ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

Isolated Wind Power Generation Employing PMSG with V-f Controller

R.Srinivas Yadav[1], Y.Manju Sree[2]

PG Student [PEES], Dept. of EEE SR Engineering College Warangal, Telangana, India[1]

Assistant Professor, Dept. of EEE SR Engineering College Warangal, Telangana, India[2]

ABSTRACT: In this paper a solid state voltage and frequency controller is proposed for distributed generation based isolated wind energy conversion system employing permanent magnet synchronous generator with Battery energy storage system. The pmsg is high efficiency power generator driven by a wind turbine with constant gear ratio and the V-f controller is a bidirectional power flow of both active and reactive power. The V-f controller is a voltage source converter which consists of IGBTs and a BESS at its dc link. The V-f controller keeps the power frequency and voltage within the reference level by controlling the active power and reactive power and also it functions as a harmonic compensator and a load balancer during the load disturbances and wind speed variations. The neutral wire is obtained in the three phase four wire distribution systems from zig-zag transformer. The performance of the proposed V-f controller is simulated using MATLAB software with its Simulink and Power System Block set (PSB) toolboxes.

KEYWORDS: wind energy conversion system, permanent magnet synchronous generator, voltage and frequency controller, VSC, zig-zag transformer, BESS

I. INTRODUCTION

The Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies. Wind energy conversion technology is one of the most important technologies of other renewable energy source technologies because of modern wind turbines providing higher efficiency. The asynchronous generators such as self excited induction generators (SEIG) [4-7] and synchronous generators such as diesel generator set and permanent magnet synchronous generator[6-11] are used in wind power generation system and such distributed generation systems require energy storage systems such as batteries super capacitor magnetic energy storage systems to stabilize the frequency and voltage.

In this paper, a voltage and frequency controller (VF) is proposed for a standalone wind energy conversion system (WECS) employing PMSG. The three-phase four-wire distribution system is connected to the PMSG (permanent magnet synchronous generator) system and the voltage and frequency are controlled using a controller consisting of insulated gate bipolar transistors (lGBTs) based voltage source converter (VSC) with a Battery Energy Storage System at its dc link. The controller having the bidirectional power flow of active power and reactive power and it eliminates the harmonics and it works as a load balancer during the load disturbances. In this WEC system permanent magnet synchronous generator is used for power generation. The high efficiency wind turbine with a gear system is used as a prime mover to PMSG in this WEC system. The neutral wire is obtained from the zig-zag transformer for neutral current circulation in the three phase four wire distribution system [10].

II. SYSTEM CONFIGURATION

Fig.1 shows the proposed schematic diagram of an isolated wind energy conversion system with V-f controller. A permanent magnet synchronous generator connected to a three phase four wire linear/nonlinear load and a wind turbine is used as a prime mover to pmsg. Gear box is used as a coupling element between the wind turbine and PMSG which has the constant speed ratio. The zig-zag transformer is used for neutral current circulation in three phase four wire load.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

The V-f controller compensates the reactive power for voltage regulation and injects/absorbs the active power for frequency regulation. The Battery Energy Storage System (BESS) stores the energy when the wind speed is increased or load decreased to stabilize the power frequency in the reference level. In the same way it supplies the power to load when the load demand is more than generation or the wind speed is decreased to stabilize the power Frequency. This may happen when the power frequency is below the reference value.

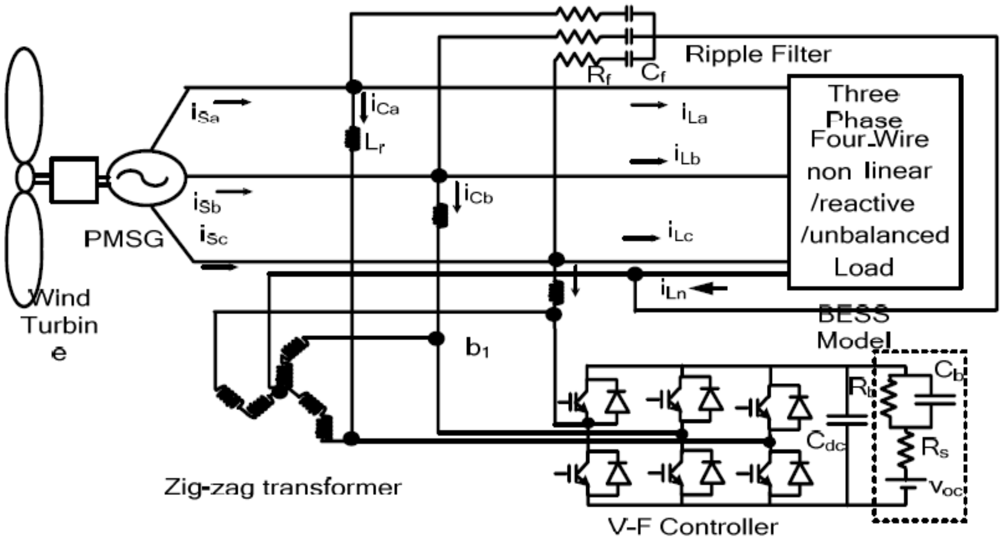

Fig.1 Circuit diagram of the proposed WECS.

III. CONTROL ALGORITHM FOR V-F CONTROLLER

As shown in fig.2, the control algorithm for V-f controller of proposed isolated wind energy conversion system is derived from estimated reference source currents. The load currents and terminal voltages are measured for estimation of reference source currents which are converted to d-q-o frame to a-b-c frame with help of synchronous reference frame theory which is as follows,

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (1)$$

Where $cos\theta$ *and* $sin\theta$ are obtained from three-phase PLL. The d-axis and q-axis currents contains the fundamental and harmonic components as,

$$i_{Ld} = i_{ddc} + i_{dac} \quad (2)$$

$$i_{Lq} = i_{qdc} + i_{qac} \quad (3)$$

A. Estimation of direct axis current of source currents

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

The direct axis current of source current is the difference of direct axis component of load current (i_{ddc}) and the output of frequency PI controller (i_{db}) . The frequency error defined as

$$f_{e(n)} = f^* - f_n \quad (4)$$

where, (f^*) is the reference and f_n is the measured frequency(f_n) of the terminal voltage at the n^{th} sampling instant. The frequency of AC terminal voltage is estimated using Phase-Locked loop (PLL). At n^{th} sampling instant the output of frequency PI controller is expressed as

$$i_{db\,(n)} = i_{db\,(n-1)} + K_{pd}\left(f_{e(n)} - f_{e(n-1)}\right) + K_{id}\, f_{e(n)} \quad (5)$$

where, K_{pd} *and* K_{id} are proportional and integral gains of the frequency PI controller. The active current to be drawn by voltage source converter is the output of frequency PI controller. The reference d-axis source current is therefore as,

$$i_d^* = i_{ddc} - i_{db} \quad (6)$$

B. Estimation of quadrature axis component of source currents

The ac voltage error is v_{se} at the n^{th} sampling instant is obtained from PI controller $v_{se\,(n)} = V_s^* - v_{s(n)}$ where V_s^* and $v_{s(n)}$ are the reference and measured voltage at terminals permanent magnet synchronous generator at n^{th} sampling instant. The amplitude of AC voltage (V_s) at PCC is calculated from the AC voltages (v_{sa}, v_{sb}, v_{sc}) as

$$V_s = \left(\frac{2}{3}\right)^{\frac{1}{2}} (v_{sa}^2 + v_{sb}^2 + v_{sc}^2)^{1/2} \quad (7)$$

The output of the PI controller ($i_{qr\,(n)}$) for maintaining constant ac terminal voltage at the n^{th} sampling instant which is considered as quadrature axis component of source current to be injected by VSC controller is expressed as

$$i_{qr\,(n)} = i_{qr\,(n-1)} + K_{pq}\left(v_{se\,(n)} - v_{se\,(n-1)}\right) + K_{iq}\, v_{te\,(n)} \quad (8)$$

where, K_{pq}, K_{iq} are the proportional and integral gains of the voltage PI controller. The reference source quadrature axis component is as

$$i_q^* = i_{qdc} + i_{qr} \quad (9)$$

Where, i_{qdc} is quadrature axis component of load current and i_{qr} is the output of voltage PI controller

C. Reference source currents

The reference source currents obtained by converting eq.(6) and (9) from d-q-o frame to a-b-c frame ($i_{Sa}^*, i_{Sb}^*, i_{Sc}^*$) by using Reverse Park's transformation the zero sequence current can be taken as zero before conversion from d-q-o to a-b-c.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

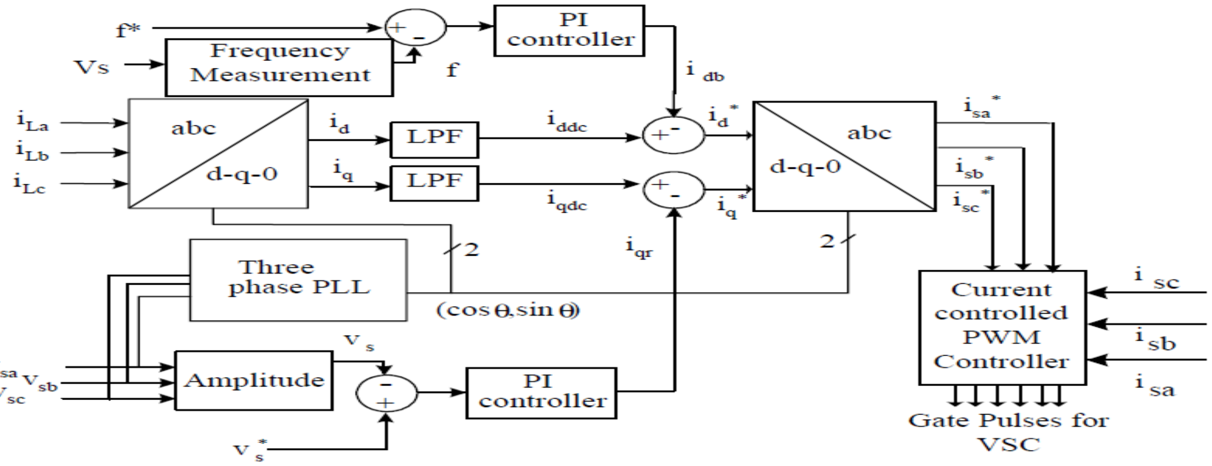

Fig.2 Block diagram of the control of the V-f controller.

D. Current controlled PWM generator

Reference source currents (i_{Sa}^*, i_{Sb}^*, i_{Sc}^*) are compared with sensed source currents (i_{Sa}, i_{Sb}, i_{Sc}) and current error in each phase amplified with proportional controller then compared with fixed frequency 10khz triangular carrier wave signals to generate the gating signals for each phase of voltage source converter

IV. MATLAB BASED MODELING

A. Modeling of the Wind turbine

The fraction of power extracted from the power in the wind by a practical wind turbine is usually given the symbol *Cp*, standing for the coefficient of performance. Using this notation and dropping the subscripts of Eq. 9 the actual mechanical power output can be written as

$$P_m = \frac{1}{2}\rho A C_p v^3 \qquad (10)$$

where, ρ is the specific density of air (m3/s), A is the swept area of the blades (M^2) and V is the wind speed (m/s). The power coefficient (*Cp*) is a function of tip speed ratio (λ), which is obtained as

$$\lambda = \omega R/v \qquad (11)$$

Where, R is the maximum radius of the rotating turbine in m, *ω* is the *mechanical angular velocity* of the turbine in rad/s, and *u* is the undisturbed wind speed in m/s. The angular velocity *ω* is determined from the *rotational speed n* (r/min) by the equation $\omega = 2\pi n/60$ rad/s. The polynomial relation between the power coefficient and the λ at a particular pitch angle for the turbine is represented as

$$C_p = C_1\left\{\left(\frac{C_2}{\lambda_i}\right) - C_3\beta - C_4\right\} e^{-\left(\frac{c5}{\lambda_i}\right)} + C_6\lambda \qquad (12)$$

Where, $1/\lambda_i = \left\{\frac{1}{\frac{1}{\lambda}+\beta_7}\right\} - \{1/(C_8+\beta^3)\}$ and β =0. (13)

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

B. Modeling of the Generator

In this investigation the permanent magnet synchronous generator is used for power generator which is based on a state space equations and it is available in the Matlab power system block set tool boxes

C. Modeling of the V-f controller

The voltage-frequency controller basically voltage source converter and it consists of IGBTs and a battery is connected at dc terminal of VSC and the battery model is Thevenin's equivalent circuit of BESS.

D. Modeling of the consumer loads

Three-phase 4-wire distribution linear and non linear loads are modeled using Resistances, Inductances, and Diodes etc which are available in power system block set toolboxes in the Matlab.

V. RESULTS AND DISCUSSION

The performance of the proposed controller has been demonstrated under different electrical and mechanical dynamic conditions. Fig 3-4 shows the performance of the controller of isolated WECs for supplying balanced/unbalanced, linear/non linear load at constant wind speed respectively. Fig 6-7 shows the harmonic spectra of load current, source current and PCC voltage. Fig 5 shows the performance of V-f controller under varying wind speed supplying balanced/unbalanced linear load.

A. Performance of V-f controller with balanced/unbalanced linear load with constant wind speed

The performance of the V-f controller for WECs with PMSG under linear lagging power factor balanced/unbalanced load condition is shown in fig.3. Initially the three-phase load is applied at time t=0s, the load is completely removed at time t=0.8s and at time t=1s single-phase load applied and at time t=1.1s two-phase load applied and then three-phase load is applied. The terminal voltage (Vs), source current (Is), load current (IL), controller current (IC), dc bus voltage (Vdc), system frequency (f), load neutral current (Iln), wind speed, battery power (Pb), load power (Pl), and wind power (Pw) are depicted in fig.3. The system frequency maintained within the permissible value, PCC voltage maintained constant and source currents maintained at constant value under all load disturbances.

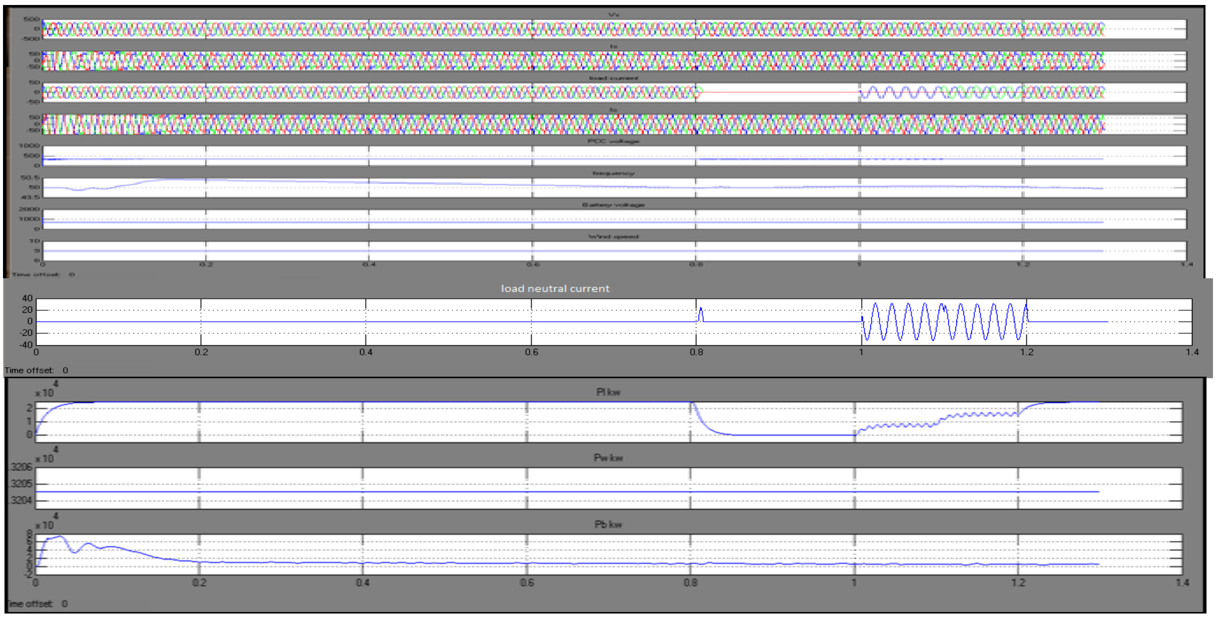

Fig. 3 Dynamic performance of V-f controller with balanced/unbalanced linear load with fixed wind speed

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

B. Performance of V-f controller with nonlinear balanced/unbalanced load of WECs with PMSG at constant wind speed

The dynamic performance of V-f controller of WECs with PMSG under nonlinear balanced/unbalanced load is shown in fig.4. The three-phase load is applied at time t=0.8s, the three phase load changed to two-phase load at time t=1s and then single-phase load applied at time t=1.1s after that total load removed at time t=1.2s. The terminal voltage (Vs), source current (Is), load current (IL), controller current (IC), dc bus voltage (Vdc), system frequency (f), load neutral current (Iln), wind speed, battery power (Pb), load power (Pl), and wind power (Pw) are depicted in fig.4. The system frequency maintained within the permissible value, PCC voltage maintained constant and source currents maintained at constant value under all load disturbances.

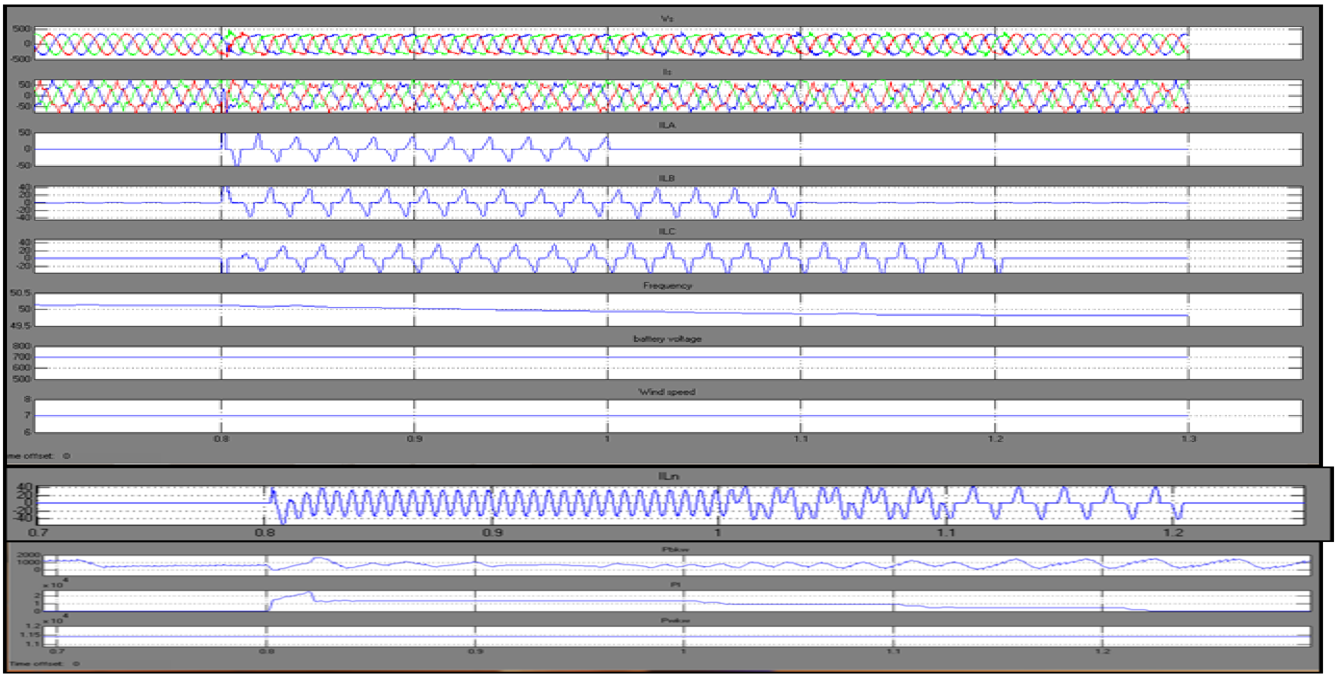

Fig. 4 Dynamic performance of V-f controller with balanced/unbalanced nonlinear load with fixed wind speed

C. Performance of V-f controller with linear balanced/unbalanced load of WECs with PMSG at varying wind speed

The performance of the V-f controller for WECs with PMSG under linear lagging power factor balanced/unbalanced load condition is shown in fig.5. At time t=0.8s the total load is removed at time t=1s single-phase load is applied and then at time t=1.1s two-phase load is applied and finally at time t=1.2s the total load is applied the wind speed is raised at time t=8s from 7m/s to 9m/s in all dynamic conditions of electrical and mechanical the system frequency regulated, terminal voltage and source current maintained constant. The terminal voltage (Vs), source current (Is), load current (IL), controller current (IC), dc bus voltage (Vdc), system frequency (f), load neutral current (Iln), wind speed, battery power (Pb), load power (Pl), and wind power (Pw) are depicted in fig.5

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

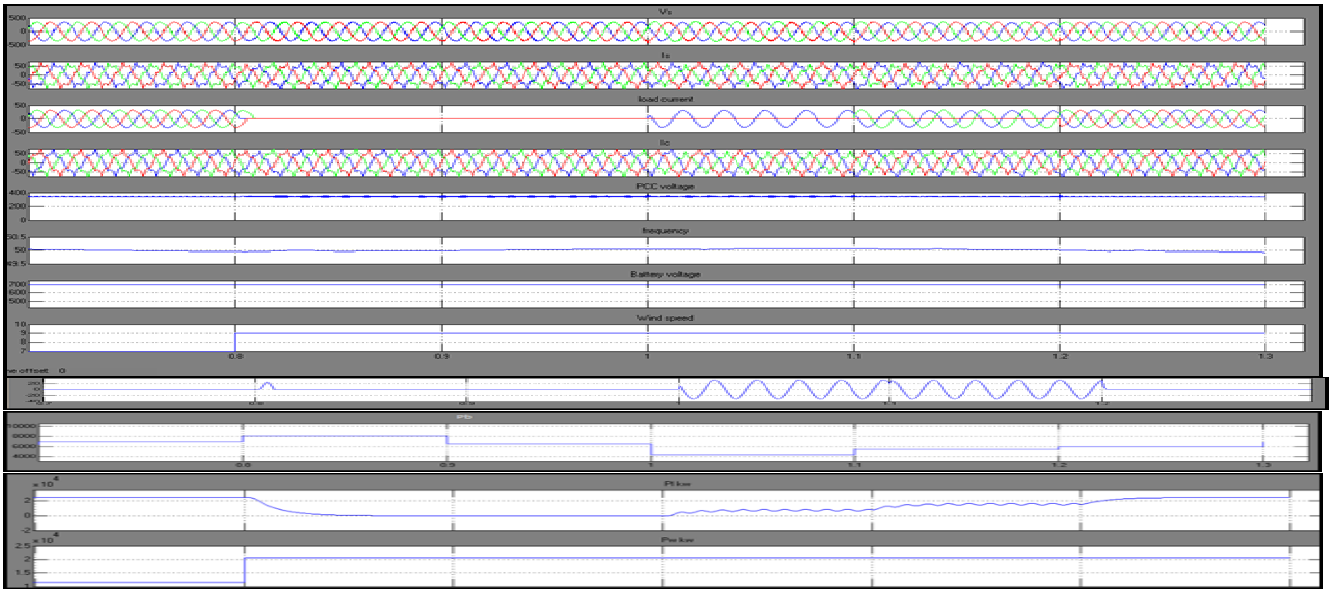

Fig. 5 Dynamic performance of V-f controller with balanced/unbalanced linear load with varying wind speed

D. Harmonics and THD of non linear balanced/unbalanced load at constant wind speed

The THD and harmonic spectra of load current is shown in fig. 6 The harmonics are eliminated by V-f controller

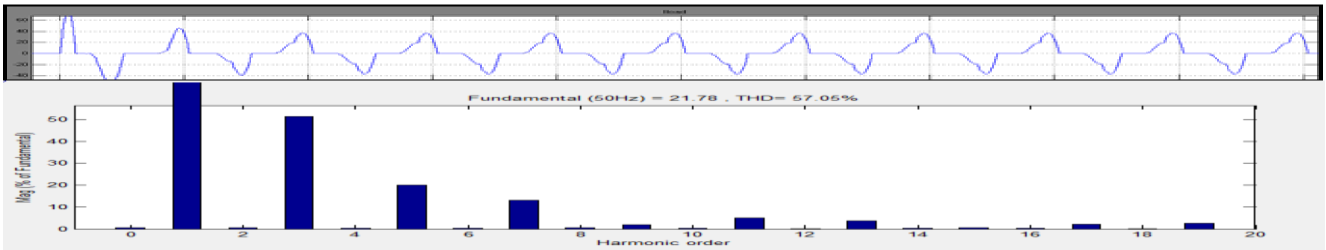

Fig.6 Load current (Ila) and harmonic spectrum

The THD and harmonic spectra of source current is shown in fig.7 The V-f controller inject proper harmonic current to eliminate the harmonics in the supply current

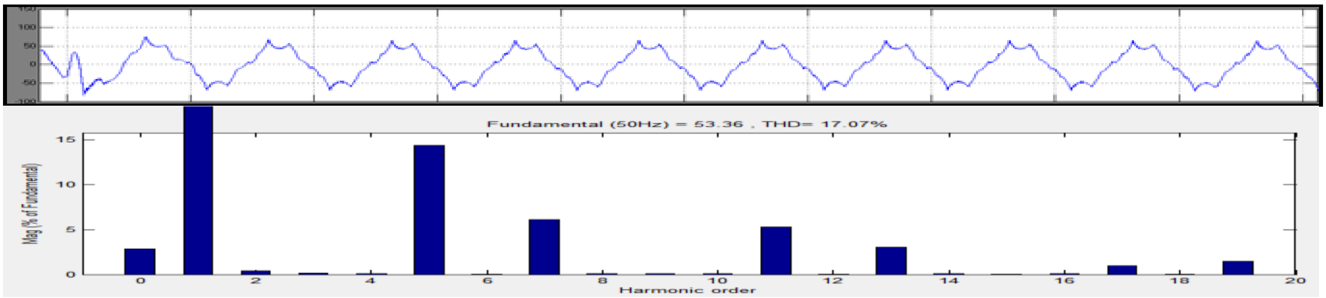

Fig. 7 Source current (Isa) and harmonic spectrum

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

The THD and harmonic spectra of PCC voltage is shown in fig.8. The THD of PCC voltage is 338v

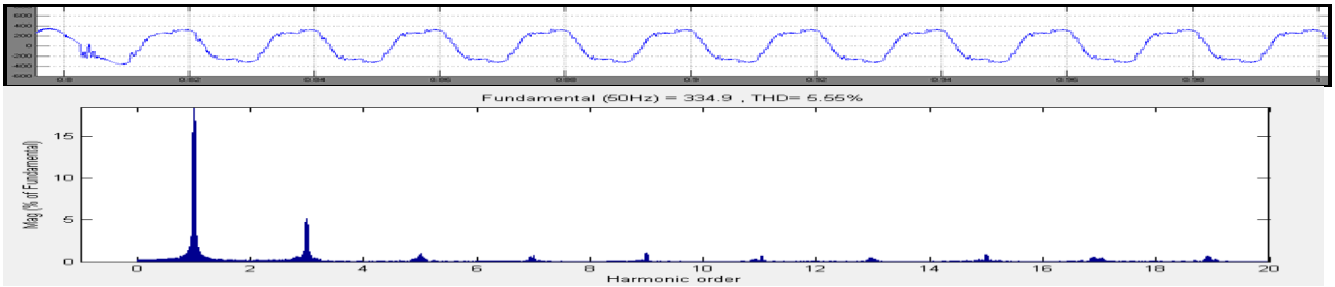

Fig. 8 Voltage at PCC (Vsa) and its harmonic spectrum

VI CONCLUSION

The performance of proposed v-f controller has been demonstrated for an isolated wind energy conversion system. Simulation results have verified the performance of the controller under different electrical (varying consumer) and mechanical dynamic conditions (varying wind speed). It has been observed that the proposed controller has been found to regulate the magnitude and frequency of the generated voltage constant in isolated wind power application. The proposed voltage-frequency controller functions as harmonic compensator and a load balancer. The BESS model stores the energy or supplies the energy according to the requirement and zig-zag transformer provides a neutral path for neutral current circulation. The proposed V-f controller modeled and simulated using Matlab Simulink and power system block set tool boxes.

APPENDIX

Wind Turbine Specifications:
Cpmax= 0.48 ,λ m = 8.1, R=6 m, *C1* =0.5176, *C2* =116, *C3* =0.4, *C4*=5, C5=21, C6=0.0068, C7=0.08, C8=0.035
Permanent Magnet Synchronous Generator: 25kW, 415V, 50Hz
Line Impedance: Rs=0.01Ω, Ls= 2 mH
Loads: (i) Linear: 30 kVA, 0.80 pf lag
(ii) Non-linear: Three single-phase bridge rectifier with R =25Ω and C = 470μF
Ripple filter: Rf = 5μF, Cf = 5μF
V-F Controller Parameters:
Battery voltage: 700 V
DC bus capacitance: 1000μF
AC inductor: 6.1mH
Frequency PI controller: Kpd=68, Kid=750
Terminal voltage PI controller: Kpq =1.7, Kiq =2.5

REFERENCES

[1] M. Godoy Simoes and Felix A Farret, "Alternative energy systems-Design and Analysis with induction generators," CRC Press, NewYork, 2008.
[2] S.N Bandra, D.Kastha and S. Banergy, "Wind Electrical Systems, "New Delhi, India, Oxford Univ. Press, 2004.
[3] L.L Lai and T.F Chan, "Distributed generation-Induction and permanent Magnet Generators," New York, Wiley, 2007
[4] Bhim Singh and Gaurav Kumar Kasal, "Voltage and Frequency Controller for a three-phase four wire autonomous wind energy conversion systems," IEEE Trans. Energy Conversion, vol. 23, no.2, pp.509–518, 2008.
[5] Bhim Singh and Gaurav Kumar Kasal, "Solid-State Voltage and Frequency Controller for a standalone wind power generating system," IEEE Trans. Power Electronics, vol. 23, no.3, pp.1170–1177, 2008.
[6] C.V Nayar, J. Perihia, F. Thomas, S,J.Philips, T.Pryor and W.L.James, "Investigation of Capacitor excited induction generators and permanent magnet alternators for small scale wind power generation " Renewable Energy, vol.1, no.3/4, pp.381–388, July 1991.
[7] Bhim Singh and Gaurav Kumar Kasal, "Neural network-based voltage regulator for an isolated asynchronous generator supplying threephase four-wire loads," Electric Power Systems Research, vol. 78, no.6, pp.985–994, 2008.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

[8] Bhim Singh and Jitendra Solanki, "A solid-state compensator with energy storage for isolated diesel-generator set," in Proc. of IEEE International Symposium on Industrial Electronics, Canada, 2006, pp.1774-1778

[9] L.M.Fernandez, J.R.Saenz and F.Jurado, "dynamic Models of wind pharms with fixed speed wind turbines," Renewable Energy, vol.31,no.8, pp.1203–1230, July 2006.

[10] Hurng- Liahng Jou, Kuen- Der Wu, Jinn- Chang Wu and Wen- Jung Chiang, "A three-phase four- wire power filter comprising a threephase three-wire active filter and a zig-zag transformer," IEEE Trans. Power Electron., vol. 23, No. 1, pp. 252- 259, January 2008.

[11] H Fugita and H Akagi, "Voltage-regulation performance of a shunt active filter intended for installation on a power distribution system," IEEE Trans. on Power Electronics, vol. 22, no.1, pp. 1046-1053, May 2007.

[12] M.C. Benhabib and S. Saadate, "New control approach for four-wire active power filter based on the use of synchronous reference frame," Electric Power Systems Research, vol. 73,no. 3, pp. 353-362, Mar 2005.