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Analysis of a Hybrid Generation Scheme involving Wind and Solar PV for Grid Isolated Applications

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***Abstract*—** Harnessing wind power using induction generators have been widely practiced throughout the world. Hybrid wind solar generation schemes are a good option in grid isolated places. This paper presents a single-phase dual stator winding induction generator combined with a strategically connected photovoltaic panel for standalone operation suitable for microgeneration. This scheme can be installed in remote and grid unreachable areas as a reliable electrical source of power. The variable reactive power requirement of the generator is provided by a single-phase inverter. The variable frequency inverter source regulates the load voltage during fluctuating loads or low wind speeds. The generated voltage is converted to DC and is also assisted by the photovoltaic panel for battery charging. A fixed frequency inverter can then be used to supply the single-phase domestic loads. Suitable simulations validate the proposed strategy backed by experimental findings on a 250W, 240V, 50Hz, 4-pole generator.

***Keywords*—** Single-phase induction generator; Hybrid generation; Wind power; Grid-isolated operation

I. INTRODUCTION

There is a constant need for development of renewable sources of power for generation purposes owing to the increased use of diminishing fossil fuel. Fossil fuel usage has not only resulted in increase in pollution but also led to increase in green-house gases and overall led to weather alterations. Wind is among a clean renewable energy source but it is intermittent. Solar energy in combination to wind is a great choice for hybrid generation purposes [1] since solar and wind energy mostly complement each other. For harnessing wind power, induction generators are commonly used coupled to wind turbines for generation of electricity in grid connected as well as standalone purposes [2]-[5]. For supplying single-phase isolated loads, single-phase induction generators are ideal candidates since most of the domestic loads are of single phase type. These machines are generally rated in fractional kW range which is an additional advantage for their use in small standalone purpose for supplying grid isolated, single-phase domestic loads. Various generation schemes are available which proposes single-phase induction machines as generators [6]-[8].

Increase in load or speed decrease will lead to the generator's increased reactive power requirement. Inverter assisted control for the same is proposed previously to increase the operating range and provide stable output for single-phase induction generator [9]. With increase in load, the steady load voltage buildup may impede without proper control or at low wind speeds when generation may be insufficient. It is generally observed that solar power is well complements wind power at various places generally at onshore installations [1]. Thus use of PV panels with wind turbine generators is also a well researched area [10]-[13]. However, not much research has been done for standalone, small scale installation for operation of such a hybrid system.

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In this paper, a wind-PV hybrid generation scheme is proposed with a 250W, 240V, 50Hz, 4-pole, single-phase induction generator. The two windings present on the stator are electrically isolated and are used as dual winding machine. It uses a fixed capacitor for initial excitation of the induction generator at nominal rotor speeds and no load condition. The main winding is used for generation purpose whereas the auxiliary winding is used for controlling the generated output. The auxiliary winding has the single-phase inverter assembly. The capacitor is connected across the main winding terminals across which a rectifier and PV panel is connected. The PV panel feeds it power to the dc bus which is connected across a fixed frequency inverter. When load increases or when the wind power becomes low, the inverter assembly provides the necessary additional excitation to maintain the magnetizing field of the generator and thus keeping the real power constant at load terminals. The generated power is augmented by the PV panel which is helpful during low wind regimes.

The proposed scheme is discussed in details in the next section, followed by the simulations and experimental results, analysis and finally conclusions are drawn. The simulation results along with experimental data justifies the suitability of the concept for remote and grid isolated purposes.

II. Proposed Hybrid Generation Scheme

In the hybrid generation scheme, a single-phase induction machine operated as dual stator winding generator is proposed which generates at wide range of speeds. The induction machine's main winding are connected to a capacitor for providing the initial VAr requirement. The generated voltage is converted into dc using a rectifier. The PV panel is connected at the output of the rectifier to augment the generation. The output of which is connected to a fixed frequency inverter for supplying domestic single-phase AC loads. A single-phase inverter is connected across the auxiliary winding to provide variable excitation during low wind or high loads. As the machine starts to generate, single phase loads can be connected across the main winding terminals across the fixed frequency inverter. The inverter frequency is maintained at 50 Hz. The inverter along with the battery is sized for low power rating as the reactive power requirement is low. The block diagram for the proposed scheme is shown in Fig.1.

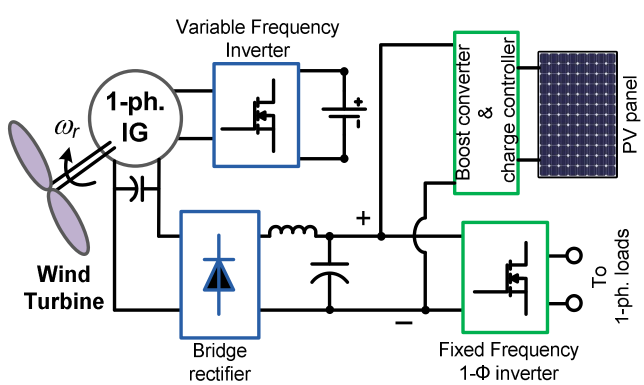


Fig. 1. Proposed hybrid generation scheme.

The single-phase inverter across the auxiliary is controlled via a hysteresis controller which senses the generated voltage and current to generate a current reference. The induction generator is modeled using the generalized d-q-axes machine model in stator reference frame as,

$$v_{ds} = R_{ds} i_{ds} + \frac{d}{dt}\psi_{ds} \tag{1}$$

$$v_{qs} = R_{qs} i_{qs} + \frac{d}{dt}\psi_{qs} \tag{2}$$

$$0 = R_{dr} i_{dr} + \frac{d}{dt}\psi_{dr} + \omega_r \psi_{qr} \tag{3}$$

$$0 = R_{qr} i_{qr} + \frac{d}{dt}\psi_{qr} - \omega_r \psi_{dr} \tag{4}$$

where, R_{ds}, R_{qs}, are respectively the d and q axis stator resistances with i_{ds}, i_{qs}, i_{dr} and i_{qr} the stator d-axis and q-axis and rotor d-axis and q-axis currents respectively. ω_r is the speed of the rotor. Flux linkage relations can be given as,

$$\psi_{ds} = L_{lds} i_{ds} + L_{dm}(i_{ds} + i_{dr}) \tag{5}$$

$$\psi_{qs} = L_{lqs} i_{qs} + L_{qm}(i_{qs} + i_{qr}) \tag{6}$$

$$\psi_{dr} = L_{ldr} i_{dr} + L_{dm}(i_{ds} + i_{dr}) \tag{7}$$

$$\psi_{qr} = L_{lqr} i_{qr} + L_{qm}(i_{qs} + i_{qr}) \tag{8}$$

where, ψ_{ds}, ψ_{qs}, ψ_{dr} and ψ_{qr} are the stator d- q-axes and rotor d- q-axes flux linkages respectively, L_{lds}, L_{lqs}, L_{ldr} and L_{lqr} are the stator d- q-axes and rotor d- q-axes leakage inductances with L_{dm} and L_{qm} are the magnetizing inductances of d- q-axes.
The PV panel can be modeled using the voltage-current relationship [14] as,

$$I_{pv} = N_P I_{PH} - N_P I_S[\exp(qV_{pv} / N_S K T_C A) - 1] \tag{9}$$

In (9) the I_{PH} is the photo diode current, I_S is the diode saturation current, charge of an electron 'q'. K is the Boltzmann constant and the PV cell temperature is denoted as T_c, A as the ideal factor for panel. The PV panel is made of series parallel connected PV cells. The number of parallel and series connected cells are denoted respectively as N_P and N_S for the panel. Usually there are shunt and series resistances in the PV panel model. It is assumed that the shunt resistance is infinite and series resistance zero for the PV panel considered. The PV panel approximate equivalent circuit is shown in Fig.2.

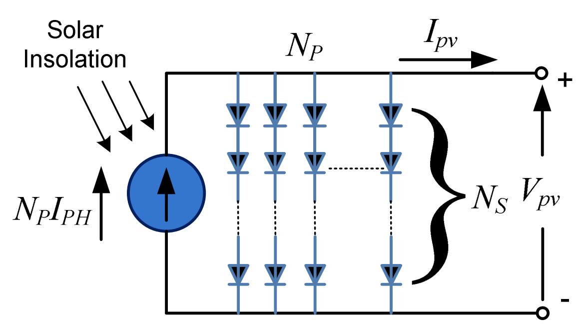
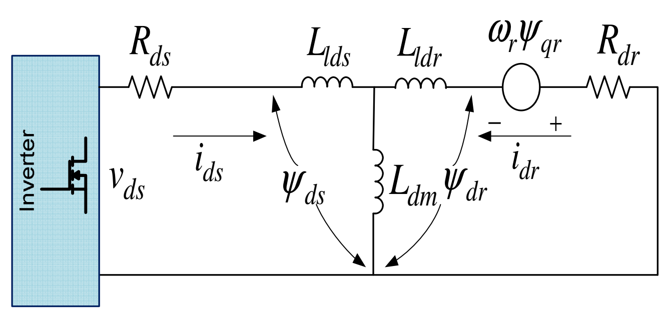
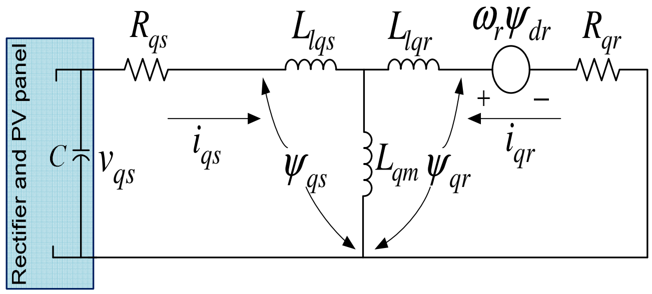


Fig. 2. PV panel approximate equivalent circuit.

Fig.3. shows the equivalent circuit of the induction generator in d-q axes stationary reference frame from (1)-(8). Fig.2 (a) and (b) are the d-q-axes equivalent circuits.



(a)



(b)

Fig. 3. Induction generator (a) *d*-axis and (b) *q*-axis equivalent circuits.

III. Simulation and Experimental Results

A 250W, 240V, 50Hz, 4-pole, single phase, cage rotor induction machine is used for the simulation and laboratory experimental study. The terminal capacitor of 10 μF is used for the initial voltage buildup at no-load condition. The inverter is operated in a hysteresis band based current controller. The controller block diagram is shown in Fig.4.

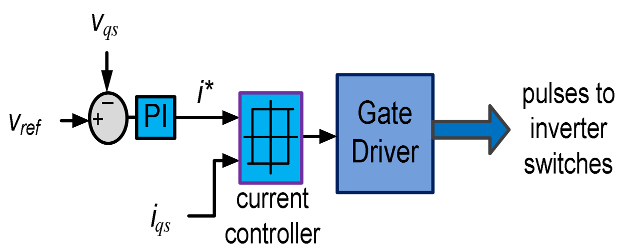


Fig. 4. Single-phase inverter controller block diagram.

The simulation study is carried out using *MATLAB/Simulink R2012b* platform. Initially with a set value of 10 μF terminal capacitor for the induction machine, the generation starts. As the IG reaches a cut-off speed of 1350 r/min, the generator initiates to generate. The simulated generator voltage build-up is shown in Fig.5.

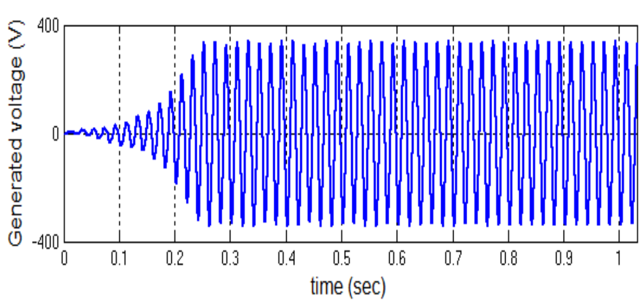


Fig. 5. Simulated waveform for voltage build-up of the IG.

The plot for the main and auxiliary currents along with speed fluxes and load at steady state are shown in Fig.6 for the IG.

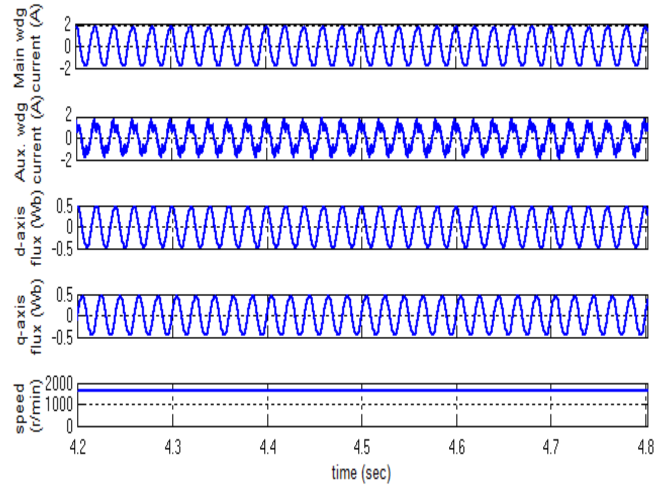


Fig. 6. Simulated waveform for stator winding currents, flux-linkages and generator speed.

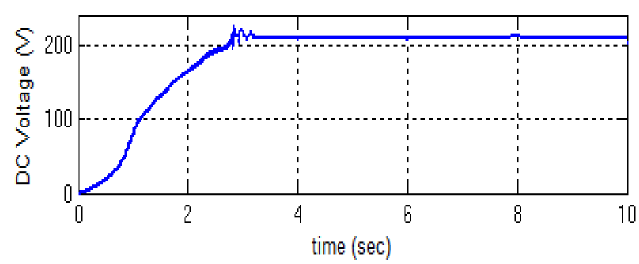


Fig. 7. Simulated waveform for DC voltage at output.

The simulated model uses a single phase inverter and battery assembly as the inverter DC bus. The rectifier output dc bus voltage is shown in Fig.7. The inverter voltage is shown in Fig.8.

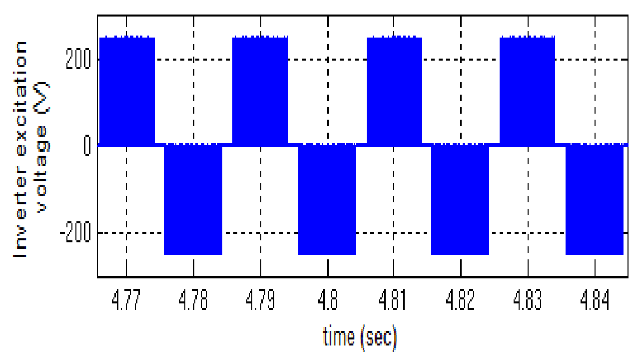
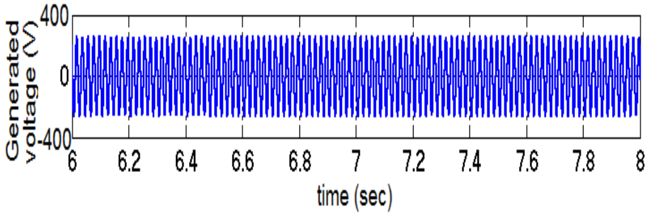
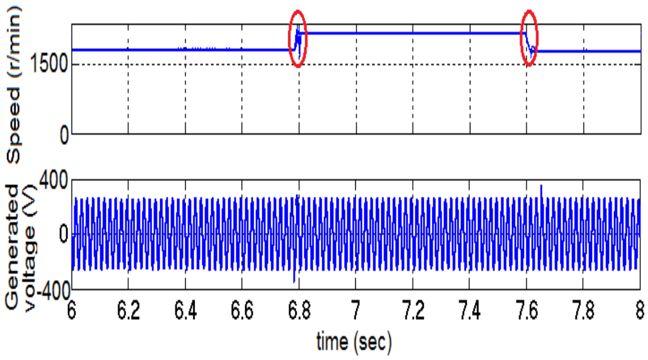


Fig. 8. Simulated waveform for inverter excitation voltage.

Fig.9 (a) and Fig.9 (b) shows the fixed frequency inverter filtered output voltage waveform in steady state and with change in rotor speeds from 1600 r/min to 1650 r/min with constant rated load. The generated voltage and frequency remains stable as shown in the figures.



(a)



(b)

Fig. 9. Simulated waveform for (a) fixed frequency inverter output voltage and (b) output voltage with step change in speeds.

Fig. 10 shows the simulated waveform for the main winding current and load voltage with step change in load from half rated to full load. As shown with the proposed control, the generated voltage at output remains almost constant.

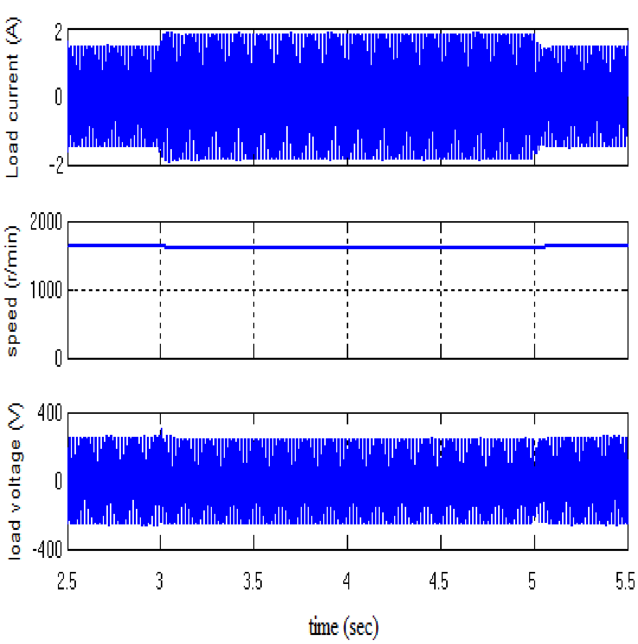


Fig. 10. Waveform for main winding current, speed and load voltage with step change in load.

Fig.11 shows the experimental load voltage waveform in steady state.

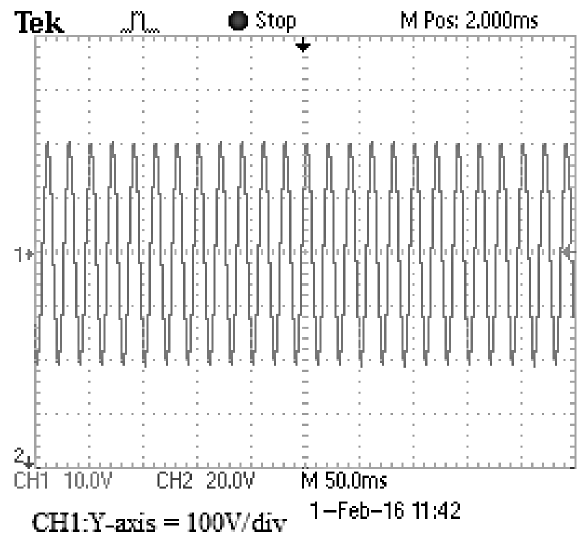


Fig. 11. Experimental waveform for load voltage waveform in steady state.

Fig.12 shows the experimental waveform of the load current and terminal voltage when step variation of load similar to simulation study is made. The experimental results as shown are in good agreement with the simulated results.

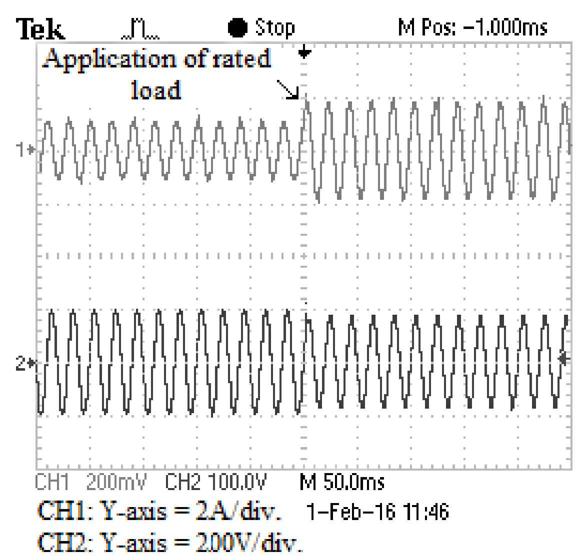


Fig. 12. Experimental waveform for load current (CH1) and terminal voltage (CH2).

IV. Conclusion

A wind-PV hybrid generation with single-phase induction generator is proposed in the paper. The generator scheme can be easily installed and used in remote and grid isolated areas with a wind turbine for household microgeneration applications. The proposed control strategy with single-phase inverter surmounts the problem of voltage regulation effectively at load or speed transients. The PV panel also helps in augmenting the generation thus serving the induction generator to operate in isolated mode. The single-phase induction generator along with its control can be a suitable option for employing in wind-PV energy for standalone, grid secluded applications.

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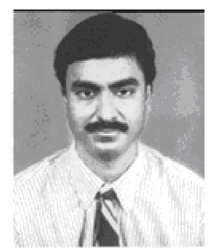

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