Wind Turbine Based Generation in Hybrid Remote Area Power Supply System

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Abstract-*The application of variable speed wind turbine in hybrid remote area power supply (RAPS) systems provides opportunities for improved voltage and frequency control. The study presented in this paper covers doubly fed induction generator (DFIG) as wind turbine technologies together with battery storage and a dump load. The battery storage system and dump load are able to assist in maintaining the active power balance during over and under generation conditions as well as sudden load changes. Through simulation studies, it has been demonstrated that the RAPS systems are able to regulate the load side voltage and frequency within the acceptable limits while extracting the maximum power from wind, which is an inherent capability of variable speed generators. The RAPS system and their associated control strategies have been developed and their performance is investigated using MATLAB.*

Index Terms— Doubly Fed Induction Generator (DFIG), Maximum Power Point Tracking (MPPT), Remote Area Power Supply (RAPS) systems.

1. INTRODUCTION

Remote Area Power Supply (RAPS) schemes are now becoming popular in remote areas including islands. However, the design and operation of such a power system are challenging due to the absence of a main grid supply system. Also, these power supply schemes are usually characterized by networks having low X/R ratios, low damping, and lack of reactive power support which may cause unexpected voltage and frequency excursions outside the allowable limits [1]. When designing and implementing RAPS systems, voltage and frequency control are the most important aspects to be controlled.

In addition, coordination between different system components, maximum power extraction from the renewable energy sources, power quality (e.g., harmonics, voltage unbalance, flicker, etc.), and cost optimization of system operation and components are the other major issues of interest [2]. The selection of the suitable generation mix of a RAPS system is entirely dependent on the availability of resources [3]. Diesel-based power generation is a well-established option to supply power to rural communities. However, increased attention given to environmental concerns and the operating costs associated with diesel power supply schemes make this option less favourable [4]. There has been a recent trend for such diesel-fed isolated power systems to be replaced with renewable energy-based power supply schemes. Among several renewable energy options available, wind is identified as the fastest growing energy industry in the electricity market. However, intermittency associated with wind profiles together with variability of load demand make Operation of wind power systems challenging especially when they operate in a standalone environment. The integration of energy storage into such a power system can be seen to provide improved security and performance [6]–[9]. In this regard, energy storage systems can be operated as a source or a load depending the demand–generation mismatch [10] and [11]. Among several energy storage technologies (e.g., super capacitors, flywheels, etc.), battery storage can be identified as one of the best options for wind power applications due to its high energy density levels [12]. The selection of a specific wind turbine generator technology is also an important design factor in a wind-based power system. In general, variable speed wind turbine generator technologies are preferred in a standalone power system as they provide better voltage and frequency regulation compared to constant speed generators such as induction generators [13]. In this regard, doubly fed induction generators (DFIGs). Typically, DFIG-based wind turbine generator systems are preferred for high-power applications.

Maximum power point tracking (MPPT) is one of the inherent characteristics of a variable speed wind turbine generator. In a RAPS environment, MPPT from wind is important to allow the RAPS system to operate optimally.

A battery storage used with DFIG in grid-connected and islanded modes of operation is presented in [22]. In that paper, the battery storage system is directly connected to the DC bus of the DFIG system. With such an arrangement, the required number of batteries that need to be connected in series to match the DC bus voltage is large and cannot be justified in real life applications. A detailed model and control aspects of a grid-connected DFIG-battery-based hybrid system are given in [23]. However, control coordination of a wind turbine generator together with battery storage system and dump load in a RAPS environment has received little research attention which is one of the main focuses of this paper. RAPS system is designed to operate with acceptable voltage and frequency regulation capability under variable wind and fluctuating load conditions while extracting the maximum power from wind, thus ensuring optimum operation. In this regard, the battery storage system and dump load are used as auxiliary system components with their respective control strategies and configurations which are unique to each type of RAPS system. In addition, a control coordination strategy is formulated with a view to manage the active power flow between the system components optimally which also contributes to regulate the frequency.

2. MAXIMUM POWER EXTRACTION FROM WIND

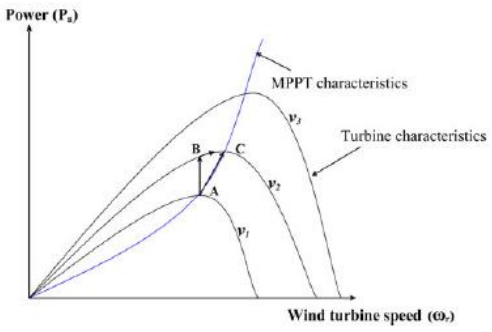

Fig.1. Wind turbine power characteristics with maximum power extraction

Not all kinetic energy available from wind can be extracted by a wind turbine and hence power coefficient *Cp* is defined which is a function of tip-speed ratio λ, and pitch angle β is employed. Therefore, power captured from a wind turbine is given by (1). The maximum power from wind can be obtained when a wind turbine is operated at its optimum power coefficient (Cp)opt . This can be achieved by operating the turbine at a desired speed to obtain the optimal tip-speed ratio λ_{opt} given in (2). The MPPT from wind without considering the associated system losses (i.e., ideal condition) can be described using (3) where the optimized constant k_{opt} is given in (4). In this paper, power losses of the system due to frictional losses, Resistive losses in stator and rotor and losses associated with power electronics1 devices have also been considered when implementing the maximum power extraction algorithm for each RAPS system. However, in this paper an approximate method considering the efficiency associated with the power electronic devices have been used to estimate the corresponding power electronic device losses. The typical turbine power characteristics and its MPPT curve described in (1)–(4) are shown in Fig.1. For the purpose of illustration of the MPPT principle, assuming that wind turbine generator operates on its maximum power curve, the wind turbine generator initially operates at point A when the wind speed is $v1$. If the wind speed changes from $v1$ to $v2$, then the turbine changes its power output from A to B. The wind generator cannot respond to this wind speed change quickly due to the inertia associated, thus retains the same electrical power (i.e., power at point A). As a result, the mechanical power input from the turbine to the generator is greater than its Electrical power, causing the wind generator system to accelerate. This acceleration would lead mechanical power to follow the path from B to C (B → C) while generator power from A to C (A → C). Finally, the system becomes stable at point C.

3. DFIG-BASED STANDALONE POWER SYSTEM

The application of variable speed wind generators in hybrid remote area power supply (RAPS) systems provides opportunities for improved voltage and frequency control together with maximum power point tracking (MPPT), where limited research outcomes exist .The battery storage system and dump load are able to assist in maintaining the active power balance during over and under generation conditions as well as sudden load changes.

In the proposed DFIG-based RAPS system shown in fig.2.below the battery storage is connected across the DC link of the back -to- back converter. Due to the limited power capacity associated with DFIG back-to-back converter system (typically 20%–30% of the rated DFIG power), the dump load is connected to the load side. The battery storage system and dump load are used to satisfy the demand–generation mismatch while extracting the maximum power from wind. The DFIG based wind turbine is used in high power application.

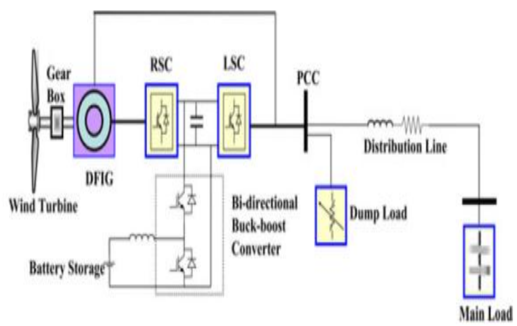

Fig.2.DFIG- based RAPS system

3.1. CONTROL COORDINATION BETWEEN DIFFERENT MODULES OF SYSTEM

To regulate the frequency and achieve acceptable level of voltage regulation at the same time, it is vital to maintain the active and reactive power balance of the RAPS system.

If wind speed stays within safe limits (i.e., when wind speed stays between cut-in speed, V_{cut-in} or cut-out speed, $V_{cut-out}$) and the power output of the wind turbine generator Pw is greater than the load demand P_L, the battery storage issued to absorb the excess power given by P_w-P_L.However, if the excess generation (P_w-P_L) is greater than the maximum capacity of the battery storage system (P_b)max, the dump load starts absorbing the additional power. When the dump load power consumption P_d reaches its maximum rating (P_d)max the wind turbine pitch regulation is activated to control the power output of the wind turbine. Where P_w is the power output of wind turbine generator, P_b is the power output from battery storage system, P_d is the dump load power output and P_L is the load demand. It is assumed that Pw and P_b are sufficient to supply the load demand at all times. Emergency situations such as wind turbine generator operation below cut-in speed or above cut-out speed have not been considered. In real life RAPS applications, a load shedding scheme can be implemented during emergency situation where the reduced load is then supplied by the battery storage system.

The behavior of RAPS system during over generation and under generation are given as follows

$$P_w = P_b + P_D + P_L$$

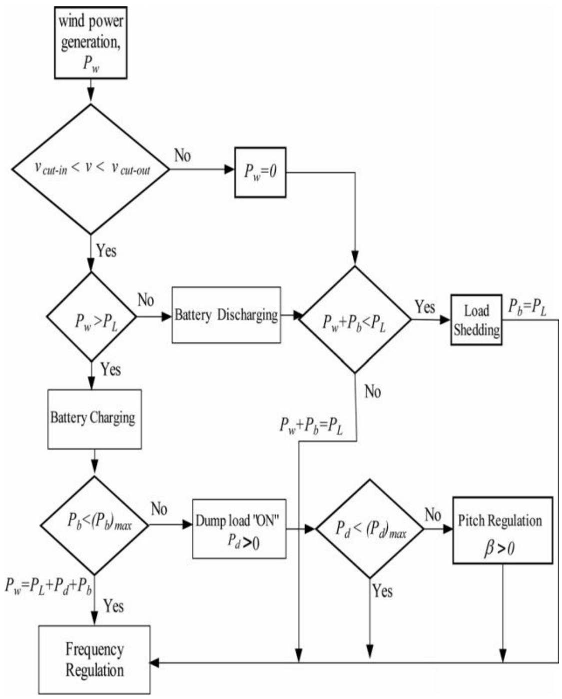

Fig.3. Control co-ordination of a wind based RAPS system

3.2. BACK TO BACK CONVERTER CONTROL

The Rotor Side Converter (RSC) is used to control the load side voltage and frequency, whereas the Load Side Converter (LSC) is designed to regulate the DC-link voltage regardless of the power flow direction of the back-to-back converter system. The stator flux spatial-vector angular speed must be made constant in order to generate a stator voltage with constant frequency. This can be achieved by defining a synchronous reference frame and forcing the *q*-axis component of the stator flux at zero that the total stator reactive power of the DFIG consists of two components Q_{mag} and Q_{gen}. The no load reactive power of the DFIG Q_{mag} given in (1) is used for magnetization purposes. The other component which is denoted by Q_{gen} given in (2) is used to satisfy the reactive power demanded by the loads.

The reactive power can be controlled using the *q*-axis component of the stator current and *d*-axis component of the same is used to regulate the DC-link voltage. In this case, however, the reactive power provision through the LSC(load side converter) is nullified by setting the reference *q*-axis component of the stator current to zero. where φ_{qs} is the q-axis component of stator flux, v_s is the stator voltage, Ls is the stator inductance, L_m is the magnetizing inductance, L_r is the rotor inductance, i_{dr}, i_{qr} are the d and q axes components of rotor current respectively, v_{dr}, v_{qr} are the d and q axes components of rotor voltage respectively, i_{qs} is the q-axis component of stator current, ω_r is the rotor speed, ω is the synchronous speed.

$$Qmag = \frac{3}{2}[-\frac{v_s^2}{\omega L_S} + v_s \frac{L_m}{L_s} i_{drmag}] \quad (1)$$

$$Q_{gen} = \frac{3}{2} v_s \frac{L_m}{L_s} i_{drgen} \quad (2)$$

3.3. CONTROL STRATEGY FOR BATTERY STORAGE SYSTEM

The battery storage is used to achieve two objectives. Firstly, it is used to minimize the demand–generation mismatch of the system. Secondly, the battery storage system is used achieve maximum power extraction from wind. The first objective is achieved by considering the demand–generation mismatch given in (3). The second objective is achieved by considering the optimal wind power (Pw) opt as one of the inputs to estimate the demand–generation mismatch as evident from (3). In this process, the battery storage system is able to impose an appropriate torque on the DFIG to extract the maximum power from wind. The proposed strategy to control the battery storage system is shown in Fig.4. With the integration of the battery storage into the back-to-back converter, the dynamics associated with the DC link can be expressed using (4) – (7). The PI controller associated with the battery storage system is tuned using the method discussed.. Furthermore, the capacity of the battery is selected to be 30% [i.e., γ = 0.30 in] of the rated load demand. Moreover, the maximum output of the battery storage, (Pb) max needs to satisfy the inverter constraint associated with the back-to-back converter as in

$$\Delta(P_b)_{ref} = (P_w)_{op} - P_L \quad (3)$$

$$P_{LSE} = P_{dc} \pm P_b \quad (4)$$

$$\frac{3}{2} v_{ds} i_{ds} = v_{dc} i_{dc} \pm v_b i_b \quad (5)$$

$$C \frac{dv_{dc}}{dt} = i_{dc} \quad (6)$$

$$v_{dc} = \frac{1}{C} \int (\frac{4}{3} m i_{ds} \pm k i_b) \quad (7)$$

$$i_{mag} = \frac{v_s}{\omega L_m} \quad (8)$$

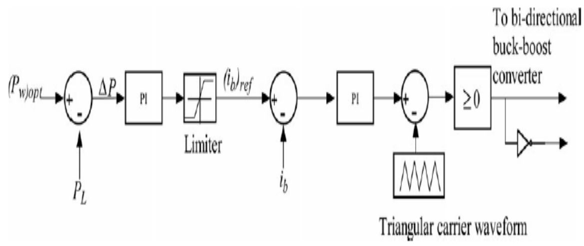

Fig.4. Battery storage control strategy of DFIG based RAPS system

3.4. CONTROL STRATEGY OF DUMP LOAD CONTROLLER

The dump load is coordinated with the battery storage to maintain the power balance of the RAPS system and to extract maximum power from wind.. A simplified control scheme associated with the dump load is shown in Fig. 5. The dump load is modeled as a set of three phase resistors which is connected across switches. The power imbalance associated with the RAPS system is selected as the input signal to the controller of the dump load which is converted into digital signals and is fed into the switches. The switching functions are performed at zero crossings of the ac voltage to ensure minimum impact on the load side voltage quality. The necessary and sufficient condition under which these operate is given in (9). The operation of the dump load is limited to when there is additional power available in the RAPS system. Also the dump load will start absorbing the additional power after battery storage reaches the maximum capacity (Pb)max

$$P_d = \{P_d (P_{w)}\ opt - (P_b)_{max} \rangle P_L \} \quad ,$$

0 otherwise (9)

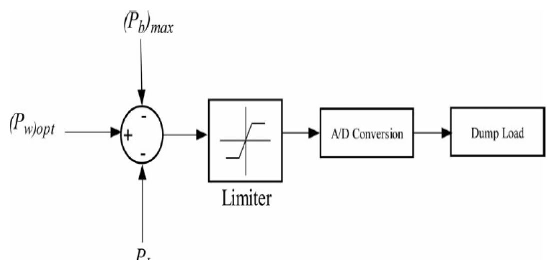

Fig.5. Dump load control strategy of the DFIG based RAPS system

Different control strategies have been developed and proposed for the each system module with a view to achieve AC voltage and frequency control, DC-link voltage stability and maximum power extraction in the hybrid RAPS systems. It is seen that both RAPS systems are able to perform well in regulating the load side voltage, frequency and DC-link voltage under changing wind and variable load conditions The proposed control coordination scheme for both RAPS systems, which also caters to maintain the active power balance among the system modules, ensures the optimum sharing of active power while regulating the voltage and frequency.

4. SIMULATION RESULT

The fig.3.shows the overall simulink model used for Remote Area Power Supply system. The simulation of the project was performed in the MATLAB/simulink software environment

Its observed that the DFIG based model provides better voltage and frequency regulation even during transient condition.

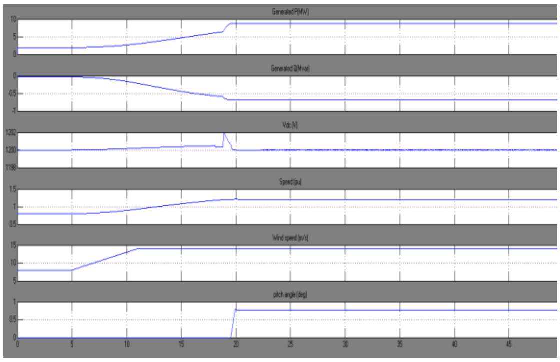

Fig.6. The variation of output parameters in accordance to wind speed

5. CONCLUSION

In this project work the investigation of the hybrid operation of two different RAPS systems, one is PMSG based and the other is DFIG based. Different control strategies have been developed and proposed for the each system module with a view to achieve AC voltage and frequency control, DC-link voltage stability and maximum power extraction in the hybrid RAPS systems. It is seen that RAPS systems are able to perform well in regulating the load side voltage, frequency and DC-link voltage under changing wind and variable load conditions.

Thus in a RAPS system in order to maintain better voltage regulation and power regulation the system components co-ordination is obtained by different control strategies of each system.

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