Voltage Stability for Hybrid Power System Feeding Loads in Isolation

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Abstract— — Reactive power limit of the system affects its Voltage stability. The wind driven self excited induction generator and permanent magnet synchronous generator (PMSG) with solarphotovoltaic (SPV) power generating system are combined to feed the linear/non-linear balanced/unbalanced loads in isolated regions. Powers from all sources are combined at common coupling point. Nonlinear and unbalanced loading condition demands reactive power from the system.Whole system with load side controller is simulated in the matlab simulink to show the voltage stability during nonlinear and unbalanced loading condition. Load side controller provides required reactive power flow in the system thereby improving voltage stability.

Keywords: Voltage Stability, Wind Turbine, Squirrel-Cage Induction Generator, PMSG, SPV, Common Coupling Point.

I. Introduction

Due to increased environmental concern, electrical power generation from renewable energy sources such as wind, solar is increased. They have come of ages and are the world's fastest growing energy resources. These are clean and effective modern technology that provides a beacon of hope for a future based on sustainable and pollution free technology. These renewable energy sources are located in remote regions, thereby causing obstacles in their development. In starting during the development of the wind generation for grid connected systems, the fixed speed wind turbines with squirrel cage induction generators have been in use. For such systems the energy conversion efficiency is very low. Now these days variable speed wind energy conversion system (WECS) [1-4] uses the maximum power tracker (MPT) [5] which adjusts the rotational speed to maximize the wind turbine output power. The turbines driving permanent magnet synchronous generators (PMSG) are gaining popularity among the variable-speed wind turbines [6]. A PMSG is a rotating electric machine, in which the field excitation is provided by permanent magnets. PMSGs have a loss-free rotor, and the power losses are confined to the stator windings and the stator core [7]. A multi-pole PMSG [8] connected to a power converter can operate at low speeds so that a gear can usually be omitted. A gearless construction represents an efficient and robust solution for a WECS. Thus, the efficiency of a PMSG-based WECS has been assessed higher than other variable-speed wind turbine systems. However, the disadvantage of PMSGs is the high cost of permanent magnet material in present time, which is expected to reduce in the near future. Full scale power converter is used in the case of PMSG-based WECSs, which allows the full controllability of the system [9]. The power converter decouples the PMSG from the grid and results in an improved reliability.

II. SYSTEMS

For the widely varying wind speeds the energy conversion efficiency of fixed speed wind energy conversion system (WECS) is very low. In many of the modern day variable-speed WECS, a maximum power tracker (MPT) adjusts the rotational speed to maximize the wind turbine output power. The variable-speed operation of WECS can be achieved in a number of ways. In the case of doubly fed induction generator (DFIG) the power converter needs to handle only the rotor power, which is only a fraction of the total power. Among the variable-speed wind turbines, the turbine driving permanent magnet synchronous generator (PMSG) is gaining popularity. In PMSG, the field excitation is provided by permanent magnets. PMSG have a loss-free rotor, and the power losses are confined to the stator windings and the stator core only [10]. At low speed a gear can usually be omitted if a multi-pole PMSG is used. A gearless construction represents an efficient and robust solution for a WECS. Thus, the efficiency of a PMSG-based WECS is higher than other variable-speed wind turbine systems [11]. In the case of PMSG based WECS, a full scale power converter is used, which allows the full controllability of the system. In such systems, the power converter decouples the PMSG from the grid, resulting in an improved reliability. For stand-alone systems supplying local loads, if the extracted power from the wind is more than the local loads (and losses), the excess power is required to be diverted either to a dump load or to be stored in the battery bank. Moreover, when the extracted power is less than the load power, the deficit power needs to be supplied from a storage element like a flywheel, a super capacitor, compressed air, hydrogen storage, a secondary battery [12]. A number of attempts have been made to address the issues of voltage and frequency control (VFC) for stand-alone systems using asynchronous generators [13][14][15][16]. Attempts are made to develop a battery-based controller for a wind-driven autonomous four-wire system using a PMSG and feeding local loads in stand-alone mode without mechanical position sensors. Further this autonomous WECS using PMSG is considered in a hybrid system with the Solar system using photovoltaic array. As solar power is an endless source of energy like wind energy, so developing a hybrid system based on these two freely available energies is a need of the present world. The Three energy sources PMSG, IG and SPV are connected in parallel to a common DC bus line as shown in fig. 1, through their individual converters. The load may be dc-connected to the dc bus line or may include an IGBT based pulse width modulated (PWM) voltage source inverter to convert the DC power into AC at 50 or 60 Hz. Each source has its individual control. The diodes, D1, D2 and D3, allow only unidirectional current flow from the source to the DC bus line, thus keeping each source from acting as a load on each other or on the battery. Therefore, in the event of malfunctioning of any of the energy sources, the respective diode will automatically disconnect that source from the system. The output of the hybrid generating system goes to the DC bus line to feed the isolating DC load or to the inverter, which converts the DC into AC. When the output of the system is not available, the battery powers the DC load or discharges to the inverter to power AC loads.

III. PRINCIPLE

The operating principle of the controller which controls the load-side converter is based on the control of the reactive power to regulate the magnitude of the load voltage and active power to regulate the frequency of the voltage. The battery system absorbs the excess active power when the frequency of the load voltage is above the nominal frequency, and it supplies the active power when the frequency is below the nominal frequency. When the magnitude of the voltage falls below the reference value, the load-side converter provides the reactive power, and when the magnitude of the voltage rises above the reference value, the reactive power is absorbed by the load-side converter.

For the control of the load-side converter, the reference three-phase phase-to-neutral voltages are compared with the sensed three-phase phase-to-neutral voltages at the load end, and the difference is fed to the voltage controller. The output of the voltage controller gives the reference three-phase load-side converter currents, which are compared with the sensed three-phase load-side converter currents to achieve control signals for the load side converter.

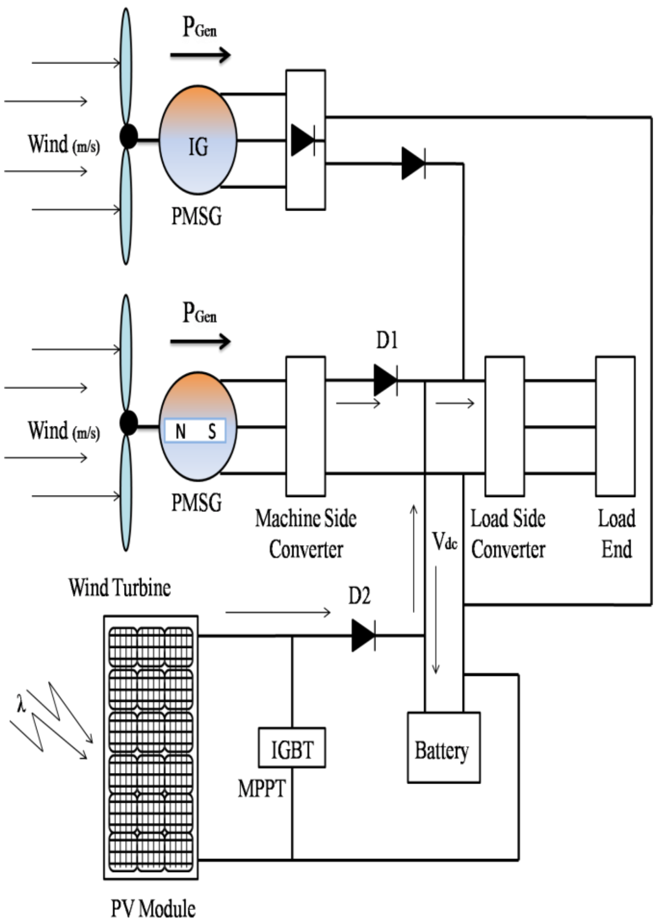

Fig. 1 Block Diagram for Proposed System

Machine Side Converter Control

The operating principle of the controller for the machine-side converter is based on the decoupled control of the d- and q-axis stator currents of the PMSG with the d-axis aligned to the permanent magnet flux or rotor electrical axis. Speed Control Loop for Maximum Power Tracking and Reference Generation for q-Axis Stator Current. In the proposed algorithm, the wind speed is sensed for the MPT. The rotor position (Θ_r). is estimated using stator flux linkages. The rotor speed (ω_r) is determined from the rotor position (Θ_r). The reference rotor speed (ω_r^*) for the MPT is generated from the wind speed and the optimum tip speed ratio and compared with (ω_r) to calculate the rotor speed error (ω_{er}). At the nth sampling instant, the output of the proportional-integral (PI) speed controller with proportional gain $K_{p\omega}$ and integral gain $K_{i\omega}$ gives reference for the q-axis stator current (I_{qs}) . To obtain maximum torque with minimum stator current, the reference d-axis stator current (I_{ds}^*) is set to zero.

Load Side Converter Control

The purpose of the load-side converter is to maintain rated voltage and frequency, irrespective of connected load. The power balance of the load-side converter is maintained by diverting excess power generated to the battery in the DC link of back-to-back connected PWM converters or by supplying active power from the battery in the case of a deficit between the generated power and load requirement. Similarly, the required reactive power for the load is supplied by the load-side converter to maintain a constant value of the load voltage. The reference voltages (v_{an}^*, v_{bn}^*, and v_{cn}^*) for the control of the load voltages at time t are given as-

$$v_{an}^* = \sqrt{2}V_t \sin(2\pi ft)$$
$$v_{bn}^* = \sqrt{2}V_t \sin(2\pi ft - 120^{\circ})$$
$$v_{cn}^* = \sqrt{2}V_t \sin(2\pi ft + 120^{\circ})$$

Where, 'f' is the nominal frequency (50 Hz), and V_t is the RMS phase-to-neutral load voltage. The load voltages (v_{an}, v_{bn}, and v_{cn}) are sensed as feedback signals. The error voltages (v_{anerr}, v_{bnerr}, and v_{cnerr}) at the nth sampling instant are calculated from the reference voltages and load voltages. The reference three-phase load-side converter currents (i_{Ca}^*, i_{Cb}^*, and i_{Cc}^*) are generated by feeding the voltage error signals to the PI voltage controllers with proportionate gain as K_{pv} and integral gain as K_{iv}.

The reference three phase load side converter currents are then compared with sensed load side converter currents (i_{Ca} , i_{Cb} , and i_{Cc}) to compute the load side converter current errors.These current errors are amplified with gain (K), and the amplified signals are compared with the fixed frequency (Z kHz) triangular carrier wave of unity amplitude to generate gating signals for IGBTs of the load-side converter.

IV. SIMULATION AND RESULTS

MATLAB simulation of the proposed system, "Autonomous WECS using PMSG" (Wind Energy Conversion System using Permanent Magnet Synchronous Generator), Solar Photovoltaic (SP) and Induction Generator (IG) is done in MATLAB using Simulink, Sim-Power System. The simulation is carried out on MATLAB version R2011a with ode23tb solver. Complete system for WECS using PMSG, SP and IG in isolation is simulated by combining the simulated models of the WECS, SP, IG, Machine Side Controller, Load Side Controller, and Battery Energy Storage System (BESS) is shown in fig. 2. In the fig. 2 two back-to-back connected insulated gate bipolar transistor (IGBT) based voltage source converters (VSCs) are connected between the PMSG and the load end. The VSCs are controlled through the pulse width modulation (PWM) based controllers. A battery bank is connected at the DC link of these VSCs. An LC filter and a step-up-transformer are connected between the load-side converter and the load.

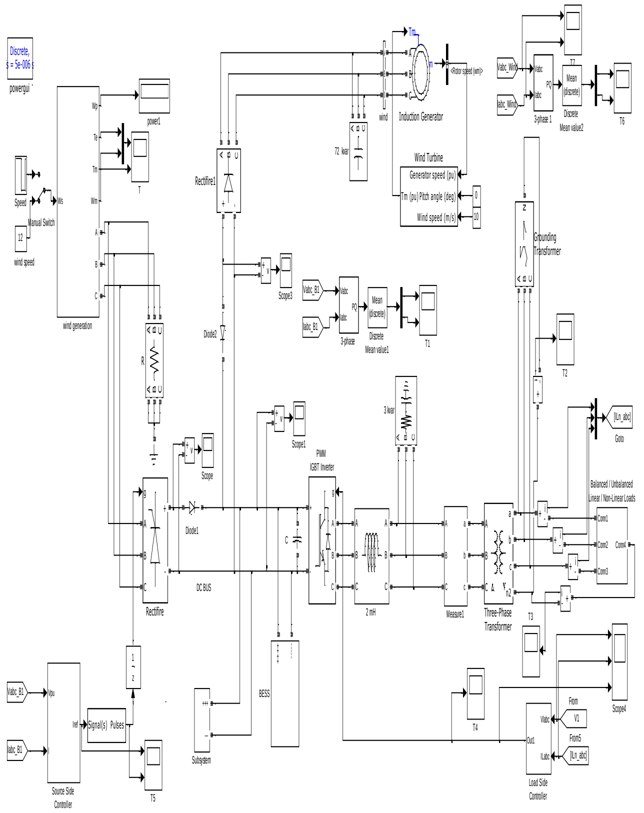

Figure 2: Simulation diagram for the system under consideration.

Linear Load

System is running with balanced load at starting. Now at 0.6 sec. an unbalance is created by disconnecting the phase 'a' from load, (by opening the connection between phase 'a' and its load). This will reduce the active power demanded by the load but cause supply imbalance which affects the source. Further at 0.7 sec. load form the phase 'b' is also removed, making the system more unbalanced. At 0.85 sec. both removed phases loads are connected again which makes the system a balanced one again. Behavior of the WECS using PMSG, IG, SP is shown by a set of waveforms in fig. 3. Here in the system during the unbalanced to maintain the constant frequency on the load side the extra active power is diverted to the BESS. It is clearly seen from the graphs that the load voltages for all three phases are in balanced condition. The system frequency remains always close to the 50 Hz.

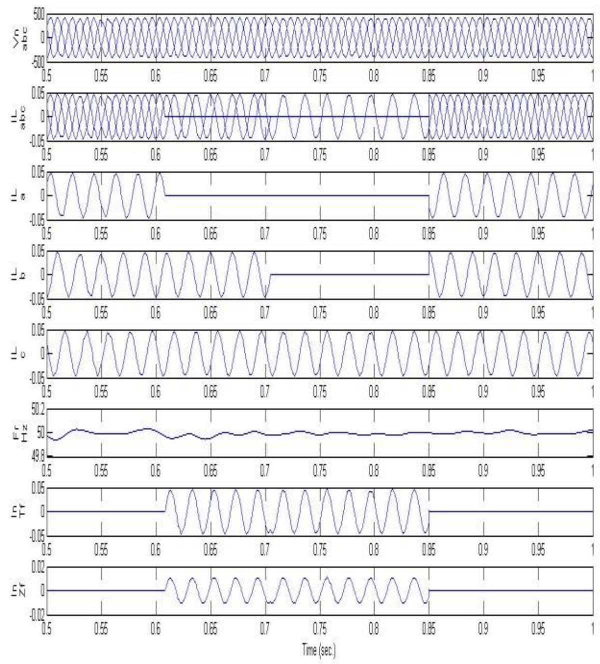

Fig. 3 Graph for Linear Balanced/Unbalanced Load

Non-Linear Balanced/Unbalanced

System is started with balanced three phase load. At 0.6 sec. an unbalance is created by disconnecting a diode bridge rectifier load from phase 'a' (by opening the connection between phase 'a' and its load).

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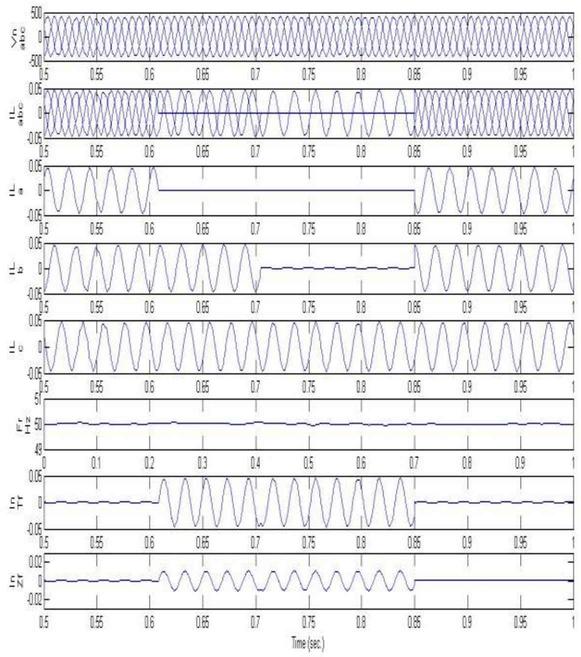

Fig. 4 Graph for Non-linear Balanced/Unbalanced Load

Further at 0.7 sec. load form the phase 'b' is also removed from its diode bridge rectifier load, making the system more unbalanced. At 0.85 sec. both removed phases loads are connected which places the system in the previous condition. It is clearly visible in fig. 4 that the voltage and frequency are almost constant even though during the disturbances.

V. Conclusion

Matlab/simulink based simulation of the proposed system shows that the voltage and frequency on load side remains balanced in all electrical loading conditions. The performance of the WECS using PMSG, IG, SPV system feeding balanced/unbalanced resistive, inductive, and non-linear load has been found satisfactory.

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