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Stability analysis and reactive power compensation issue in a microgrid with a DFIG based WECS

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ABSTRACT

This paper presents a novel methodology for compensating reactive power in a microgrid, having a DFIG based wind–diesel system, to enhance the voltage stability of the hybrid system. UPFC as a FACTS device is proposed in order to improve the control of reactive power mismatch and the stability of the system. A small signal model of the wind–diesel system, DFIG based wind turbine system, UPFC and the controllers are designed for the stability analysis. Further, the voltage variation and reactive power compensation is analysed with the incorporation of proposed ANFIS based UPFC controller. Simulations are performed in MATLAB environment for transient stability analysis in a wind–diesel based microgrid with different wind power input and 2% step increase in load demand. Simulation results illustrate the efficiency and effectiveness of the proposed approach and its impact upon transient behaviour of the microgrid.

Introduction

Increase in energy demand and depletion of fossil fuel have led to the upsurge of Renewable Energy Sources (RES) and Distributed Generations (DGs) like wind, photovoltaic (PV), fuel cell (FC), and diesel engine generator (DEG). The popularity of RES are due to their non-exhaustible and environment friendly characteristics. Now-a-days researchers are putting emphasis upon decentralised power supply and therefore centralised power supply is being supported by Distributed Generation Sources. As the size and rating of the DG is always small in comparison with the conventional resources, they are connected in the distribution system near to the consumers. This helps in reducing energy loss that occurs during transmission. DG can also efficiently improve the voltage profile of the system by providing the reactive power support [1]. The different types of RES and DG can be integrated to form microgrid which can increase the reliability of power supply into the load. The main advantage of microgrid is that it operates independently in an isolated manner whenever there is a fault in the inter connected power network, i.e., distributed energy resources can operate either independently or in grid-connected mode as per the system requirement. In the inter-connected power system, as the centralized control becomes more complex, controllers are provided in a decentralized manner in order to improve the system performance. Some of the vital issues like voltage instability and reactive power imbalance are better addressed in an isolated mode and decentralized system.

Under these circumstances, wind–diesel hybrid systems are widely used because of their reliability. It is a system in which a wind turbine combines with a diesel generator to provide uninterruptible power in standalone mode. Normally, a synchronous generator is preferred to act as diesel generator and induction generator is used in wind turbine for improved performance [2–6]. Induction generators are preferred because of its rugged characteristics. But, it consumes reactive power while in operation which may affect the system voltage. Generally, variable speed wind turbines are equipped with doubly fed induction generators (DFIGs) [7–11] and due to its wide operating range, they are preferably used. According to the [12,13] active and reactive power of DFIG is regulated by the rotor current which is controlled through the output voltage of the rotor side converter. So, the applied voltage of the rotor is the direct control variable. DFIG 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.

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Nomenclature

P_{DFIG}, Q_{DFIG}	real and reactive power delivered by induction generator (DFIG) based wind turbine
P_{SG}, Q_{SG}	real and reactive power delivered by synchronous generator based diesel generator
E_M	electromagnetic energy stored in the induction generator (DFIG)
ΔE_M	incremental change in the stored electromagnetic energy of induction generator (DFIG)
ΔQUPFC	reactive generated by UPFC
ΔQ_{COM}	incremental change in reactive power delivered by compensator
K_A, K_E, K_F	gain constants of voltage regulator, exciter, stabilizer
ΔV	incremental change in the system voltage
K_α, K_v	exciter gain, gain of energy balance loop
T_α, T_r, T_S	exciter time constant, rising time constant, settling time constant
X_d, X'_d	direct axis reactance of SG under steady state, under transient state
Te, Tm	change in electromagnetic torque, change in mechanical torque
$\Delta\alpha$	incremental change in phase angle of compensators
ΔE_q	incremental change in internal armature voltage
ΔE_{fd}	incremental change in the voltage of the exciter
η	performance index

But, a system having both synchronous generator as well as induction generator [11], becomes more complex where the reactive power requirement of the induction generator and loads is provided by the synchronous generator. But, the reactive power supplied by the synchronous generator fails to meet the requirement and therefore a big gap is created between the demand and supply of reactive power. As a consequence of this, problems like voltage instability and fluctuations become very common due to the mismatch between the demand and supply of reactive power. Though, many authors have advocated the use of capacitor banks to improve voltage stability and to compensate the reactive power in the system [14,15], due to the uncertain nature of wind and wide variation of load the fixed capacitors fail to deliver the required amount of reactive power to the system in order to stabilize the system voltage. To meet the challenge of these voltage instability and reactive power compensation, researchers had extensively used FACTS (Flexible AC Transmission System) devices like SVC, STATCOM, UPFC and other FACTS devices which are commonly used for controlling and compensating the reactive power [16].

SVC, STATCOM and UPFC are important members of FACTS family which are used to compensate the reactive power of the power system for voltage and angle stability studies in power system. Reactive power management is an important aspect in hybrid power system because of the variability of load and uncertainty in renewable resources, leading to a wide voltage variations and unnecessary fluctuations in other system parameters. Many papers in literature [17,18] have projected these FACTS devices as a reactive power compensating devices with PI controllers. But, because of the heuristic nature of PI controller in selecting its gains, the system parameters and hence the stability of the system is sometimes highly affected due to the system uncertainty and parameter variations.

Therefore, in order to eliminate the difficulties, this work proposes Adaptive Neuro-Fuzzy Inference System (ANFIS) [19] based UPFC controller for reactive power compensation and transient stability study in wind–diesel based microgrid. The ANFIS based controller for controlling the reactive power support by UPFC 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 ANFIS based UPFC controller and the conventional PI controller. The fuzzy inference system optimizes the parameters of the neural network and PI gains to control the reactive power requirement in order to improve the system transient performance. Simulation results show the superior performance of the proposed Neuro-fuzzy controller in comparison with the conventional PI controller in terms of the settling time, overshoot against various load changes. Also the stability analysis [20,21] of the hybrid system has been studied using Nyquist, Bode, Popov criterion, eigen values and participation factor.

System configuration and its mathematical modelling

The block diagram of the proposed system shown in Fig. 1 consists of a DFIG based wind turbine coupled with a synchronous generator based diesel generator with IEEE 1 excitation system. SG considered with IEEE type-I excitation system. The WECS model is subjected to periodic change of reactive loads for which the system parameters are affected and mismatch of reactive power occurs in the system. The System is subjected to incremental change in load which changes the system parameters by small value. Small change in real power depends upon system frequency while incremental change in reactive power is voltage dependent.

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

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

Q_{SG} = reactive power generated by synchronous generator; Q_{COM} = reactive power generated by the FACTS devices; Q_L = reactive power needed by the load; Q_{DFIG} = reactive power of the doubly fed induction generator

When the system experiences a change of load ΔQ_L the other parameters also experience change in reactive power.

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

$\Delta Q_{SG} + \Delta Q_{COM} - (\Delta Q_L + \Delta Q_{DFIG})$ = surplus 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 can be written as

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

$$\Delta V(S) = \frac{K_V}{1 + ST_V}[\Delta Q_{SG}(S) + \Delta Q_{COM}(S) - \Delta Q_L(S) - \Delta Q_{DFIG}(S)] \tag{4}$$

where $T_V = \frac{2H_r}{D_v}V^0$ and $K_V = \frac{1}{D_v}$.

This hybrid system consists of one induction generator (IG), a synchronous generator (SG), electrical loads and reactive power control in the form of UPFC with ANFIS control strategy. The block diagram is clearly depicted in Fig. 2. In a system like this the active power is supplied by the DFIG and synchronous generator. But the reactive power need of the induction generator and the load is met