An optimised FOPID controller for dynamic voltage stability and reactive power management in a stand-alone micro grid

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ABSTRACT

This paper proposes the application of fractional order PID controller (FOPID) for reactive power compensation and stability analysis in a stand-alone micro grid. For enhancement of voltage stability and reactive compensation of the isolated system, a SVC based controller has been incorporated. This paper emphasizes the role of fractional PID based SVC controller for reactive power management and improved stability in the stand alone micro grid, as it provides a special advantage of having two more degree of freedom for accurate tuning in comparison with the conventional controller The system performance, particularly the variations in different parameters values are studied properly with different input parameters and loading conditions. Further improvement of stability margin and optimisation of the system parameters have been achieved by the controller, based on Imperialist competitive algorithm.

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Introduction

During the past decades researchers have shifted to Distributed power generation from conventional power generation and the reliability has been increasing at a rapid pace in the past decades. The logic is very simple as distributed generation (DG) units deliver cleaner and smarter power close to the customer's end. Though Distribution generation based power generation make a small share out of the total power generation presently, the reliability will definitely increase in future. Moreover generation of power at the site of consumption reduces the cost, complexity and interdependency and enhances the reliability to a great level. Different types of renewable and DGs integrated to form micro grid which increases the reliability of power supply. Micro grid operates independently in an isolated manner whenever there is a fault in the inter connected power network or as per the system requirement [1]. Micro grids supplied by non conventional energy sources are widely studied because of their environmental friendly impact and non polluting nature. It is essential for a stand-alone to have its own resources for maintenance of the power quality, mainly the voltage and frequency values. The voltage variations of the system depend on system reactive power, while the frequency depends of the system active power. Voltage control is achieved by controlling the excitation field of the synchronous generator (SG) or by using FACTS based power electronics converters [2–4].

Control of an inter-connected hybrid power system is always a difficult and challenging job. The controlling of the output power of generating units and thereby getting a power balance stage is one of the most important control objectives in power systems. The Controlling of the output power of generating units and simultaneously getting the active and reactive power balance are done in such a way that the transient deviations of the system parameters remain within the specified limits and the system achieves stability [5,6].

Wind based hybrid systems are widely used in remote places, because of their reliability. Majority of the wind turbines are equipped with Induction generators, mainly squirrel cage induction generators for fixed speed and double fed induction generators for variable speed and rugged characteristics. But the disturbance in input wind and load cause mismatch in generation and consumption of both active power and reactive power in the system which directly or indirectly influence the system voltage and frequency. The system voltage gets disturbed by the variation of reactive power and therefore it becomes necessary to compensate and manage reactive power in the hybrid system. The active and reactive power of DFIG is generally regulated by the rotor current and is controlled through the output voltage of the rotor side converter. DFIG in wind turbine is widely accepted because of its ability to supply power at constant voltage and frequency with the variation of rotor speed. DFIG based Wind Energy Conversion System (WECS) employs back to back converters in the rotor circuit where rotor side ensures decoupling control of stator side active and reactive power [7–9]. In a hybrid system reactive power requirement is

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generally managed by the synchronous generator. Due to the uncertain nature of wind and wide variation of load the FACTS devices like SVC, STATCOM, UPFC, and SSSC are commonly used for controlling and compensating the reactive power [10].

Control strategies have been proposed in the literature for reactive power compensation and stability analysis using conventional PI, PID controller with several optimisation techniques [11–14]. The PID controllers always provide more damping for power system than PI controller. It has been widely proposed in the literature for reactive power control and stability analysis. Further in many literatures designing of PID controller has been done by using particle swarm optimisation algorithm Artificial Bee Colony (ABC) algorithm etc. Several novel heuristic stochastic search techniques are also presented in the literatures for optimising PID gains. Some researchers have also presented articles showing a new decentralized robust optimal MISO PID controller based on matrix Eigen values and Lyapunov method. Because of the heuristic nature of PI and PID controllers in selecting the gains, the system parameters and the stability are sometimes highly affected. In recent days the enhancement of the performance of conventional PID has been considerably improved by FOPID controllers [15–17], where the order of derivative and integral is not integer. FOPID controllers have been applied in different fields of engineering. Like designing aerospace control systems, for hypersonic flight vehicle, for stabilizing fractional order time delay systems, for weapon system, and for automatic voltage regulator system. The main advantages of FOPID controller is that it has two extra tuning knobs (parameters) known as k (non-integer order of integrator) and l (non-integer order of differentiator) which provides more flexibility for adjustment of the system dynamics. The FOPID controller consists of different parameters like proportional gain K_P, Integral gain K_I, the differential gain K_D, integral order λ and differential order μ.

There are number of methods available in the literature for tuning FOPID controllers. This work proposes Imperialist competitive algorithm (ICA) based FOPID controller for reactive power compensation and transient stability study in wind-diesel based micro grid. This Imperialist competitive algorithm (ICA) is a novel evolutionary algorithm which is widely used for solving different optimisation problems. It is a recently developed novel socio-politically motivated optimisation algorithm which is inspired by socio-political process of Imperialism. ICA is employed in many applications to solve the problems because of its higher efficiency, good convergence and global minimum achievement. The FOPID based controller for controlling the reactive power support by SVC is designed for improved voltage profile of the wind-diesel hybrid system with different wind power input and 2% step increase in load demand. A comparative analysis is carried out using the proposed FOPID based SVC controller with conventional PID controller and with the optimised results of ICA based FOPID controller [18–20]. The Imperialist competitive algorithm optimises the parameters of the SVC PID gains to control the reactive power requirement and improves the system transient stability margin. Simulation results show the superior performance of the proposed ICA based FOPID controller in comparison with the conventional PID controller in terms of the settling time, overshoot against various load changes. Further the stability analysis of the system is studied using Nyquist, Bode, Eigen values and participation factor criteria.

System configuration and its mathematical modelling

The proposed isolated micro grid with wind- diesel hybrid system (shown in Fig. 1), consists of a DFIG based wind turbine and works with a synchronous generator based diesel generator having IEEE type-I excitation system. There is periodic change of reactive power load input for the WECS model (Fig. 2) for which the system parameters are affected. The system faces misbalance of reactive which affects the voltage profile of the system. When the system experiences a change of load ΔQ_L the other parameters also experience change in reactive power. The system parameters vary with the variation of load. The load reactive power Q_L can be expressed as $Q_L = C_1 V^q$ where C_1 is the constant and q is the exponent depends upon the reactive load type. For small change the load voltage characteristic $D_V = \frac{\Delta Q_L}{\Delta V} = q \frac{Q_L^0}{V^0}$.

The reactive power balanced equation can be formed from the above diagram

$$Q_{SG} + Q_{COM} = Q_L + Q_{IG} \tag{1}$$

$$\Delta Q_{SG} + \Delta Q_{COM} = \Delta Q_L + \Delta Q_{IG/DFIG} \tag{2}$$

$$\Delta Q_{SG} + \Delta Q_{COM} - (\Delta Q_L + \Delta Q_{IG/DFIG})$$
$$= \text{balanced reactive power of the system}$$

The system voltage is highly affected by the reactive power surplus of the system as it increases the electromagnetic energy absorption of induction generator and increases the reactive load consumption.

The equation is

$$\Delta Q_{SG} + \Delta Q_{COM} - (\Delta Q_L + \Delta Q_{IG}) = \frac{d}{dt}(\Delta E_m) + D_V \Delta V \tag{3}$$