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Analysis and Control of Self-Excited Induction Generator with DC-AC Boost Converter for Stand-Alone Applications

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Abstract— This paper proposed a control scheme of a Three-Phase Self-Excited Induction generator (SEIG) supplying single-phase and three-phase load for voltage regulation under variation of wind speed and load. This system contains single-phase and three-phase boost DC-AC inverter connected separately with three-phase induction generator, capacitor bank and three-phase diode bridge rectifier. This proposed scheme is used for island-mode applications where the grid connection is not feasible. This Boost inverter provides boosted AC output voltage from input DC voltage. This control scheme achieves robust, accurate, fast and highly immune to input voltage and output load variations.

Index Terms— Boost Converter, Island-mode, SEIG, Wind Energy. Wind Turbine.

1 Introduction

IN recent years there is an increase in demand for non-renewable energies like coal, crude oil, etc. Nowadays people are well aware for using renewable energies like solar, wind power and bio-mass because of their environment friendly nature. Wind turbine technology has become essential to adopt a low cost generating system, which is used to produce electricity in the remote areas where the grid connection is not available. This system shows a single-phase and three-phase boost inverter connected separately with the three-phase SEIG supplies electricity for both single-phase and three-phase applications.

The induction generator is considered as an alternative choice to the synchronous generators because of their lower cost, simple in maintenance and ruggedness. This generator has an ability to generate power at varying speed in various modes such as self-excited stand-alone or isolated mode. This proposed system has been simulated and verified using MATLAB/Simulink.

2 Boost DC-AC Inverter

Normally for isolated wind energy supplies the first stage of the converters used in electrical generation of wind energy conversion systems would be a phase controlled rectifiers to get DC constant voltage from variable output AC voltage from SEIG. The second stage must be an AC for stand-alone systems, so inverters are needed after the rectifiers. In this work single-phase and three-phase Boost DC-AC inverters are used to obtain single-phase and three-phase AC output which is greater than the given input DC voltage.

2.1 Single-phase Boost Inverter

The Single-phase DC-AC Boost inverter consists of individual two Boost converters. These converters are driven by two 180 degree DC-biased phase-shifted sinusoidal references whose output is an AC voltage with a peak value that can be greater than the DC input voltage. It uses double loop regulation scheme. It consists of two control loops an outer output voltage control loop and inner inductance current control loop. Both are based on averaged continuous-time model topology of the boost. It makes the system controlled to be robust to input DC voltage and AC output current variations, which represents a very effective additional advantage.

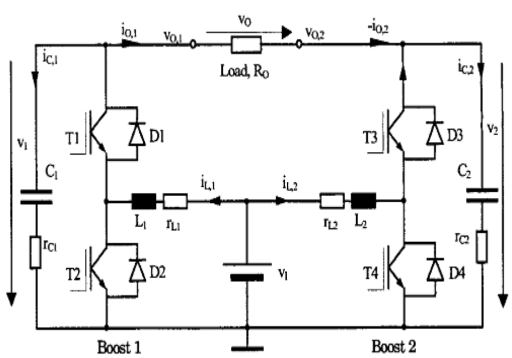

Fig.1 Single-phase Boost inverter

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This inverter can be used in AC driver systems design and uninterruptible power supply (UPS) whenever an AC voltage larger than the DC input voltage is needed, depending on the duty cycle instantaneous value. So there is no need of a second conversion stage of power. The classical VSI does not have this property it generates AC output always lower than the input DC voltage. So it is very efficient for single-phase applications.

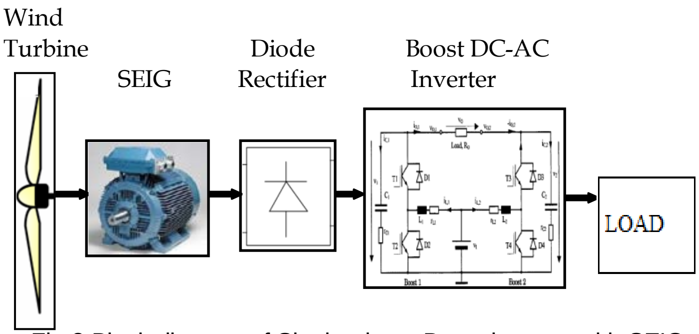

Fig.2 Block diagram of Single-phase Boost inverter with SEIG

(i) Control of DC-AC Boost Inverter

The Boost inverter output voltage control is achieved by the both boosts control strategy and operating them with proper voltage references. The following sinusoidal DC-biased references are used to driven the Boosts (1-4):

if sin (ωt)<0

$$v_{1,ref} = V_{DC} + 1/\sqrt{2}V\sin(\omega t) \quad (1)$$

$$v_{2,ref} = V_{DC} - 1/\sqrt{2}V\sin(\omega t) \quad (2)$$

if sin(ωt)>0

$$v_{1,ref} = v_2 + v_{O,ref} = v_2 + \sqrt{2}V\sin(\omega t) \quad (3)$$

$$v_{2,ref} = v_1 - v_{O,ref} = v_1 - \sqrt{2}V\sin(\omega t) \quad (4)$$

where V is the rms value of the AC output voltage and V_{DC} is the DC-biased reference value.

This control strategy improves the response of the system in case of perturbations. Dynamic properties of the Boost converter depend on the duty cycle's actual value, which is changed according to the output voltage variations. The boost has to compensate the voltage output variations that can be selected from the sign of the output sinusoidal voltage.

(ii) Double loop control strategy

As mentioned earlier, each Boost converter is controlled by Boost averaged continuous-time model, which is shown in the following equations:

$$i_C + i_O = (1-d)i_L \quad (5)$$

$$v_I - v_L = (1-d)v_O \quad (6)$$

where v_o is the output capacitor voltage, v_I is the voltage input, v_L is the voltage of the inductor, i_o is the current output, i_C is the capacitor current, i_L is the inductor current and d is the duty cycle time-averaged value.

Transfer functions for the inductor and capacitor are

$$I_L(s)/V_L(s) = 1/(r_L + L_s) \quad (7)$$

$$V_o(s)/I_c(s) = (1 + r_c C_s)/C_s \quad (8)$$

where L, C, r_L and r_c are the values for the inductance, capacitance and internal resistance of L and C.

2.2 Three-phase Boost DC-AC Inverter

The single-stage three-phase inverter has three DC-DC bi-directional boost converters connected with a point (X) as shown in Fig.3. These boost converters produce a sine wave DC biased output. The advantage of this converter is the use of only six IGBTs with small passive elements to generate an AC output voltage larger than the input DC voltage. The AC component of each boost converter is 120 degrees out of phase with the other.

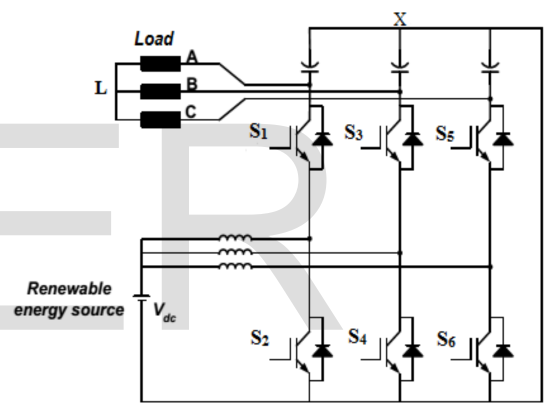

Fig.3 Three-Phase Boost Inverter

Boost inverter each phase consists of two IGBTs, one capacitor and one inductor. There is a common point (X) for capacitors connected with DC supply negative terminal. The inverter terminals are connected to the load creates another point (L) that is not to be connected with capacitors common point (X).

Reference voltage of each capacitor has two components:

i. DC component (K_{dc}): It is equal for all phases and it must be more than the summation of AC component peak (K_{ac}) and input DC voltage (V_{dc}).

ii. AC component: Each converter AC component having equal magnitude but 120 degrees out of phase to the other converters.

The capacitors connected with the load terminals to prevent DC component from appearing across the load. The equation (9-10) shows the line-voltages and phase-voltages which can supply any three-phase load.

$$v_{AO}(t) = V_{DCo} + V_{aco}\sin(\omega t)$$

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$$v_{BO}(t) = V_{DCo} + V_{aco}\sin(\omega t - 2\pi/3) \quad (9)$$
$$v_{CO}(t) = V_{DCo} + V_{aco}\sin\left(\omega t + 2\pi/3\right)$$

$$v_{AB}(t) = v_{AO}(t) - v_{BO}(t) = \sqrt{3}V_{aco}\sin\left(\omega t + \pi/6\right)$$
$$v_{BC}(t) = v_{BO}(t) - v_{CO}(t) = \sqrt{3}V_{aco}\sin\left(\omega t - \pi/2\right) \quad (10)$$
$$v_{CA}(t) = v_{CO}(t) - v_{AO}(t) = \sqrt{3}V_{aco}\sin\left(\omega t + 5\pi/6\right)$$

$$v_{AO}/v_{DCi} = 1/(1 - D_{Aref}(t)) \quad (11)$$
$$D_{Aref}(t) = 1 - (v_{DCi}/v_{AOref}(t)) \quad (12)$$

The voltage output relation for phase-A for the continuous conduction mode can obtain from (11), where D is the DC-DC converter duty cycle. To get phase-A V_{AOref} across the capacitor, the reference duty cycle instantaneous value for this phase can be obtained from (12).
The Fig.4 shows the pattern of PWM pulses generation, where f_s is frequency of the inverter.

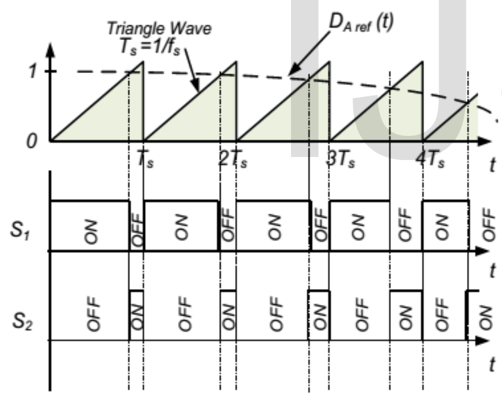

Fig.4 PWM Generation

3 SEIG WITH BOOST INVERTER

The proposed system consists of three-phase SEIG connected with single-phase or three-phase boost inverter for single-phase or three-phase stand-alone applications. The three-phase squirrel cage induction machine or wound rotor could work as induction generator either connected to AC power utility distribution or operated in self-excitation mode with an additional capacitor bank in the stator terminal. The three-phase induction machine starts to operate in the generation mode with the fixed frequency of the utility AC power source, when the rotor speed is above synchronous speed. The range of the shaft rotor speed is limited by slip of the induction machine. For high slip range, copper winding losses also increases as the current increase. The main disadvantage when using the induction machine is that the capacitor bank for the reactive power consumption.
When connected with grid the machine will get reactive power from the grid. Since it is a stand-alone system excitation capacitor must be connected in parallel with its stator terminal and driven by prime mover as renewable wind energy. SEIG determines its own terminal voltage generation and its frequency output which depend on the excitation capacitance, machine parameters, passive electrical load parameter constants and speed of the prime mover.
SEIG is connected to boost inverter with capacitor bank and diode bridge rectifier. Wind turbine is used as a prime mover to give constant speed for the machine input. Thus the machine starts to rotate above constant speed that is synchronous speed as generator. From the induction machine the AC power is generated by exciting the reactive power from the capacitor bank. Variable AC power from the SEIG is rectified by three-phase diode-bridge into fixed DC then this DC is used as a source for boost inverter. Boost inverter simply produces the AC output which is greater than the DC input. So the transformer is not a needed one.

4 RESULTS

A. PARAMETERS USED IN MATLAB/SIMULINK

The parameters used for single-phase inverter, three-phase inverter and induction machine in MATLAB/Simulink model are shown in the following.

TABLE 1. Parameters of Single-phase Boost Inverter

Inductor	150 (µH)
Capacitor	30 (µF)
Resistive output load	25 (Ω)
Switching Frequency	20 (kHz)
Supply Voltage	120 (V)
AC output frequency	50 (Hz)

TABLE 2. Parameters of Three-phase Boost Inverter

Vdc	100 (V)
Inverter capacitance, inductance	1 (mH), 40 (µF)
Switching frequency	3 (kHz)
VAOref	200+100 sin(314t) (V)
AC load	5 (Ω) per phase

TABLE 3. Induction Machine Parameters

Nominal Power	3.7 (kW)
Line-Line Voltage	230 (Vrms)
Frequency	50 (Hz)
Stator resistance and Inductance	Rs=1.3(Ω),Lls=0.00827 (H)
Rotor resistance and Inductance	Rr=1.75(Ω),Llr=0.00827(H)
Pole Pairs	P=2
Excitation Capacitance	C=300e-6 (F)

B. Simulation Results

The results for MATLAB/Simulink model of the proposed system is shown in the following

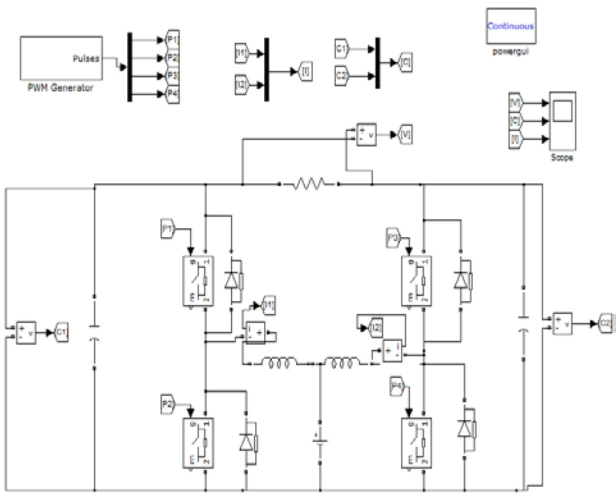

Fig.5 Simulink model Single-phase inverter

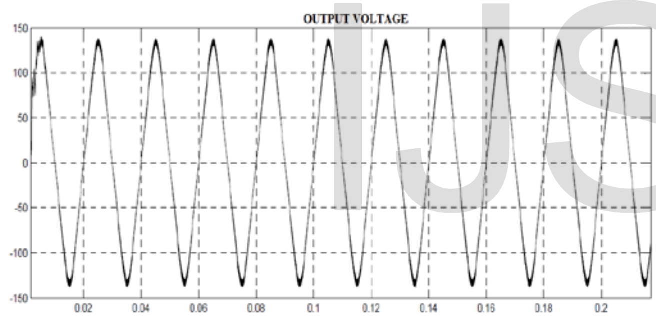

Fig.6 Simulated Output voltage waveform of Single-phase inverter

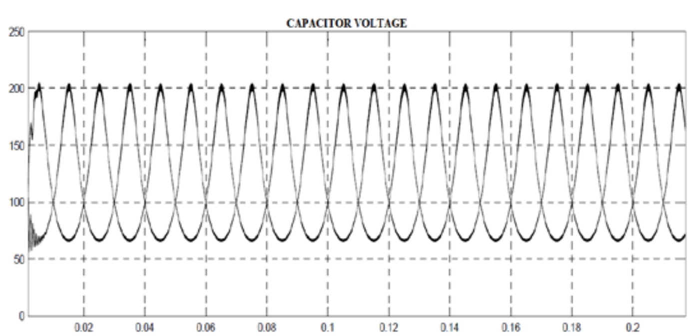

Fig.7 Simulated Output Capacitor Voltage waveform of Single-phase Inverter

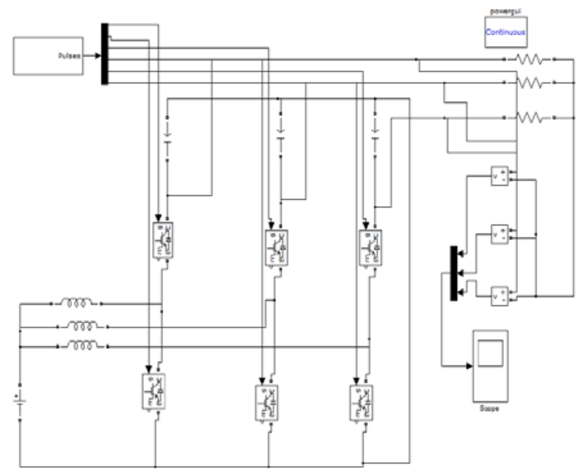

Fig.8 Simulink model Three-phase inverter

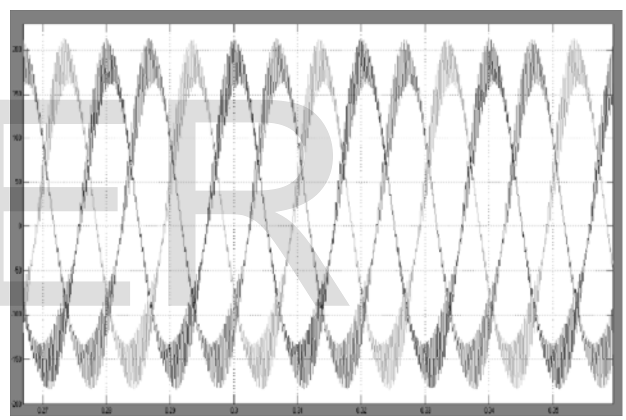

Fig.9 Simulated Output voltage waveform of Three-phase inverter

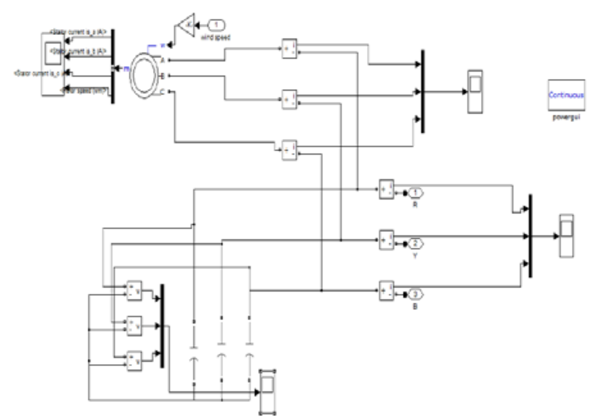

Fig.10 Simulink model of SEIG

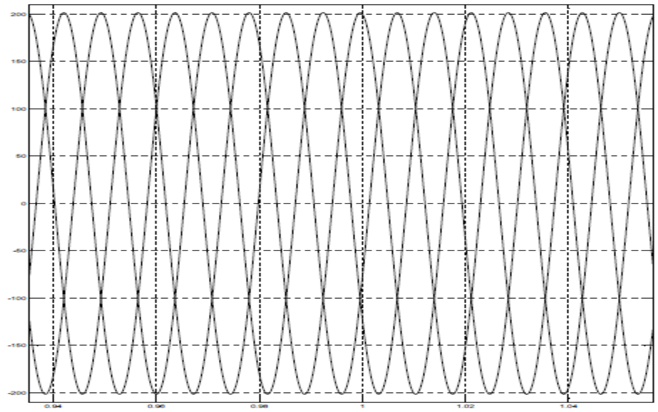

Fig.11 Simulated Output voltage waveform of SEIG

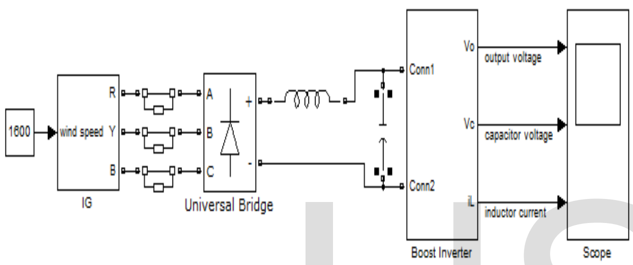

Fig.12 Simulink model of Single-phase inverter with SEIG

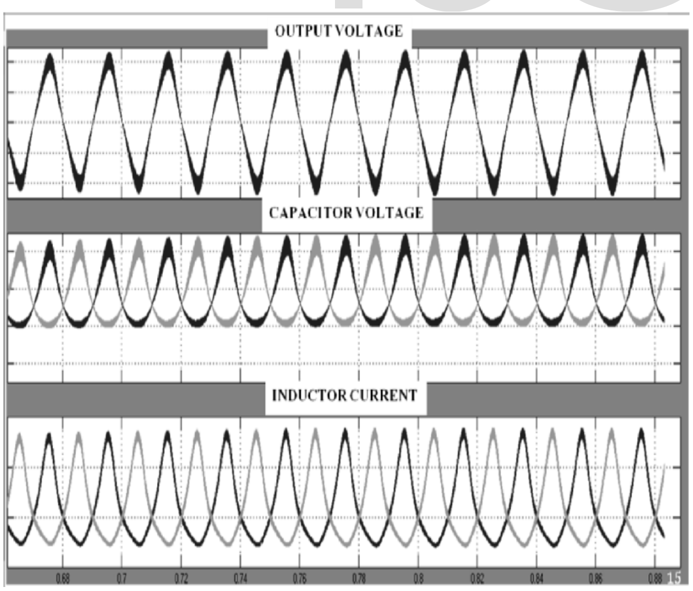

Fig.13 Simulated Output waveform of Single-phase inverter connected with SEIG

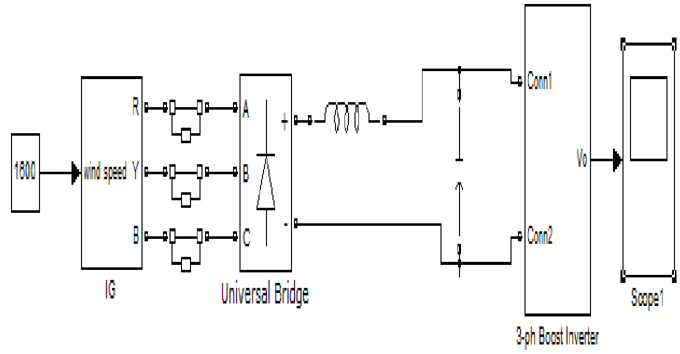

Fig.14 Simulink model of Three-phase inverter with SEIG

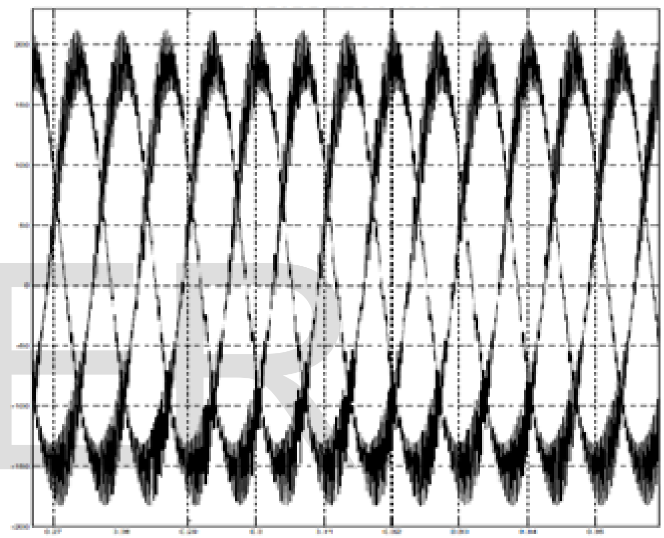

Fig.15 Simulated Output waveform of Three-phase inverter with SEIG

5 Conclusion

This paper deals with the single-phase and three-phase boost inverter operated by wind driven SEIG suitable for supplying power to the stand-alone application. The output AC power produced is greater than the input DC voltage. It produces sinusoidal AC supply by changing the instantaneous duty cycle. Simulation results show that the proposed boost inverter control strategy is accurate, robust and highly insensitive to input voltage and output load variation.

References

[1] G. K. Singh, “Self-excited Induction Generator Research - a Survey”, Electric Power Systems Research, Vol. 69, no. 2-3, pp. 107-114, May 2004.

[2] A. Abbas Elserougi, "Studying the effect of over-modulation on the output voltage of three-phase single-stage grid-connected boost inverter", Alexandria Engineering Journal (2013) Vol.52, 347–358.

[3] D. Seyoum, C. Grantham, "Analysis of an isolated self-excited induction generator driven by a variable speed prime mover", The University of New South Wales.

[4] S. Heier, "Grid Integration of Wind Energy Conversion Systems", John Wiley & Sons, 1st Edition, West Sussex, England, 1998.

[5] E.Muljadi and C.P.Butterfield, "Investigation of Self-Excited Induction Generators for Wind Turbine Applications" IEEE Industry Applications Society Annual Meeting, Phoenix, Arizona (1999).

[6] Bhim Singh,"Stand-Alone Single-Phase Power Generation Employing a Three-Phase Isolated Asynchronous Generator", IEEE transactions on industry applications, Vol. 48, no. 6, November/December 2012.

[7] N. Mohan, T. Undeland, W. Robbins, "Power Electronics: converters, applications and design", 1st Ed., New York: John Wiley & Sons, 1995.

[8] R. Caceres and I. Barbi, "A Boost DC-AC converter: analysis, design and experimentation", IEEE Transactions on Power Electronics, Vol. 14, n. 1, January 1999.

[9] Charles I. Odeh, "A Three-Phase Boost DC-AC Converter" Nigerian Journal of Technology Vol. 30, No. 1 (2011).

[10] Carlo Cecati , Antonio Dell'Aquila, and Marco Liserre, "A Novel Three-Phase Single-Stage Distributed Power Inverter", IEEE Transactions on Power Electronics, Vol. 19 , No. 5 ,pp.1226-1233 September 2004.

[11] Neris A.S, Vovos N.A, Giannakopoulos G.B., "A variable speed wind energy conversion scheme for connection to weak AC systems", IEEE Trans Energy Conversion 1999 Vol.14 (1):122–7.

[12] A.K.Aljabri and A.I.Alolah, "Capacitor Requirement for Isolated Self-Excited Induction Generator", IEE Proceedings, part B, Vol.137, No.3,pp.154-159, May, 1990.

[13] B.Koushki, H. Khalilinia, J. Ghaisari, and M.S. Nejad, "A New Three-Phase Boost Inverter: Topology and Controller", IEEE 2008, pp.757-760.

[14] T.F. Chan, "Self regulated induction generators driven by regulated and unregulated turbines", IEEE Trans. Energy Conversion Vol.11 (2) (1996) 338–343.

[15] R. Bonert, S. Rajakaruna, "Self excited generator with excellent voltage and frequency control", IEE Proc. Generation, Transmition, Distribution Vol.145 (1) (1998) 33–39.

[16] R. C. Bansal, "Three-Phase Self-Excited Induction Generators: An Overview", IEEE Transactions on Energy Conversion, Vol. 20, no. 2, pp. 292-299, June 2005.

[17] H. S. Timorabadi, "Voltage Source Inverter for Voltage and Frequency Control of a Stand-alone Self-excited Induction Generator", in Canadian Conference on Electrical and Computer Engineering, Ottawa, May 2006.