacitor and a coupling transformer

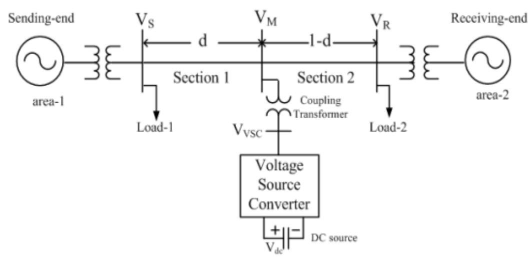

Fig. 1: Two area power system with STATCOM

(Mohd and Bin, 2010). Control of reactive current given to power system is possible by change of the magnitude of output voltage (VSC) with respect to bus voltage (V_B) and thus operating the STATCOM in inductive region or capacitive region. In the general case a STATCOM actually acts same as variable source current to maintain or control specific power system variables. The main reasons for installing a STATCOM are to improve dynamic voltage control, increase system load ability and increase power system stability.

Analysis of the two area power system with presence of STATCOM: The single line diagram of this power system is presented in Fig. 1. As can be seen, active power follows from area 1 to the area 2. We can divide the transmission line in two sections (section 1 and section 2). The distance between sending and receiving ends of section 1 is characterized by "d".

The relationship between the sending and receiving ends of long transmission line can be written as:

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{12}$$

Also, the sending-end active power (P_s) and the receiving-end active power (P_R) can be given as:

$$P_s = K_1\cos(\theta_B - \theta_A) - K_2\cos(\theta_B + \delta) \tag{13}$$

$$P_R = K_2\cos(\theta_B - \delta) - K_3\cos(\theta_B - \theta_A) \tag{14}$$

where,

$K_1 = AV^2_S/B$ $\quad K_2 = AV_SV_R/B \quad K_3 = AV_R/B$
$A = |A|\angle\theta_A \quad B = |B|\angle\theta_B$
$V_R = |V_R|\angle 0 \quad V_S = |V_S|\angle\delta$

Also, A, B, C and D are the constants of the transmission line.

In simplified model the transmission line, the values of resistance and capacitance are disregarded. Thus, both P_s and P_R become maximum at power angle $\delta = 90°$. But, when STATCOM is connected to a long transmission line, the responses in actual power system may be different with the responses in simplified power system. According to the Eq. (14), the receiving-end power reaches the maximum value when the angle δ becomes θ_B. However, according to the Eq. (13), the sending-end power becomes maximum at $\delta = (180 - \theta_B)$

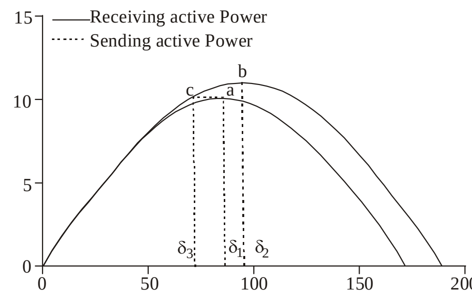

Fig. 2: Sending and receiving ends of active power_angle characteristics in actual line model

The power angle curve considering the actual line model in absence of STATCOM is shown in Fig. 2.

STATCOM via providing the required reactive power can maintain the voltage constant at the point of connected STATCOM in transmission line. In this section, it is considered that STATCOM does not absorb/inject any active power. The active power which is received from the end point section 1 must be equal to the sending active power at end point of section 2. If maximum active power has been delivered from end point of section 1 ("a"), the sending active power of section 2 can be determined by the same power level (point c). Consequently, the total transmission angle at the maximum power point is defined by the following equation:

$$\delta = \delta_1 + \delta_3 \tag{15}$$

Thus, the maximum receiving end power of section 1 limits the maximum power transfer capability of the system. The curve of the power-angle depends on the "d". By decreasing the value of "d" the maximum receiving active power of section 1 increases, while the maximum sending active power of section 2 decreases.

Due to the existence of resistance in transmission line, both the maximum active power of two sections will be equal at d<0.5.

Application of RCGA technique to access the optimum location of STATCOM in transmission line:

Structure of the power system: The model of the two area power system under study has been simulated in MATLAB/SIMULINK environment. It is almost similar to the power system used in Ref (Falehi, 2011). All of the other relevant parameters are given in Appendix.

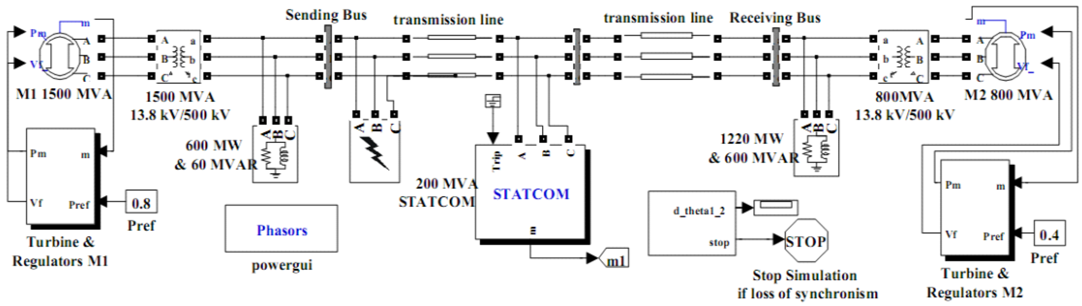

Fig. 3: Simulation of the two area power system

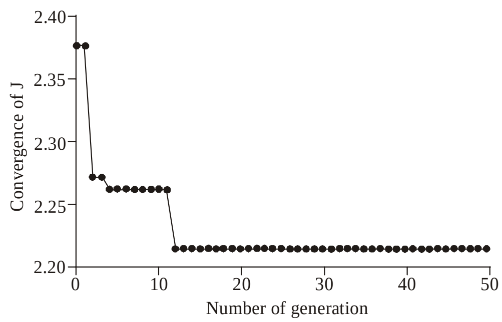

Fig. 4: Convergence of objective function

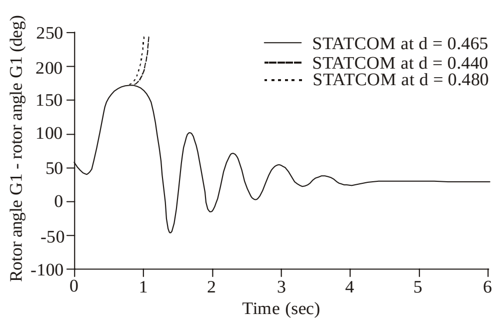

Fig. 5: Variation of rotor angle under 3-ph fault

Aforesaid power system with presence STATCOM is shown in Fig. 3.

Objective function: To acquire the maximum power system transient stability, the overshoot of the rotor angle deviation is considered as objective function which is given as follows:

$$J = \text{maximum}(\Delta\delta_1 - \Delta\delta_2) \tag{16}$$

To find the optimum location STATCOM, the value of objective must be minimized. Provided that:

$$0 \le d \le 1 \tag{17}$$

SIMULATION RESULTS

A three phase short circuit is taken into account at sending end bus at time t = 0.1 s. and after 0.159 s fault is cleared. The convergence of the RCGA technique and the system response are presented in Fig. 4 and 5, respectively. As can be seen in Fig. 5, STATCOM at d = 0.465 have maximum performance to restore system in stable condition.

As mentioned before, the value of active power losses causes the receding of STATCOM from center point of transmission line. However, by changing the transmission line losses via altering the local loads which are located at sending and receiving ends of transmission line, the exact values "d" employing RCGA technique have been obtained. The optimum values of "d" accompanied by other parameters have been presented in Table 1.

According to the aforesaid Table, the optimum location of STATCOM approaches to midpoint of transmission line by decreasing the values of transmission line losses.

CONCLUSION

STATCOM is designed to obtain fast voltage control and to damp out the power system oscillations. The performance of May 25, 2012this device in order to obtain

Table 1: Optimum location of STATCOM transmission line

Transinis sion line losses	Load at receiving bus	Load at sending bus	Optimum location of STATC	Reduction of transmission line losses
32.2^{MW}	1360^{MW}600^{MVAR}	400^{MW}60^{MVAR}	d = 0.443	
28.4^{MW}	1340^{MW}600^{MVAR}	500^{MW}60^{MVAR}	d = 0.453	
23.5^{MW}	1220^{MW}600^{MVAR}	700^{MW}70^{MVAR}	d = 0.465	
16.9^{MW}	1040^{MW}600$_{MVAR}$	700$_{MW}$60^{MVAR}	d = 0.473	

the maximum power system transient stability when it has been placed at the center point of a transmission line has been well proved. The value of transmission line losses affects the optimum location of STATCOM in long transmission line. RCGA optimization technique has been applied to acquire the optimum location of this device in transmission line. Finally, the results of non-linear simulation under severe disturbance reveal that by reducing the transmission line losses the optimum location of STATCOM in order to access the maximum power system transient stability approaches to midpoint of transmission line.

Appendix:

Generators parameters:
M_1= 1500 MVA, M_2= 800 MVA, V = 13.8 KV, f = 60 Hz, X_d= 1.305 pu, X'_d = 0.296 pu, X''_d = 0.255 pu, X_q = 0.474 pu, X'_q = 0.243, X''_q = 0.18 pu

Transformer parameters:
T_1 = 1500 MVA, T_2 = 800 MVA, 13.8/500 KV, R_2 = 0.002 pu, L_2 = 0.12 pu, R_m = 500 pu, X_m = 500 pu.

Transmission line parameters:
R_1 = 0.1755 Ω/km, R_0 = 0.2758 Ω/km, L_1 = 0.8737 e-3 H/km, L_0 = 3.22 e-3 H/km, C_1 = 13.33 e-9 F/km, C_0 = 8.297 e-9 F/km.

STATCOM parameters:
500 KV, ±200 MVAR, R = 0.071, L = 0.22, V_{dc} = 40 KV, C_{dc} = 375 μF, V_{ref} = 1.0, K_p = 50, K_i = 1000.

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