Electrical Power and Energy Systems 62 (2014) 507–518

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Voltage control through reactive power support for WECS based hybrid power system

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ARTICLE INFO

Article history:
Received 7 January 2014
Received in revised form 3 April 2014
Accepted 30 April 2014
Available online 5 June 2014

Keywords:
Reactive capability
WECS
LSC
DFIG

ABSTRACT

This paper presents a novel technique for voltage and reactive power control a multi wind generator based hybrid power system. The proposed configuration consists of wind energy conversion system (WECS) comprising number of wind turbines each having doubly fed induction generator (DFIG), and power generation from biomass source using synchronous generator (SG). The dynamics of the system is analyzed with the step change in inputs applied in both reactive load demand and wind speed. The analysis is focused on the voltage and reactive power control of the hybrid power system using reactive capability of the load side converter (LSC) of DFIG. When the reactive load and thereby the terminal voltage deviates by a small amount, the LSC works as a reactive power generator. A PI control is used in LSC and it provides the effective control of system voltage.

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Introduction

Renewable energy presents a promising future as it provides the clean energy and eliminates dependency on fossil fuels. It also has positive implications on financial and social growth of a country. The priority should be to harness green energy locally available. As the renewable sources are inherently intermittent, bulk power production is difficult by a single unit. Therefore depending upon the availability of renewable energy sources at a site, use of multiple units can increase the generation capacity, improve the reliability and help in the gradual development of projects.

In this paper the study conducted is for an isolated load for which the power is supplied by two wind turbines using DFIG and biomass source using SG with excitation control. The system voltage control is analyzed with small change in reactive power load and in wind speed (generator slip). Earlier the induction generator (IG) was popularly being used as wind generator [1], and now permanent magnet synchronous generator (PMSG), SG and DFIG are also being considered for this application [2]. A hybrid system can be used to provide electric power to an isolated load if sufficient renewable potential is available.

Bansal presented voltage control scheme using SVC for reactive-power supply in a hybrid power system having IG as wind generator [3]. Reactive power and voltage control of the multi wind-diesel hybrid system using static compensator (STATCOM) is presented in [4]. The improved models of STATCOM transient stability and power flow are proposed in [5]. The DFIG can supply reactive power from the rotor side through the machine as well as through the LSC [6]. The reactive power capability of DFIG is explored for voltage control and controllers designed for RSC and LSC to provide maximum reactive power support in Ref. [7]. With the increase or decrease in terminal voltage and wind speed, the reactive power consumed by the DFIG is to be compensated [2]. The distributed control of reactive power to control voltage and loss reduction in a distribution network is advised using capability of the inverters of distributed PV generations [8]. The possible scope of supplying voltage support ancillary service to an MV or LV distribution system by means of PV production units is presented in [9].

Dynamic modeling and power control of DFIG is proposed in [10] for variable speed under sub and super synchronous operation. The problem of stator side power regulation of DFIG is addressed in [11] with the operating condition of active power generation with demanded reactive power. Peña presented wind-diesel system using DFIG as generator for both the sources and 'front end inverter' [12]. Mei et al. in [13] presented the model analysis of a grid-connected DFIG. Two RX models of multiple wind-driven wound-rotor induction generators are given with dynamic slip control in [14]. The large size wind farm has predominate effect on the stability of the smaller wind farm [15]. The DFIG is most attractive and suitable machine for WECS due to its advantages like high efficiency, improved stability and power quality [16]. Presently it is the preferred generator for the large size wind

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http://dx.doi.org/10.1016/j.ijepes.2014.04.067
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Nomenclature

V, ΔV reference voltage and its small deviation respectively
Q_L, $Q_{DFIG1\&2}$, $Q_{LSC1\&2}$, Q_{SG} reactive demand/generation of load, DFIG, LSC and SG respectively
ΔQ_L, $\Delta Q_{DFIG1\&2}$, $\Delta Q_{LSC1\&2}$, ΔQ_{SG} small deviation in reactive power demands and generations
K_P, K_I PI controller gains
K_1–K_8 constants of DFIG, converter and SG
P_{in}, ΔP_{in} mechanical input power & its small change
X_{ls}, X_{lr}, X_{eq}, X_m, X_{RC} stator & rotor leakage, equivalent, magnetizing and rotor side converter (RSC) reactances
R_s, R_r, R_{eq}, R_{RC} stator, rotor, equivalent and RSC resistances respectively
X_{sd}, X'_{sd} d-axis steady state (SS) and transient reactance of SG
K_V, T_V gain and time constant of hybrid system
T_G time constant of exciter of SG
ΔE_{fd} change in exciter voltage of SG
E'_q voltage behind transient reactance of SG
T_d, T_α average dead time of zero crossing in a three phase system and thyristor firing delay time

turbines because of its reactive power capability and better control features [17].

Although lot of work has been done for voltage control using reactive power compensation devices and other methods for isolated and grid connected WECS based systems (as presented in literature) [2–9]. However the issue of voltage stability for step by step load changes in isolated systems using DFIG inverter capability needs to be addressed.

This paper presents a novel technique using reactive power capability of the inverter (LSC) of the DFIG, and the controller and small signal model is developed, for voltage control through reactive power support. This scheme is used first time for the voltage stability analysis when step by step small changes in reactive power load and wind speed are applied. This scheme also eliminates the need of additional reactive power compensation devices. The designed controller solves the problem of voltage variation with load changes in the hybrid power system.

Mathematical modeling of the hybrid system is given in Section 'Mathematical model of hybrid system'. Section 'System simulation and discussion' includes the system simulation and discussions about the results, controller performance and comparison of results. Section 'Conclusion' concludes the contributions of this work.

Mathematical model of hybrid system

To understand the performance and the dynamics of the multi wind machine based hybrid system here we consider two wind generators (DFIG) connected together on the common bus with one biomass generator (SG). This hybrid system can be operated in two arrangements, (I.) with two separate VSC (one for each DFIG) and (II.) with a common front end inverter (one inverter and two converters). The two possible configurations are modeled and simulated to test the performance for load voltage control. Both the systems above can operate at three speed modes, super synchronous, synchronous and sub synchronous mode.

The presented system is designed for the rural electrification in an isolated area. In this hybrid system it is assumed that both the generating sources are close to each other and to the load also. The entire generation is pumped to the common bus (point of common coupling) and all the loads are supplied by the outgoing distribution feeder/lines. The aim is to study the response of the system for the net reactive power load change on the system. So it is sufficient to represent the system by a single bus bar model.

(I) For the first configuration with two separate converters, as shown in Fig. 1, under normal operation of the system, the reactive power balance equation is

$$Q_{SG} + Q_{LSC1} + Q_{LSC2} = Q_{DFIG1} + Q_{DFIG2} + Q_L \tag{1}$$

When system inputs (load and/or wind speed) are changed by a small amount, the load bus voltage is also changed. Due to this the reactive power demands of various system components will change. The surplus reactive power of the system under small disturbance is given by

$$\Delta Q = \Delta Q_{SG} + \Delta Q_{LSC1} + \Delta Q_{LSC2} - \Delta Q_{DFIG1} - \Delta Q_{DFIG2} - \Delta Q_L \tag{2}$$

The net reactive power imbalance in the hybrid system, will increase the system voltage (i) by increasing the electromagnetic energy (E_m) absorbed by the wind generator (WG) at the rate d/dt (E_m), and (ii) by increasing the system reactive load consumption due to increased system voltage. This is represented as

$$\Delta Q = d/dt(E_m) + D_V \Delta V \tag{3}$$

The electromagnetic energy (EM) stored in WG is given by

$$E_m = \frac{1}{2} L_m \left(\frac{V}{X_m}\right)^2 = \frac{V^2}{4\pi f X_m} \tag{4}$$

where L_m, X_m and f are magnetizing inductance, reactance and system frequency respectively.

The change in EM energy stored is given from (4) is

$$\Delta E_m = E_m - E_m^0 = 2\left(\frac{E_m^0}{V^0}\right)\Delta V \tag{5}$$

where V^0 and E_m^0 are the nominal values of terminal voltage and EM energy stored in WG.

All the reactive power loads connected to the system will experience an increase by $D_V = \partial Q_L / \partial V$ (pu kVAR/pu kV) due to increase in voltage.

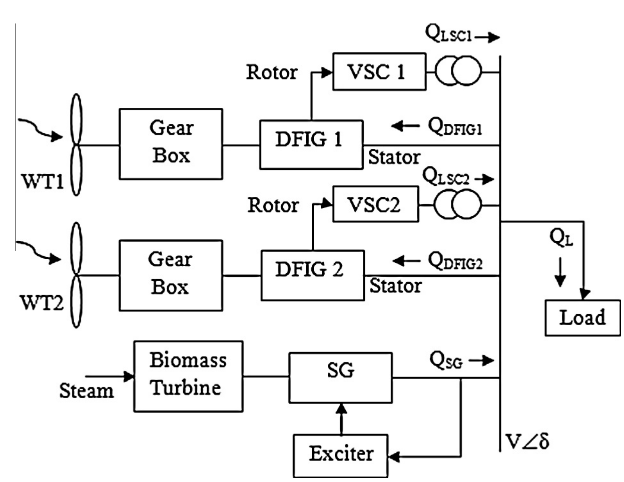

Fig. 1. Schematic diagram of multi wind biomass hybrid system using separate converters for both DFIG.

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