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A STAND-ALONE PV/WIND ENERGY MANAGEMENT SYSTEM USING Z-SOURCE INVERTER

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ABSTRACT

The use of renewable energy sources is on the rise because of the energy crisis in the world today. Power electronics plays a major role in implementing the renewable energy based power generation. The impedance source inverter (ZSI) which has both voltages buck and boost capabilities is used to interface the wind, photovoltaic array (PV), as primary sources, and battery as backup and storage. A power management strategy is designed for the proposed system to manage power flows among the different energy sources and the storage unit in the system. A simulation model for the proposed hybrid energy system has been developed using MATLAB/Simulink. The system performance under different scenarios has been verified by carrying out simulation studies using a practical load demand profile and real weather data.

KEYWORDS: Battery; Inverter; Renewable; Solar; Wind; Z-Source

INTRODUCTION

The usage of renewable energy sources is increasing all over the world. The increasing energy demand and the need for clean energy sources are the driving forces for this development. Wind and solar power generation are the two of the most promising renewable power generation technologies. The growth of wind and PV power generation systems has exceeded the most optimistic estimation. However each of the above mentioned technologies has its own drawbacks. For instance, wind and solar radiation are highly dependent on climate. Nevertheless, as different alternative energy sources can complement each other to some extent, multi-source hybrid alternative energy systems have great potential to provide higher quality and more reliable power to customers than a system based on a single resource. Due to the intermittent nature of wind and solar radiation, stand alone wind and PV energy systems normally require energy storage devices to form a hybrid system. In the proposed system nickel metal hydride battery is used as a storage medium [1] [2]. In PV systems, to get maximum power, the Maximum Power Point Tracking (MPPT) technique, the perturb and observe (P&O) method is employed from the different techniques available for the same [3],[4]. For the wind energy conversion systems (WECS) pitch angle control is implemented [5]. To facilitate the variable speed operation for the wind energy system and to boost the voltage from the PV array variety of power electronics converters are required [6]. The Z-Source Inverter (ZSI) has been identified to exhibit in steady state, both buck and boost capabilities. It employs unique impedance network included between dc power source and converter circuit [7]. The output voltage of ZSI mainly depends upon the shoot through states or boost factor. The two inductors of impedance source will induce high voltage which appears across the two capacitors [8]

PROPOSED SYSTEM DESCRIPTION

A proposed zsi based wind/pv/battery fed load is shown in the fig below:

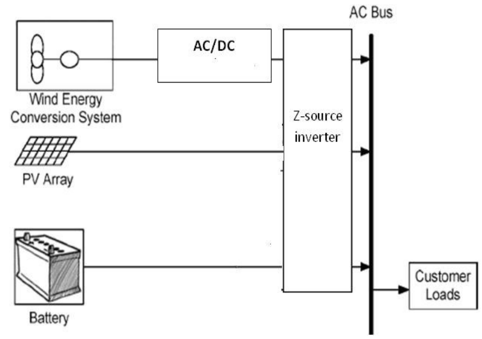

Figure 1: Block Diagram of the Proposed System

In the system, the power from wind and PV is taken as the primary source while the battery bank is also used in the system to supply transient power to load transients, ripples, and spikes. There are several ways to integrate different alternative energy sources to form a hybrid system. Each method has its own advantages and disadvantages. In this work, a 60 Hz ac link is used due to its high reliability, modular and scalable structure, and readiness for grid connection [6]. The two energy sources are connected to the ac bus through advanced power electronic interfacing circuits like z-source inverter. The different parameters and components employed in the system are as given in the table 1.

Table 1: The Parameter Details Employed in the Proposed System

Wind Turbine	
Rated Power	50 kW
Cut in Speed (Cut out Speed)	3 m/s (25 m/s)
Rated Speed	14 m/s
Induction Generator	
Rated Power	50 kW
Rated Voltage	670 V
Rated Frequency	60 Hz
PV Array	
Module Unit	153 cells, 173 W @ 1 kW/m^2, 25° C
Module Number	16 X 2 = 192
Power Rating	192 X 73 ≈ 33 kW
Battery	
Capacity	10 kWh
Rated Voltage	400 V

COMPONENTS CHARACTERISTICS

Wind Energy Conversion System

The power Pwind (in watts) extracted from wind is

$$P_{wind} = \frac{1}{2}\rho A v^3 C_P(\lambda, \theta) \quad (1)$$

Where ρ is the air density in kilogram per cubic meter, A is the area swept by the rotor blades in square meter, and v is the wind velocity in meters per second. Cp is called the power coefficient or the rotor efficiency and is a function of tip speed ratio (TSR or λ) and pitch angle (θ) A variable-speed pitch-regulated wind turbine is considered in this paper, where the pitch angle controller plays an important role. Fig. 1 shows the groups of Cp- λ curves of the wind turbine used in this study at different pitch angles. It is noted from the figure that the value of Cp can be changed by changing the pitch angle (θ). In other words, the output power of the wind turbine can be regulated by pitch angle control. A self-excited induction generator (SEIG) model was Fig. 2. Cp - λ characteristics of the WECS at different pitch angles (θ) developed and used as a part of the WECS model. The ratings of the SEIG are given in I.

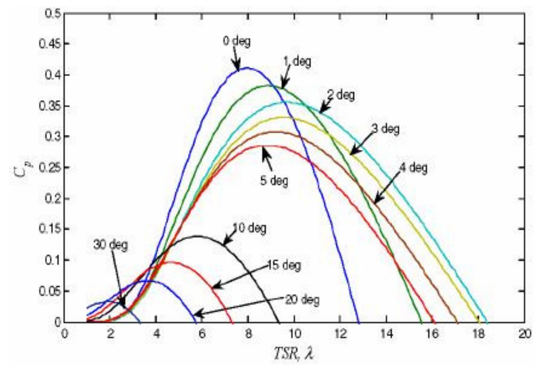

Figure 2: Cp - Λ Curves of the WECS at Different Pitch Angles (Θ)[6]

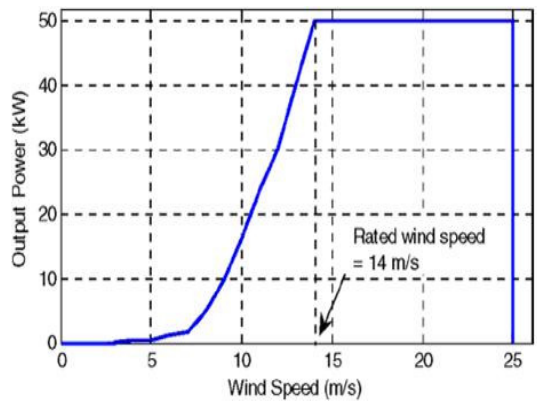

Figure 3: Output Power Vs. wind Speed[6]

Fig. 2 shows the output power of the WECS vs. wind speed. It can be observed that the output power is kept constant when wind speed is higher than the rated wind velocity even though the wind turbine has the potential to produce more power. This is done through the pitch angle control to protect the electrical system and to prevent over speeding of the rotor. When wind speed is higher than the cutout speed (25 m/s), the system is taken out of operation for protection of its components [6].

Photovoltaic System

PV effect converts solar energy directly into electrical energy. The relationship between the output voltage V and the load current I of a PV cell or a module can be expressed as

$$I = I_L - I_0\left[\exp(\frac{V + IR_a}{\alpha} - 1\right] \quad (2)$$

Where IL is the light current of the PV cell (in amperes), I0 is the saturation current, I is the load current, V is the PV output voltage (in volts), Rs is the series resistance of the PV cell (in ohms), and α is the thermal voltage timing completion factor of the cell (in volts). The I-V characteristic curves of the PV model used in this study under different irradiances (at 25◦C) are given in Fig. 4. It is noted from the figure that the higher the irradiance, the larger are the short-circuit current (Isc) and the open circuit voltage (Voc). As a result, the larger will be the output PV power. Temperature plays an important role in the PV performance because the four parameters (IL, I0, Rs, and α) in (6) are all functions of temperature. The effect of the temperature on the PV model performance is illustrated in Fig. 5. It is noted that the lower the temperature, the higher is the maximum power and the larger the open circuit voltage [6].

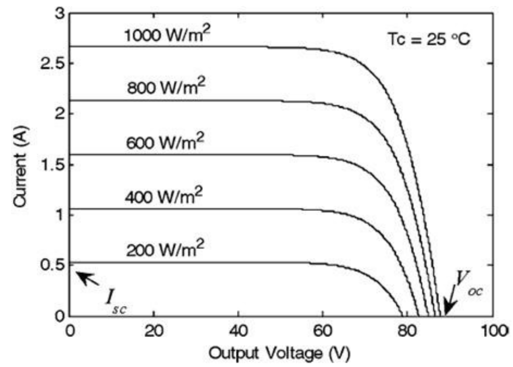

Figure 4: I-V Characteristics of the PV Model at Different Irradiances [6]

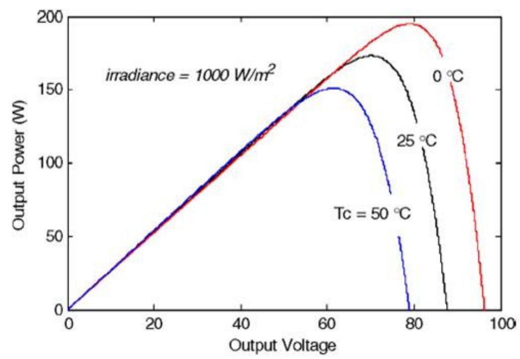

Figure 5: P-V Characteristic Curves of the PV Model at Different Operating Temperatures[6]

Z-source Converter/Inverter

The Z-source converter employs a unique impedance circuit to couple the converter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage source and current-source converters where a capacitor and inductor are used, respectively. The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter and provides a novel power. Fig. 6 shows the general Z-source converter structure. It employs an impedance circuit to couple the converter main circuit to the power source, load, or another converter, for providing unique features that Fig. 3. I-V characteristic curves of the PV model at different irradiances cannot be observed in the traditional V- and I-source converters where capacitor and inductors are used, respectively. In Fig. 6, a two-port network that consists of a split-inductor and capacitors and connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source, load, or another converter. The dc source/or load can be either a voltage or a current source/or load. The inductance L1 and L2 and can be provided through a split inductor port two separate inductors. The Z-source inverter is a buck-boost inverter that has a wide range of obtainable voltage. The traditional V- and I-source inverters cannot provide such feature. The three phase Z-source inverter bridge has nine permissible switching states (vectors) unlike the traditional three-phase V-source inverter that has eight.

The traditional three-phase V-source inverter has six active vectors when the dc voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, respectively. However, the three-phase Z-source inverter bridge has one extra zero state when the load terminals are shorted through both the upper and lower devices of any one phase leg (that is, both devices are gated on), any two phase legs, or all three phase legs. This shoot through zero state (or vector) is forbidden in the traditional V-source inverter, because it would cause a shoot-through. This third zero state (vector) is called the shoot-through zero state (or vector), which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter. The equivalent circuit of the Z-source inverter shown in Fig. 7 is when viewed from the dc link. The inverter bridge is equivalent to a short circuit when the inverter bridge is in the shoot-through zero state, as shown in Fig. 8, whereas the inverter bridge becomes an equivalent current source when in one of the six active states. Note that the inverter bridge can be also represented by a current source with zero value (i.e., an open circuit) when it is in one of Fig. 6. General structure of the Z-source converter. The two traditional zero states. Therefore, Fig. 9 shows the equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in one of the eight non shoot through switching states [9]. The Z-source inverter for solar and z-source inverter for wind energy conversion system are explained in [7],[8],[10].

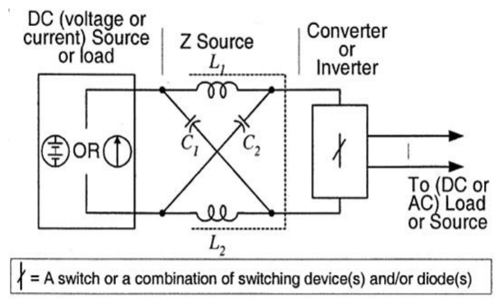

Fig. 6: General Structure of the Z-Source Converter [9]

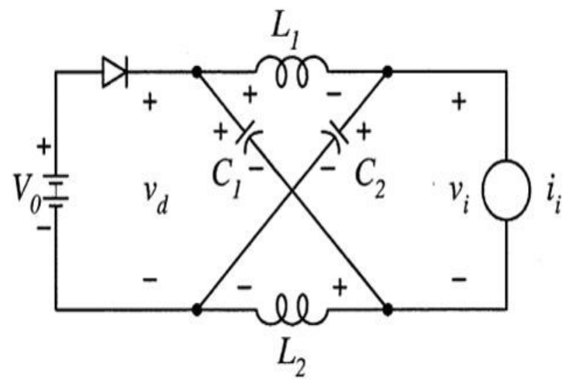

Fig.7: Equivalent Circuit of the ZSI Viewed from the Dc Link [9]

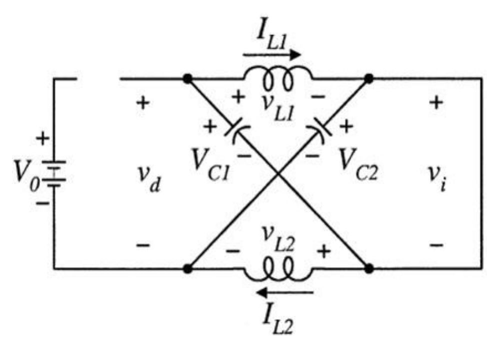

Fig.8: Equivalent Circuit of the ZSI Viewed from the dc dc Link When the Inverter Bridge is in the Shoot-Through Zero State

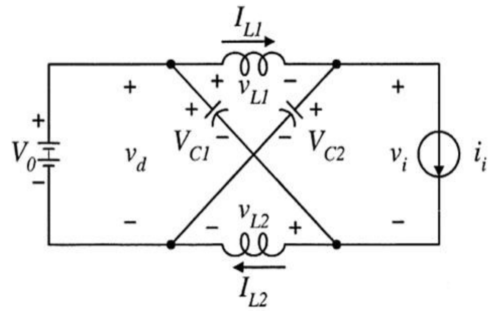

Fig.9: Equivalent Circuit of the ZSI Viewed from the Link when the Inverter Bridge is in One of the Eight Nonshoot-Through Switching States [9]

Battery

A nickel-metal hydride (NiMH) cell is a type of rechargeable battery employed in this work. It is very similar to the nickel-cadmium cell (NiCd). NiMH use positive electrodes of nickel oxyhydroxide (NiOOH), like the NiCd, but the negative electrodes use a hydrogen-absorbing alloy instead of cadmium. A NiMH battery can have two to three times the capacity of an equivalent size NiCd, and their energy density approaches that of a lithium-ion cell. The components of NiMH batteries include a cathode of Nickel-hydroxide, an anode of Hydrogen absorbing alloys and a Potassium-hydroxide (KOH) electrolyte which are Fig. 8. Equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in one of the eight nonshoot-through switching states Fig. 9. The PV System Output Voltage at the common bus. Collectively more benign than the active chemicals used in rival Lithium batteries and they are considered better for the environment.. Much safer than Lithium based cells in case of an accident or abuse due to the use of more benign active chemicals, a particularly important property in high power and automotive applications.

RESULTS

The proposed system is simulated on MATLAB Simulink and the following results were obtained. The individual source voltages namely, PV output and Wind Generator output are shown in figures 9 and 10. Both the systems have developed the rated voltages at the common bus with Z source inverter. Battery also responded as per the model requirement and the voltage when fully charged. Under load condition the model gave satisfactory results, the load current and voltages are shown in Figs. 11 and 12. The power consumed is shown in Fig. 13. The benefits of Z source inverter are fully utilized in this work.

CONCLUSIONS

In this work the Z-source inverter fed wind/pv/battery based power generation system has been proposed. The wind and PV generation system are the main power generation devices and the battery is the overcome short term fluctuations. The simulation model of the hybrid system has been developed using MATLAB/simulink.

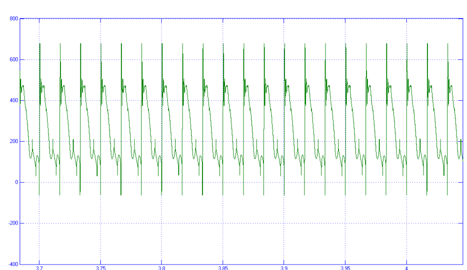

Fig. 10: The PV System Output Voltage at the Common Bus

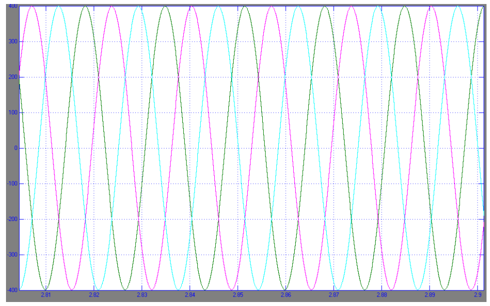

Fig. 11: The Load Current Waveform

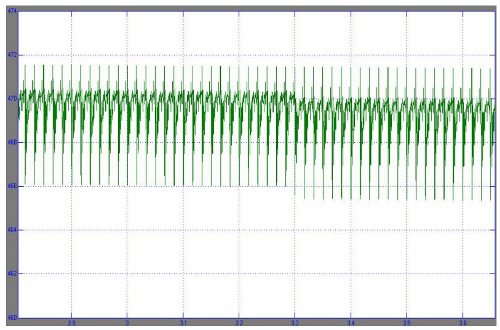

Figure.12: Load Voltage at the Common Bus

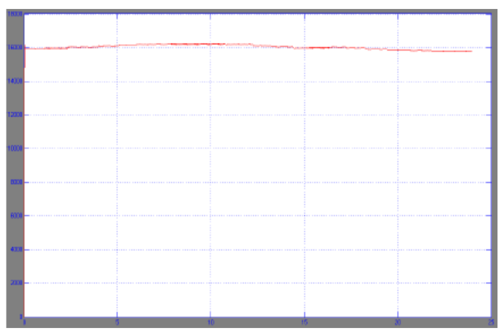

Figure.13: Real Power Consumed by the Load

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