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Modeling and seeker optimization based simulation for intelligent reactive power control of an isolated hybrid power system

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ABSTRACT

Seeker optimization algorithm (SOA) is a novel heuristic population-based search algorithm based on the concept of simulating the act of human searching. In SOA, the acts of human searching capability and understanding are exploited for the purpose of optimization. In this algorithm, search direction is based on empirical gradient by evaluating the response to the position changes and the step length is based on uncertainty reasoning by using a simple fuzzy rule. In this paper, effectiveness of the SOA has been tested for optimized reactive power control of an isolated wind–diesel hybrid power system model. In the studied power system model, a diesel engine based synchronous generator (SG) and a wind turbine based induction generator (IG) are used for the purpose of power generation. IG offers many advantages over the SG but it requires reactive power support for its operation. So, there is a gap between reactive power demand and its supply. To minimize this gap between reactive power generation and its demand, a variable source of reactive power such as static VAR compensator (SVC) is used. The SG is equipped with IEEE type-I excitation system and dual input power system stabilizer (PSS) like IEEE-PSS3B. The performance analysis of a Takagi–Sugeno fuzzy logic (TSFL)-based controller for the studied isolated hybrid power system model is also carried out which tracks the degree of reactive power compensation for any sort of input perturbation in real-time. In time-domain simulation of the investigated power system model, the proposed SOA–TSFL yields on-line, off-nominal coordinated optimal SVC and PSS parameters resulting in on-line optimal reactive power control and terminal voltage response. The performance of the proposed controller, with the influence of signal transmission delay, has also been investigated.

1. Introduction

Many energy companies are considering installation of distributed generation (DG) as the energy sector is being restructured with a significantly more rapid pace inviting healthy competition in the energy market. DG is small-scale power generation that is, usually, connected to the distribution system [1]. These could be reciprocating engine driven generators, microturbines, cogeneration or combined heat and power, fuel cells, wind turbines, solar panels and other *non-dispatchable* forms of energy sources. DGs may be installed within the distribution system or at a customer's site to improve reliability [2] by (a) adding system generation capacity, (b) freeing up additional system generation, transmission and distribution capacity, thereby, relieving transmission and distribution bottlenecks, (c) adding generation capacity at the customer site for continuous power supply backup and (d) supporting power system maintenance and restoration operations with generation of temporary backup power.

But DG in the power system will change the structure of the grid network and has a great impact on real-time operation and planning for traditional power system. It increases the complexity of controlling, protecting and maintaining distribution systems. Connection of the DG to the weak parts of power network will [3] (a) increase fault levels, (b) induce voltage variations, (c) degrade network transient stability, (d) reverse the power flow and (f) increase losses, depending on the relative size of the plant and the local loads.

The steady-state, slow and transient variations of voltage levels related to the connection of a DG may lead to undesired operation of voltage control equipment on transformers at the primary substations of the network. A net reversal or increase of power flow in the line due to the presence or the loss of a DG, respectively, may cause intolerable voltage fluctuations [3–4].

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List of symbols

$abs\ (\cdot)$	returns the absolute value of the input vector
$B_c = \omega C$	susceptance of the fixed capacitor
$B_l = 1/\omega L$	susceptance of the fixed reactor
B_{svc}	equivalent susceptance of the SVC
$d_{ij}(t)$	search direction for the ith seeker on the jth variable at time t
E_{ss}	steady-state error, p.u.
FOD	Figure of demerit (a time domain performance index)
K_a	exciter gain
K_v	gain of energy balance loop
M_p	overshoot, p.u.
r_j, $rand_j$	random number in [0, 1]
$sign\ (\cdot)$	signum function on each variable of the input vector
S	population size
t_r	rising time, s
t_s	settling time, s
T_a	exciter time constant, s
T'_{do}	direct-axis open circuit transient time constant, s
T_r	voltage transducer time constant, s
T_v	time constant of energy balance loop, s
X_d	direct-axis reactance of synchronous generator under steady state condition, p.u.
X'_d	direct-axis reactance of synchronous generator under transient state condition, p.u.
ΔE_{fd}	incremental change in exciter voltage, p.u.
ΔE_q	incremental change in internal armature emf under steady state, p.u.
ΔP_{ig}, ΔQ_{ig}	incremental changes in active and reactive powers, respectively, of induction generator, p.u.
ΔP_{load}, ΔQ_{load}	incremental changes in active and reactive powers, respectively, of load, p.u.
ΔP_{sg}, ΔQ_{sg}	incremental changes in active and reactive powers, respectively, of synchronous generator, p.u.
ΔQ_{svc}	incremental change in reactive power of static VAR compensator, p.u.
ΔT_e	incremental change in electromagnetic torque, p.u.
ΔT_m	incremental change in mechanical torque, p.u.
ΔV	incremental change in load voltage, p.u.
ΔV_{pss}	incremental change in PSS output, p.u.
ΔV_{ref}	incremental change in reference voltage, p.u.
ΔV_t	incremental change in terminal voltage, p.u.
$\Delta \omega_r$	incremental change in rotor speed, p.u.
$\alpha_{ij}(t)$	step length
$\Delta \delta$	incremental change in rotor angle, p.u.

In any hybrid energy system, there may be more than one type of electrical generators [5]. In such circumstances, it is normal although not essential for diesel engine based generator(s), usually, to be synchronous and wind-turbine based generator (s) to be asynchronous (induction generator (IG)). An IG offers many advantages over the conventional synchronous generator (SG) as a source of isolated power supply. Reduction in unit cost, ruggedness, absence of brushes (in squirrel cage construction), absence of separate DC source for excitation, easy maintenance, self-protection against severe overloads and short circuits etc. are the main advantages of an IG [6] but it requires reactive power support for its operation. Due to the mismatch between generation and consumption of reactive powers, more voltage fluctuations occur at generator terminal in an isolated system which reduces the stability and quality of the supply. The problem becomes more complicated in hybrid system having both IGs and SGs. In the present investigated isolated hybrid power system model, SGs and IGs are chosen with diesel generators and wind turbines, respectively. The maximum efficiency may be achieved by using the full reactive power capability of the wind system for decreasing the system losses and improving the post-fault voltage profile.

Various flexible AC transmission systems (FACTs) devices are available which may supply fast and continuous reactive power support [7]. For stand-alone applications, effective capacitive VAR controller has become central to the success of the IG system. Switched capacitors, static VAR compensator (SVC) and static synchronous compensator may provide the requisite amount of reactive power support. Prior to the development of SVC, the adjustment of voltage in transmission system, other than generator and synchronous compensator, was made possible only by mechanically switched shunt reactors and capacitors. The switching of shunt reactors and capacitors is, normally, crude causing abrupt voltage changes along with voltage and current transient. Incidentally, a synchronous condenser may raise the fault level while providing controllable reactive power. The SVC, on the other hand, provides rapid and fine adjustment of voltage, which is desirable in power system control and operation [7]. In a stand-alone hybrid power system, the reactive power device has to fulfill the variable reactive-power requirements for the operation of the IG and that of the load. In the absence of proper reactive power support and its proper control, the system may be subjected to large voltage fluctuations, which is not desirable.

Various types of SVC controllers have been proposed in the literature like lead-lag controllers [8,9], proportional-controllers [10,11], proportional-integral controllers [12,13] and proportional-integral-derivative (PID) controllers [14]. Generally, the parameters of the SVC controller are selected on the basis of a typical load but these values may not be optimum for different voltage characteristics. Therefore, the parameters of the SVC controllers require proper tuning to have always optimum settings for variations in the load voltage characteristics with load. The constant impedance model is not accurate and is not the proper approximation in view of the strong influence of load voltage sensitivity on the dynamic performance of the power system [15]. The SVC damping controller, designed under constant impedance model, may become unstable under other values of loads.

Power system stabilizer (PSS) is linked with a generator whereas SVC is used with transmission service providers. There are many PSSs and limited number of SVCs in a power system. The objectives of their operations are very different. PSS tackles local mode problems whereas SVC, mainly, tackles inter-area problems. Simultaneous tuning of these devices is a challenging problem for the power industry. But with the advent of fast acting and low price communication technology, it may be possible to provide the control center with the real time signals from remote areas. However, the use of centralized controller entails inputs that may arrive after a certain time delay. Time delays may make the control system to have less damping features. In order to satisfy specifications for wide-area control systems, the design of a controller should take into account this time delay in order to provide a controller that is robust, not only for the range of operating conditions desired, but also for the uncertainty in delay. In view of the above, this paper will focus on the design of the SVC-based damping controller considering the potential time delays [16–18].