PSO Algorithm-Based Optimal Tuning of STATCOM for Voltage Control in a Wind Farm Integrated System

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Abstract

In this paper a method based on Particle Swarm Optimization (PSO) algorithm is presented for tuning static synchronous compensator (STATCOM) parameters. STATCOM is used for voltage and reactive power control in a wind farm integrated power system in both steady state and contingency situations. Doubly-fed induction generator (DFIG) is used as the wind generator model. In order to investigate the proposed performance, the method is applied to the IEEE-14 bus test system. Simulations are implemented in Power System Analysis Toolbox (PSAT) and MATLAB. The main purpose of the approach is to keep to voltage at the wind farm connection bus in reference value and to minimize the voltage deviations immediately after a heavy loaded line outage which is connected to the wind farm. Simulation results prove the capability of the PSO technique in optimal tuning of STATCOM for voltage control.

1. Introduction

Number of wind farms connected with transmission network increases rapidly day by day, due to the enviromental and economical reasons [1]. Doubly-fed induction generators (DFIG) are commonly used as variable speed wind turbines because of the reactive power and voltage control ability. DFIG is equipped with power electronic converters. Hence, it can regulate its own reactive power [2]. DFIG can usually generate or consume a reactive power up to 30% of the nominal active power, subject to its technology. DFIG connection to transmission network usually results with the voltage increase at the related bus. So, it must be guaranteed that voltage is below the maximum voltage bounds [3].

Voltage profile in power systems maintained by voltage controllers such as AVRs (automatic voltage regulators) in generating units, STATCOMs (static synchronous compensators), SVCs (static Var Compensators) and other FACTS devices in power network. The main purpose of using voltage controllers are the maintenance of the voltage at the connection points of the voltage controllers for setting reference voltage values and to keep voltage deviations in its limits during normal conditions and contingency conditions in power system [4]. In this study, STATCOM is used for bus voltage support. Main objective of STATCOM is to control bus voltage by injecting or absorbing reactive power and it is connected in shunt with the power system [5]. But obtaining the optimal STATCOM controller parameters is a problem. Several heuristic methods such as evolutionary computation, simulated annealing, tabu search and particle swarm have invented to solve such difficult optimization problems. They can be used to avoid from the burden of the complex and time-consuming process of STATCOM tuning. Success for handling optimization problems of particle swarm optimization (PSO) which is one of the last evolved techniques, has been reported in the literature. PSO is population-based search technique as genetic algorithm and inspired by behaviours of herds of animals such as birds and fishes [6].

The purpose of this paper is to contribute the application of PSO for designing a STATCOM controller for voltage control of a wind farm integrated power system which is subject to a disturbance. In this study, proposed method is applied to IEEE 14-bus test system. After a wind farm is integrated to the system, voltage profile of the connection bus exceeds the maximum limits. In order to control the voltage profile of the connection bus, STATCOM is used. Controller parameters of STATCOM are optimally tuned by using PSO technique. During the progress of particle swarm optimization, Power System Analysis Toolbox (PSAT) is used for time-domain analysis of the system.

2. Problem Formulation

2.1. STATCOM modeling

STATCOM model which is performed by PSAT is current injection model. According to this model, just reactive power exchange between grid and STATCOM is possible. Dynamic model of STATCOM is shown in Fig. 1. Differential equation and injected reactive power at the connection bus are defined, respectively as [7]

$$\dot{i}_{\mathrm{SH}} = (K_r(V_{\mathrm{ref}} + v_{\mathrm{POD}} - V) - i_{\mathrm{SH}})/Tr \qquad (1)$$

$$Q = i_{\mathrm{SH}}V \qquad (2)$$

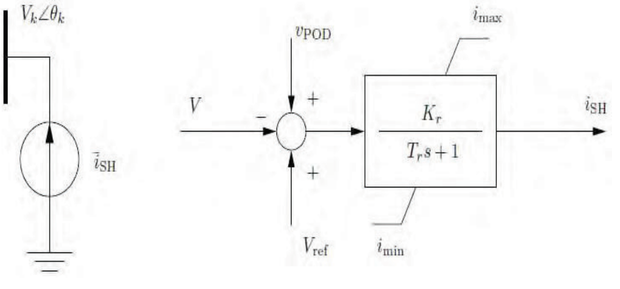

Fig. 1. Circuit and control block diagram of STATCOM [7].

K_r *and* T_r are controller gain and controller time constant respectively, in equations (1) and (2). v_{POD} represents output signal of Power Oscillation Damper. According to the block diagram, input signal of proposed model is voltage deviation and output signal is STATCOM current. Hence, voltage profile of the connection bus is maintained by controlling the reactive current of STATCOM.

2.2. PSO-based optimal tuning of STATCOM parameters

As mentioned before, wind farm integration to grid may cause voltage increase that is exceeded maximum limits at connection bus [3]. In this study, STATCOM controller parameters are obtained by PSO to keep bus voltage at the reference value for steady-state operation and to minimize the voltage deviations immediately after a heavy loaded line loss which is connected to the wind farm. So, K_r *and* T_r are obtained to support voltage stability. For maintaining the sufficient voltage profile, objective function, J is formulated as

$$J = \frac{1}{t}\int_0^t (|V_{ref} - V|)dt \qquad (3)$$

V_{ref} and V represents reference bus voltage value and bus voltage, respectively at the connection bus of STATCOM. V_{ref} is set to 1.0 pu for this study. Optimization problem of the present study can be defined as

Minimum J

Subject to

$$K_r^{min} \le K_r \le K_r^{max}$$
$$T_r^{min} \le T_r \le T_r^{max} \qquad (4)$$

Objective function which is constrained by controller parameters' limits is minimized by using PSO technique. PSO technique which is applied by PSO Toolbox is performed by using MATLAB. Time-domain simulation, which is implemented using PSAT, is run for each particle to get optimum controller parameters. Flowchart of PSO algorithm is shown in Fig. 2. Depending on the options that are specified by user, PSO generates initial swarm, randomly. Then, time domain simulation is performed by PSAT for each particle. By this way, fitness of each particle in the current swarm is found. PSO updates the particle position and velocity using equations (5) and (6). This process continues until maximum iteration number is reached. Finally, the particle that gives the minimum objective function is chosen as STATCOM controller parameters. Velocity and position of each particle is calculated as [5]:

$$v_{j,g}^{(t+1)} = w \times v_{j,g}^{(t)} + c_1 \times r_1() \times (\text{pbest}_{j,g} - x_{j,g}^{(t)}) + c_2 \times r_2() \times (\text{gbest}_g - x_{j,g}^{(t)}) \qquad (5)$$

$$x_{j,g}^{(t+1)} = x_{j,g}^{(t)} + v_{j,g}^{(t+1)}, \qquad (6)$$

The position corresponding to the best fitness is known as *pbest* and the overall best out of all the particles in the population is called *gbest*. *j= 1,2,...,n* and *g=1,2,...,m,* where *n* is the number of particles in a group; *m* the number of members in a particle; t the number of generations (iterations); $v_{j,g}^{(t)}$ the velocity of particle *j* at generation *t*, $V_g^{min} < v_{j,g}^{(t)} < V_g^{max}$; w the inertia weight factor; c_1 and c_2 are the cognitive and social acceleration factors, respectively; r_1 and r_2 are random numbers; $x_{j,g}^{(t)}$ is the current position of the particle j at the generation; $pbest_j$ the *pbest* of particle j; *gbest* the $gbest_g$ of the group [5].

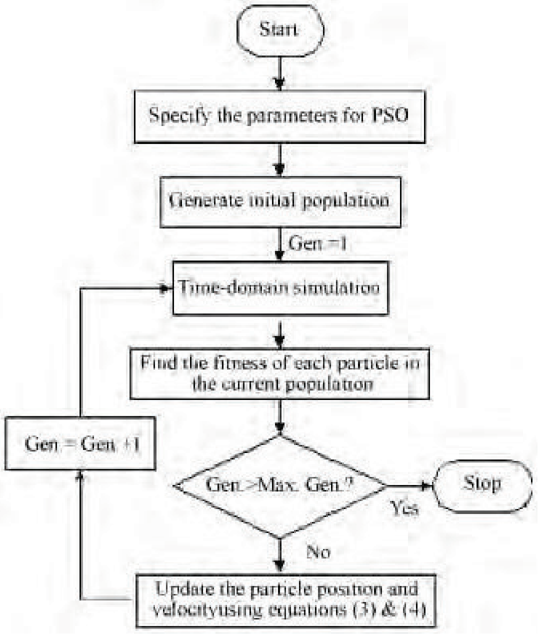

Fig. 2. Flowchart of the PSO [6].

In Table 1, specified PSO parameters' values are given for present study.

Table 1. Specified PSO Parameters' Values

Specified PSO parameters	**Values**
Swarm Size	20
Max. Iteration Number	20
c_1	2
c_2	2
w_{start}	0.95
w_{end}	0.4

3. Simulation Results

Simulations are implemented for IEEE 14-Bus Test system. Effects of wind farm and STATCOM integrations to the systems are investigated. STATCOM controller parameters are optimized by PSO technique. Time-domain analysis is used to solve the optimization problem. Objective function and controller parameters are evaluated by contingency case for the system. The contingency case is obtained as a heavy-loaded line loss which is connected to the wind farm and STATCOM. For all simulations, time-domain analysis is implemented by using PSAT which is MATLAB-based open- source program [8].

Also, PSO technique is performed by using PSO Toolbox on MATLAB.

Firstly, only wind generation system which is equipped with DFIG is connected to the IEEE 14-Bus Test System to analyze the effect of wind farm on the system. As it is shown in Fig. 6, wind farm is connected to Bus 14. It consists of 30 turbine and each turbine supplies 2 MW. Nominal active power and reactive power of wind farm that is injected to transmission system is assumed as 60 MW and 8.5 MVAR, respectively. Bus1 is selected as slack bus.

As it is seen in Fig. 3, after the wind generation system connection to grid, voltage of the Bus14 increases from 1.0358 pu to 1.1002 pu. Due to the wind farm integration, bus voltage exceeds the maximum voltage limit. When the line between Bus14 and Bus9 which is heavy-loaded line connected to the wind farm is lost at the 2nd second, voltage of Bus14 increases to 1.108 pu. A 50 MVAR STATCOM is connected to Bus14 in order to set the voltage value to reference value and minimize the voltage deviations and settling time after the line outage. Optimized STATCOM parameters' values by PSO is given in Table 2. According to the time–domain simulation results, the effect of optimal parameter setting by PSO on voltage profile of Bus14 is shown in Fig 4. Test results show that acts of the STATCOM is successfully improved by applying PSO technique. Hence, voltage deviation and settling time after the line outage is minimized by applying optimized parameters of STATCOM.

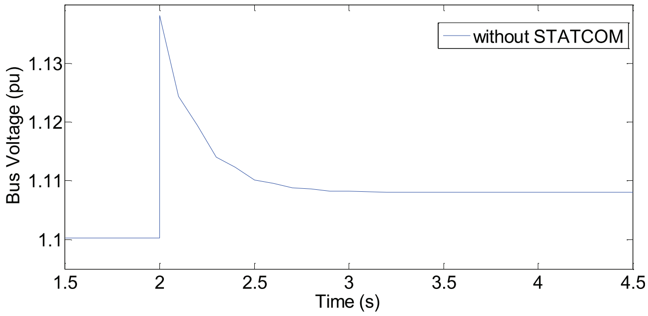

Fig. 3. Voltage profile of the Bus 14 after the wind farm integration.

Table 1. Optimization results

Parameters	Unoptimized (default) values	Optimized values
K_r	50	971.7972
T_r	0.1	5.0697

As shown in Fig. 5, in order to decrease the bus voltage to 1.0000 pu, STATCOM (with optimized values) absorbes 46.589 MVAr from the grid during the normal operation. The bus voltage decreases suddenly to 0.932 pu when the line is lost. So, absorbed reactive power decreases to 24 MVAr and then bus voltage is set to 0.9994 pu. Load flow results of the system for different cases are given in Table 3.

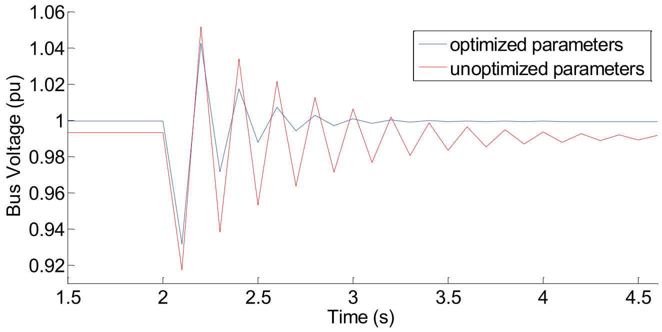

Fig. 4. Voltage profile of Bus 14.

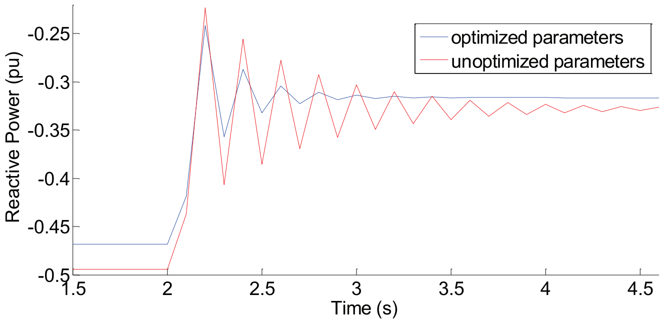

Fig. 5. Reactive power of STATCOM.

4. Conclusions

In this paper, the effects of doubly-fed induction generator (DFIG) and STATCOM on voltage profile of grid connection bus are investigated for normal condition and contingency condition. Morever, optimal parameters of STATCOM is obtained by applying particle swarm optimization technique. Simulation results show that DFIG connection can increase the bus voltage above maximum limits. In order to control the reactive power and voltage, STATCOM can be used. Because, STATCOM can act very fast and efficiently to control the voltage profile with optimal parameters setting at the contingency condition. Results also shows the success of PSO.

5. References

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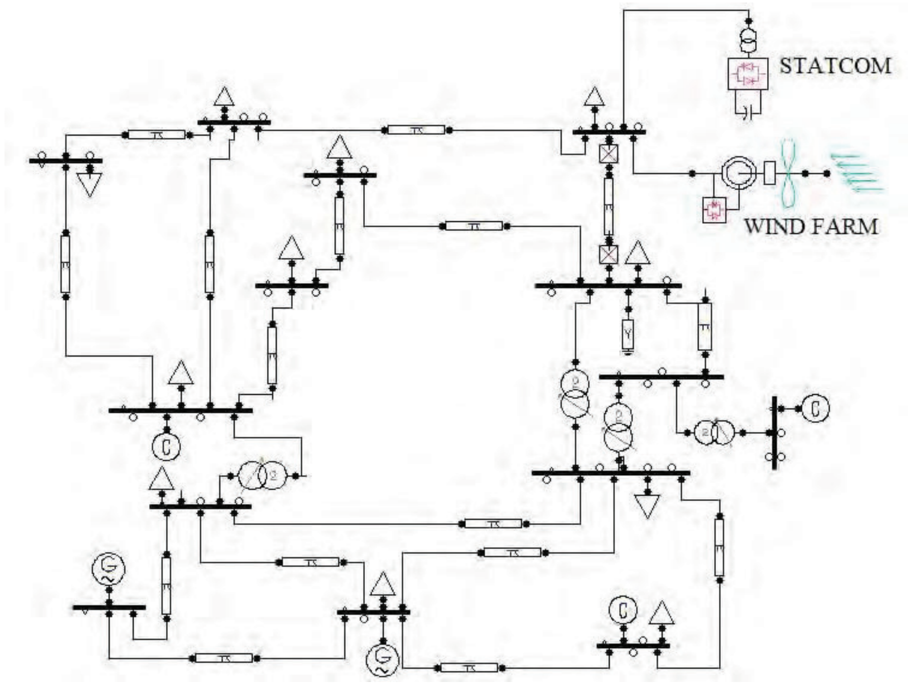

Fig. 6. System configuration.

Table 3. Load flow results for many cases

CASE	**From Bus 14 to Bus 13**		**From Bus14 to Bus 9**		**$Q_{STATCOM}$ (pu)**	**V_{BUS14} (pu)**
	P (pu)	**Q (pu)**	**P (pu)**	**Q (pu)**		
Base Case for normal condition	-0.05578	-0.0158	-0.0932	-0.0342	-	1.0358
Only wind farm integration for normal condition	0.18414	0.02182	0.26686	0.01318	-	1.1002
Only wind farm integration for the line loss case	0.426	-0.048	-	-	-	1.108
Wind farm and (optimized)STATCOM connections for normal condition	0.17585	-0.19573	0.27515	-0.23516	-0.46589	1.0000
Wind farm and (optimized)STATCOM connections for the line loss case	0.46535	-0.282	-	-	-0.31	0.9994
Wind farm and (unoptimized)STATCOM connections for the line loss case	0.4653	-0.295	-	-	-0.33	0.9905