International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.2, Issue.2, Mar-Apr 2012 pp-398-402 ISSN: 2249-6645

A Novel Voltage and Frequency Control Scheme for a Wind Turbine Driven Isolated Asynchronous Generator

[1]K. Premalatha, [2]S. Vasantha rathna, [3]R.K.Isvarya
[1,3]Department of EEE, Kumaraguru College of Technology, Coimbatore.
[2]Coimbatore Institute of Technology, Coimbatore.

Abstract
This paper deals with the control of voltage and frequency of a wind turbine driven isolated asynchronous generator. The controller consists of an IGBT (Insulated Gate Bipolar Junction Transistor) based 3-leg voltage source converter and a battery at its DC link. The controller is having bidirectional flow capability of active and reactive powers by which it controls the system voltage and frequency with varying wind speed and load conditions. Inverted sine carrier pulse width modulation switching strategy is used in VSC to enhance the fundamental output voltage and to minimize the switching losses. The proposed system is simulated in MATLAB using Simulink and PSB (Power System Block-set) toolboxes.

Keywords: Isolated asynchronous generator**,** wind energy conservation system, voltage and frequency controller, Inverted sine carrier PWM.

1. Introduction
There has been an exponential increase in the energy demand during the last few decades, which has accelerated the depletion of the world fossil fuels. Environmental concerns and international policies are supporting new interests and developments of small scale renewable power generation [1, 2].As a renewable energy source the wind power is one of the prominent energy sources and various types of electrical generators such as synchronous generator, asynchronous generators in squirrel cage and slip ring rotor construction [3-6], reluctance generators [7] have been reported in standalone applications. It is reported in the literature that in small scale wind power generation, a capacitor excited squirrel cage asynchronous generator (CEAG) which is also known as isolated asynchronous generator (IAG) is a most suitable candidate where the grid connection is not accessible because of its low cost, robustness, less maintenance and high power density (W/kg) [3, 4]. However the magnitude and frequency of the generated voltage depends upon the wind speed, the amount of excitation and the load.

In this paper, a voltage and frequency (VF) control scheme for an isolated capacitor excited asynchronous generator driven by wind turbine with Inverted sine carrier PWM technique in VSC is proposed to enhance the fundamental output voltage [8].

2. Principle of operation

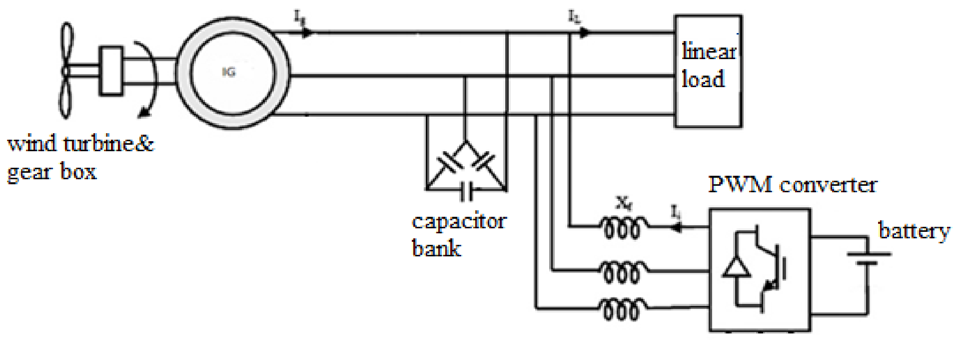

Fig 1 Schematic diagram of wind turbine driven isolated asynchronous generator feeding linear load

Fig. 1 shows a schematic diagram of wind turbine-driven asynchronous generator along with VSC. The delta connected capacitor bank is used to generate the rated voltage at no load while additional demand of the reactive power is met by the controller. The proposed controller is having bidirectional flow capability of active and reactive powers and it controls the voltage by controlling the reactive power while the frequency is controlled by the active power control.

The basic principle of operation is that at high wind speed the generated power is also high and accordingly for frequency regulation the total generated power should be consumed otherwise difference of mechanical and electrical power is stored in the revolving components of the generator and by which the speed of the generator and in turn it increases the output frequency. Therefore this additional generated power is used to charge the battery to avoid the frequency variation as stated above. During deficiency of the generated power, when there is an insufficient wind power to meet the consumer demand an additional required active power is supplied by the battery to the consumer loads. In this manner, the battery energy storage system based voltage and frequency controller also provides load leveling and frequency regulation.

3. Modeling of the proposed system

A. Modeling of the wind turbine

The mechanical system consists of a wind turbine and the gear ratio is selected such that the IAG generates the rated voltage at rated frequency and a rated wind speed of 12m/s to extract the maximum power from the wind turbine. The aerodynamic power generated by the wind turbine can be expressed as

$$P = 0.5\rho A C_p v_w^3 \quad (1)$$

where ρ is the specific density of air,
A is the swept area of the blades,
v_w is the wind speed and
C_p is the performance co-efficient.
Turbine characteristics is given by

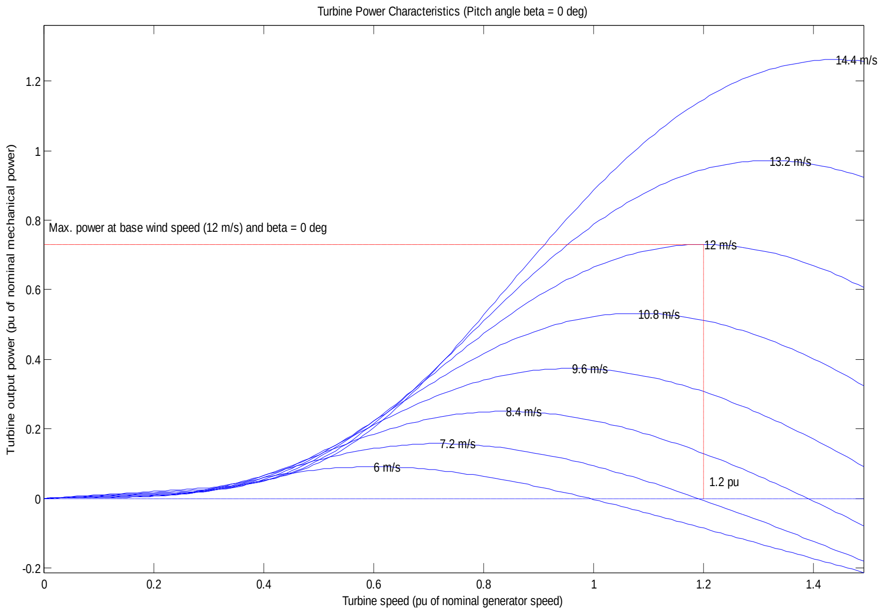

Fig 2 Turbine characteristics

B. Modeling of Asynchronous generator

The electrical system consists of an asynchronous generator with the excitation capacitor. The Asynchronous generator model is established using rotating (d, q) field reference. Stator and rotor voltage equations are given by

$$V_{sd} = R_s i_{sd} + \frac{d}{dt}\lambda_{sd} - \omega_d \lambda_{sq} \quad (2)$$

$$V_{sq} = R_s i_{sq} + \frac{d}{dt}\lambda_{sq} - \omega_d \lambda_{sd} \quad (3)$$

$$V_{rd} = R_r i_{rd} + \frac{d}{dt}\lambda_{rd} - \omega_{dA} \lambda_{rq} \quad (4)$$

$$V_{rq} = R_r i_{rq} + \frac{d}{dt}\lambda_{rq} - \omega_{dA} \lambda_{rd} \quad (5)$$

Where V_{sd} , V_{sq} , V_{rd} , V_{rq} are the direct and quadrature axes stator and rotor voltage.
R_s , R_r are the stator and rotor resistance,
i_{sd} , i_{sq} , i_{rd} , i_{rq} are the direct and quadrature axes stator and rotor current,
λ_{sd} , λ_{sq} , λ_{rd} , λ_{rq} are the flux linkages and
ω_d is the angular velocity.
Electromagnetic torque is expressed as

$$T = {}^{P}\!/_{2} L_m \left(i_{sq} i_{rd} - i_{sd} i_{rq}\right) \quad (6)$$

where L_m is the mutual inductance.

C. Modeling of controller

Voltage-source converter (VSC) is connected to a battery of 1500VAh at its dc link and provides a switched voltage waveform.

Line to line voltage is given by

$v_{ab} = v_{an} - v_{bn}$ (7)

$v_{bc} = v_{bn} - v_{cn}$ (8)

$v_{ca} = v_{cn} - v_{an}$ (9)

Phase voltage is given by

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = v_{dc} \begin{bmatrix} 2/3 & -1/3 & -1/3 \\ -1/3 & 2/3 & -1/3 \\ -1/3 & -1/3 & 2/3 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (10)$$

Where a, b, c are switching variable vector

4. Control strategy

The control strategy of the proposed voltage and frequency controller is based on the generation of reference source currents. Three-phase reference source currents are having two components such as active and reactive components. One is in phase or active power component while other one is in quadrature or reactive power component for regulating the frequency and voltage respectively.

A. In Phase Component of Reference Source Currents

For generating the active power component of reference source current, the output of the frequency Proportional-Integral (PI) controller is compared with the rated generator current (I_G) and the difference in these two currents is considered as amplitude of in-phase component of reference current. The multiplication of amplitude of in-phase component of reference current with in-phase unit amplitude templates (u_a, u_b and u_c) yields the in-phase component of reference source currents. These templates (u_a, u_b and u_c) are three-phase sinusoidal functions, which are derived by dividing the AC voltages v_a , v_b and v_c by their amplitude V_t.

The rated current of the generator is calculated as

$$I_G = \sqrt{2}\,(P_{rated})/(\sqrt{3}V_{rated}) \quad (11)$$

Where P_{rated} and V_{rated} are rated power and rated line voltage of the asynchronous generator.

The instantaneous line voltage at the asynchronous generator terminals (v_a , v_b and v_c) amplitude is computed as

$$V_t = \{(2/3)\,(v_a^2 + v_b^2 + v_c^2)\}^{1/2} \quad (12)$$

The unity amplitude templates are having instantaneous value in phase with instantaneous voltage (v_a , v_b and v_c) which are derived as

$$u_a = v_a/V_t;\ u_b = v_b/V_t;\ u_c = v_c/V_t \quad (13)$$

B. Quadrature Component of Reference Source Currents

To generate the quadrature component of reference source current, another set of sinusoidal quadrature quantity amplitude unity template (z_a , z_b and z_c) is obtained from in-phase unit templates (u_a, u_b and u_c). The multiplication of these components with output of AC voltage PI controller gives the quadrature or reactive power component of reference source current.

z_a , z_b and z_c are another set of unit templates having a phase shift of 90º leading with the corresponding unit templates u_a, u_b and u_c which are computed as follows

$$\begin{bmatrix} z_a \\ z_b \\ z_c \end{bmatrix} = \begin{bmatrix} 0 & -1/\sqrt{3} & 1/\sqrt{3} \\ \sqrt{3}/2 & \sqrt{3}/2 & -\sqrt{3}/2 \\ -\sqrt{3}/2 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \quad (14)$$

C. Reference Source Currents

Total reference source currents are the sum of in-phase component and quadrature components of the reference source currents as

$i^*_{sa} = i^*_{sad} + i^*_{saq}$ (15)

$i^*_{sb} = i^*_{sbd} + i^*_{sbq}$ (16)

$i^*_{sc} = i^*_{scd} + i^*_{scq}$ (17)

D.PWM Current Controller

Reference source currents (i^*_{sa} , i^*_{sb} and i^*_{sc}) are compared with sensed source currents (i_{sa} , i_{sb} and i_{sc}). The current errors are computed as

$i_{saerr} = i^*_{sa} - i_{sa}$ (18)

$i_{sberr} = i^*_{sb} - i_{sb}$ (19)

$i_{scerr} = i^*_{sc} - i_{sc}$ (20)

These current errors are amplified and the amplified signals are compared with fixed frequency (5 KHz) inverted sine carrier wave to generate gating signals for IGBTs of VSC of the controller.

E. Inverted sine carrier PWM

The control scheme uses an inverted sine (high frequency) carrier that helps to maximize the output voltage for a given modulation index.

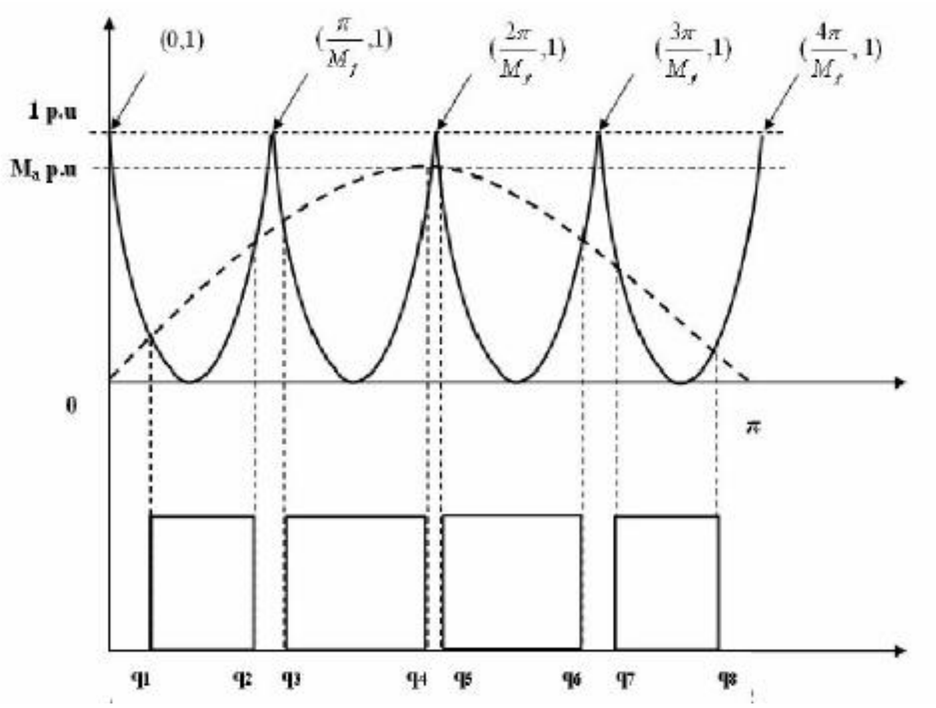

Fig 3 Inverted sine carrier PWM pulse pattern

For the ISCPWM pulse pattern, the switching angles may be computed as the same way as SPWM scheme. The equations of inverted sine wave are given by (21) and (22) for its odd and even cycles respectively. The switching angles for ISCPWM scheme can be obtained from (23) and (24).

$$y = 1 - \sin[M_f x - \frac{\pi}{2}(i-1)] \quad (21)$$

$$y = 1 - \sin[M_f x - \frac{\pi}{2}(i-2)] \quad (22)$$

$$M_a sinq_i + \sin\left[M_f q_i - \frac{\pi}{2}(i-1)\right] = 1 \quad \text{for i=1,3,5….} \quad (23)$$

$$M_a sinq_i + \sin\left[M_f q_i - \frac{\pi}{2}(i-2)\right] = 1 \quad \text{for i=2,4,6….} \quad (24)$$

Where M_a - Modulation index
M_f - Frequency ratio
q_i - Intersection between the inverted sine waveform

5. Simulation Results

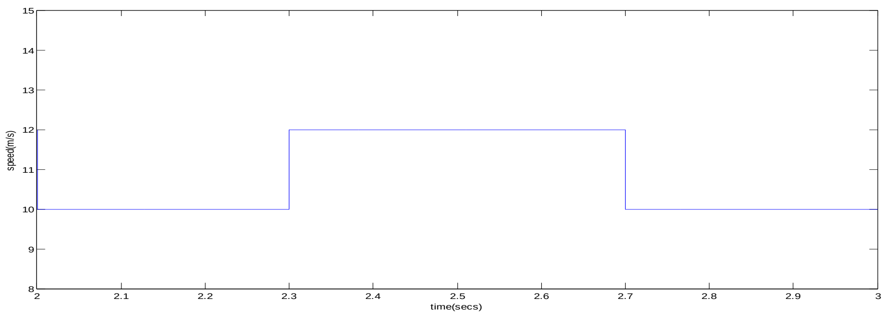

Fig4 Wind speed variation

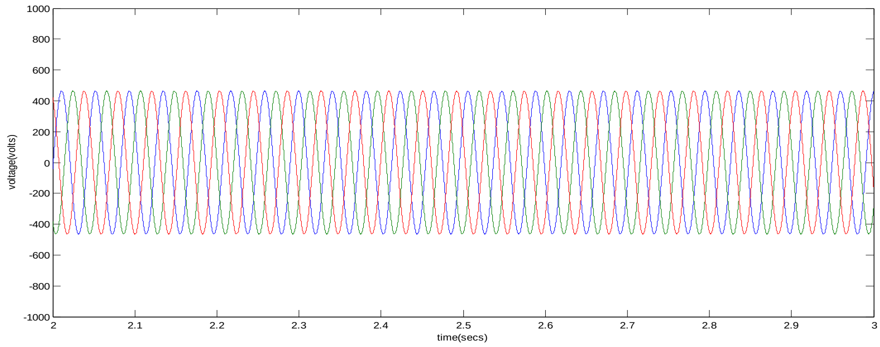

Fig 5 Load voltage waveform

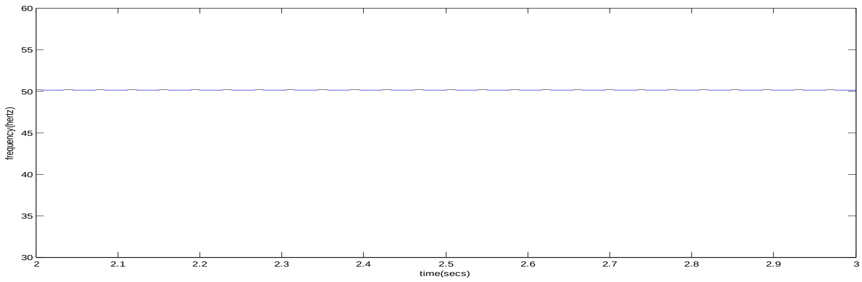

Fig 6 Frequency waveform

A 7.5KW, 415V, 50Hz asynchronous machine is used as an IAG. Fig. 4, 5 and 6 show the performance of the controller for varying wind speeds at constant consumer load. At 2 s, the wind speed is 10m/s and the consumer load (5kW) is applied at the generator terminals. It is observed that due to insufficient power generation at low wind speed an additional load power is supplied by the battery to regulate the frequency. At 2.3 s as the wind speed is increased from 10m/s to 12m/s, output power of the generator is increased so that at particular load now the power supplied by the battery is reduced because now the load demand is met by the generator itself. At 2.7s, the wind speed is again reduced and the additional power is supplied by battery.

6. Conclusion

The performance of the proposed Inverted sine carrier PWM based VSC for isolated asynchronous generator driven by wind turbine is demonstrated. The proposed controller has been found suitable with simple control strategy to regulate the voltage and frequency under varying wind speeds. Also it presents a novel PWM scheme (ISC PWM) for controlling the output of an inverter with improved fundamental component values and to reduce the switching losses of the converter.

References:

[1] Bhim Singh and Gaurav Kumar Kasal, “Analysis and Design of Voltage and Frequency Controllers in a Constant Power Applications”, in Proc of IEEE International Conf on Power Electronics Drives and Energy Systems (PEDES’06),New Delhi, India, Dec 12-15, 2006.

[2] Siegfried Heier, "Grid Integration of Wind Energy Conversion Systems", IEEE Trans. on Energy Conversion, Vol. 19, No. 1, March 2004, pp.136-143.

[3] T.F. Chan and L.L Lai, “A novel excitation scheme for a stand-alone three-phase induction generator supplying single-phase loads”, IEEE Trans. on Energy Conversion, Vol. 19, No. 1, March 2004, pp.136-143

[4] T.F. Chan, and L.L. Lai, “Single-phase operation of a three phase induction generator using a novel current-injection method”, IEEE Trans. on Energy Conversion, Vol. 20, No.2, June 2005, pp. 308-315.

[5] M Ermis, H. B Ertan, M Demirekler, “Various induction generator schemes for wind electricity- generation”, Electric Power Systems Research, Vol. 23, No.1, Jan1992, pp 71-83.

[6] T.F. Chan, K.A. Nigim, L.L. Lai, “Voltage and frequency control of self-excited slip-ring induction generators”, IEEE Trans. on Energy Conv, Vol. 19 1No.1, Mar 2004, pp 81-87.

[7] Y.S. Wang, L Wang, “Minimum Loading resistance and its effects on performance of an isolated self-excited reluctance generator”, IEE Proc.Gen. Trans. and Dist. Vol. 148, No.3, May 2001, pp 251-256.

[8] R.Nandha kumar and Jeevananthan, “ Inverted sine carrier pulse width modulation for fundamental fortification in DC-AC converters”.

Author Biography

K. Premalatha received B.E. in Electrical and Electronics Engineering from Madras University, Tamilnadu, India, in 1997, M. Tech. in Power Electronics and Drives from SASTRA University, Tamilnadu, India, in 2002 and pursuing Ph.D. in Electrical Engineering at Anna university, Coimbatore, Tamilnadu, India. Currently she is Asso. Professor in Electrical & Electronics Engineering at Kumaraguru College of Technology, Tamilnadu, India. She is Life Member in Systems Society of India and ISTE. Her research interest includes Power Quality, Power Electronics and Wind Energy Conversation systems.

S. Vasantharathna received B.E. in Electrical Engineering from Bharathiar University, Tamilnadu, India, 1989, M. E. in Power Systems from Bharathiar University, Tamilnadu India, 1994 and Ph.D. in Electrical Engineering from Bharathiar University University, Tamilnadu, India, 2006. Currently she is Asso. Professor in Electrical & Electronics Engineering at Coimbatore Institute of Technology, Tamilnadu, India. She is Member of IEEE, and Life Member of ISTE. Her research interest includes Operating systems, Power and Energy Systems and Signal Processing.

R. K. ISVARYA received bachelor degree from Sona College Of Technology, Salem in Electrical and Electronics Engineering in 2010. She is currently doing her master degree in Power Electronics and Drives at Kumaraguru College Of Technology, Coimbatore.