Voltage-Frequency Controlling for an Isolated Wind Energy Conversion System for Three-Phase Four Wire Loads by using Adaline based Control technique

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ABSTRACT

In this paper, A stand alone wind energy conversion system based on a permanent magnet synchronous generator with an Adaline (adaptive linear element) controlled voltage and frequency(VF) controller has been found suitable for three-phase four-wire system. The VF controller has used a VSC with a battery energy storage system (BESS) at its dc link.. The proposed electro-mechanical system along with its controller and Scott connected transformer has been modeled and its behavior is simulated using MATLAB with its Simulink. The Adaline based neural network is used to control the VSC of the proposed controller. The Adaline control technique is simple and has a fast response. The Scott-connected transformer is used for providing a papth to the zero sequence current for three-phase four-wire loads. This reduces the complexity and also cost of the VF controller. The VF controller consists of insulated gate bipolar transistors (IGBTs) based 3-leg VSC with a battery energy storage system (BESS) at its dc link. The VF controller injects and absorbs both active and reactive power by which it controls both frequency and voltage with varying consumer loads and wind speed.the VF controller also functions as a harmonic compensator and a load balancer.

Keywords- Wind energy conversion system, Neural network, Permanent magnet synchronous generator, Voltage and frequency controller, VSC, Scott- transformer.

1. INTRODUCTION

Wind turbine is considered today as energy source which allow electrical production with minimum environment perturbations. This energy source is especially suitable for remote areas, which are not connected to the conventional electrical grid. Since this energy source is intermittent, a suitable energy storage device is required for long-term storage. Wind energy is one of the important renewable energy source which is used for power generation for isolated as well as grid connected applications [1-4]. Environmental issues and national policies are supporting development of small scale isolated power generation. The asynchronous generators such as self excited induction generators (SEIG) [5] and synchronous generators such as permanent magnet synchronous generator (PMSG) [6-11] are used for power generation and such distributed isolated system require energy storage systems such as batteries to stabilize the voltage and frequency.

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 (lGBT) based voltage source converter (VSC) with a battery energy storage system (BESS) at its dc link. The controller injects/ absorbs both active power and reactive power by which it controls both frequency and system voltage with varying consumer loads and wind speeds. A Scott-connected transformer is reported for neutral current compensation in three-phase four-wire distribution system [12]. The proposed VF controller compensates for harmonic current and load unbalance along with reactive power compensation for voltage regulation and active power injection and absorption for frequency regulation.

2. PROPOSED SYSTEM

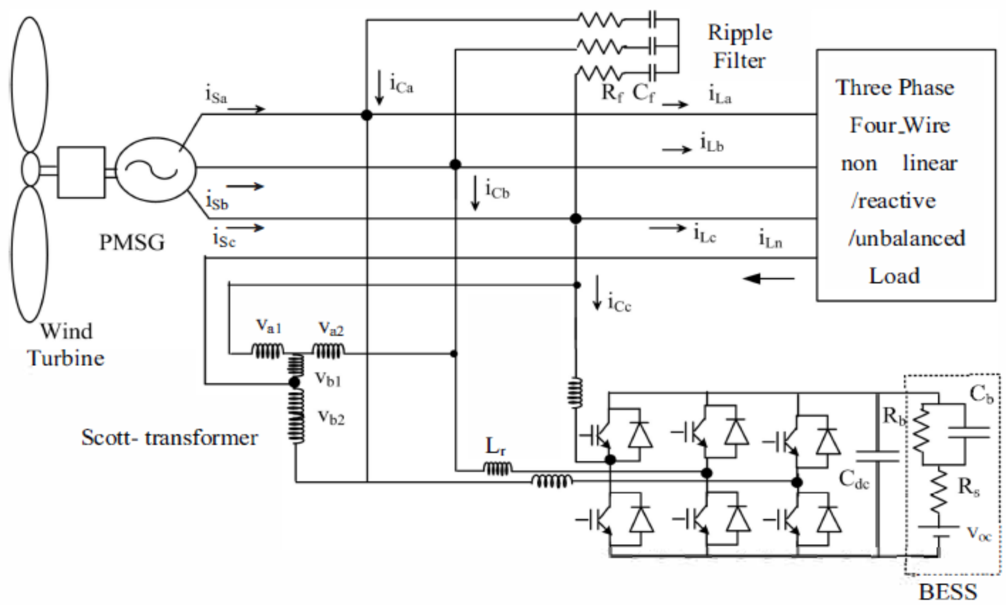

Fig: 1. Schematic diagram of the isolated WECS with the proposed VF controller.

Fig: l shows the schematic diagram of the proposed WECS with its Scott- transformer based isolated VF controller. A permanent magnet synchronous generator (PMSG) is driven by a constant speed wind turbine connected through a gear system with constant speed ratio. The generator is connected to a three-phase four-wire consumer loads where the neutral terminal is obtained from the Scott- transformer. The Scott- connected transformer is used for providing a path to the zero sequence current in a three-phase four-wire system. The VF controller consists of IGBT based VSC with a battery energy storage system (BESS) at its dc link. A ripple filter is designed to eliminate high frequency harmonics from the terminal voltage. The BESS is designed for a back up of 6 hours and the kVA rating is equal to the generator kVA so that it is able to meet a maximum load demand of twice the generator kVA.

3. CONTROL OF WECS

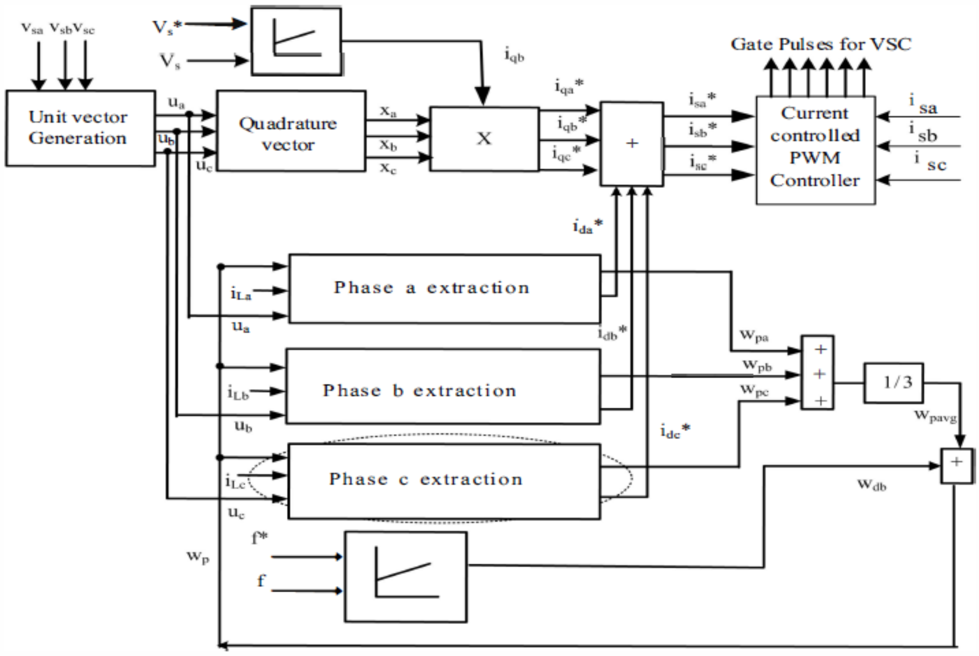

Fig: 2 (a) Block diagram of Adaline based control of voltage and frequency of the isolated WECS

The block diagram of the control algorithm of VF controller for the permanent magnet synchronous generator based stand alone wind energy conversion system is shown in Fig: 2(a). The basic theory of decomposer is based on Least Mean Square (LMS) algorithm and its training is through Adaline and use the unit vector for generating the reference source current [13]. The fundamental active component of load current is extracted in each phase using Adaline based extraction algorithm.

3.1 Extraction of in-phase balanced fundamental reference source component

Fig: 2 (a) shows the block diagram for the estimation of active fundamental reference source current using Adaline algorithm.The load currents (iLa, iLb, iLc,), source currents (isa iSb, isc), the pcc voltages (Vsa, Vsb, Vsc) are sensed for simulating the Adaline based extraction algorithm. Three phase unit voltage vectors (ua, Ub, ue) are derived in-phase with the source voltages. The amplitude of the source voltage is obtained using eqn. (1) and the unit voltage vectors are derived from eqn. (2) as,

$$V_S = \sqrt{(2/3)(v_{sa}{}^2 + v_{sb}{}^2 + v_{sc}{}^2)} \tag{1}$$

$$u_a = v_{Sa}/V_S;\, u_b = v_{Sb}/V_S;\, u_c = v_{Sc}/V_S \tag{2}$$

Also, the quadrature unit vectors (xa, Xb, xc) are derived from the in-phase unit vectors as,

$$\begin{aligned} x_a &= -u_b/\sqrt{3} + u_c/\sqrt{3} \\ x_b &= \sqrt{3}u_a/2 + (u_b - u_c)/2\sqrt{3} \\ x_b &= -\sqrt{3}u_a/2 + (u_b - u_c)/2\sqrt{3} \end{aligned} \tag{3}$$

It is known that the load current can be decomposed as real, reactive and harmonic components as,

$$i_L = i_{Ld} + i_{Lq} + i_{Lh} \tag{4}$$

where, iLd, iLq, iL_h are active, reactive and harmonic components of the load current.

Now, the Adaline based extraction technique gives the weight corresponds to active component of current (W_{pa}, W_{ph}, Wpe). These weights are variable and changes as per the load current magnitude. The weights are updated using the LMS adoption algorithm tuned Adaline technique as (Fig: 2(b))

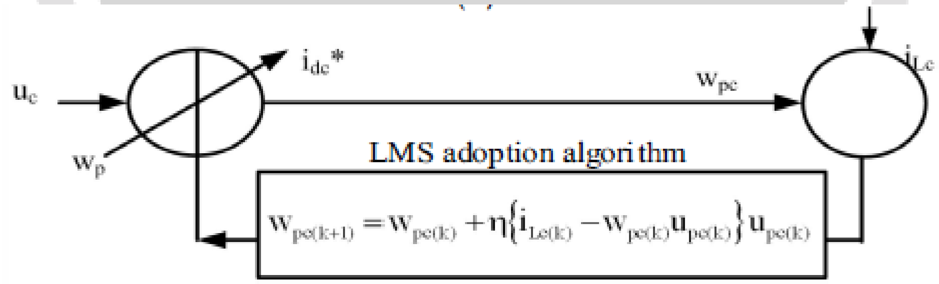

Fig: 2(b) Extraction of weight in a single phase.

Wpe(k+l) = Wpeek) + η{iLe(k) - Wpeek)Upe(k) }Upe(k) (5)

where, η is the coefficient of convergence and k is the sampling instant. The value of decides the rate of convergence and accuracy of estimation and the practical range of values lies in between 0.1 and 1.0. Then, the average weight of active component is estimated in all the three phases as,

Wpavg =(Wpa + Wpb + Wpc)/3 (6)

The system frequency is obtained using a PLL with input as three phase terminal voltages. The frequency is compared with the reference frequency and the error is controlled using a PI (proportional-integral) controller. The output of the PI controller is considered as the weight corresponds to active current to be drawn by the VSC as,

wdb(n) = wdb(n-l) + Kpd(fe(n) -feCn-I)) + Kidfe(n) (7) where, $fer_{n)}$ = j* - $fc_{n)}$ is the error between the reference (f*) and the measured (t) frequency of the terminal voltage at t is known that the load current can be decomposed as real, reactive and harmonic components as, the n^{th} sampling instant using PLL. Kpd and Kid are the proportional and the integral gains of the frequency PI controller.Then the new average weight of active power component is estimated in all the three phases as,

$$w_p = w_{pavg} + w_{db} \tag{8}$$

Now, the active power component of reference source currents are computed as,

$$i_{da}^* = w_p * u_a$$
$$i_{db}^* = w_p * u_b$$
$$i_{dc}^* = w_p * u_c \tag{9}$$

3.2 Extraction of quadrature balanced fundamental reference source component

The reactive component of source current to be injected by the controller is estimated using a PI controller which is operated over the error of the reference (Vs *) and measured (Vs) amplitude of the terminal voltages. The output of the PI controller is estimated as the amplitude of quadrature axis component of the reference source current (wq). So, the reactive component of reference source currents are obtained as,

$$i_{qa}^* = w_q * x_b$$
$$i_{qb}^* = w_q * x_b$$
$$i_{qc}^* = w_q * x_c \tag{10}$$

3.3 PWM Current Controller

In a current controller, the sensed source currents (isa, iSb, isc) and reference source currents (isa*, isb*, isc*) are compared and a proportional controller is used for amplifying current error in each phase. These current error signals are amplified and amplified current errors are compared with a triangular carrier signal of frequency, fs to generate the gating signals for six IGBT switches of VSC of the VF controller.

4. MODEL EQUATIONS OF WECS AND MATLAB BASED SIMULATION

The WECS, Scott-transformer and the VF controller are modelled using MATLAB software with its simulink and power system block set toolboxes.

4.1 Modeling of the Turbine

If is the specific density of air (m^3 A is the P swept area of the blades (m^2)$^{/s),}$,V is the wind speed (m/s), the power coefficient is Cp' the aerodynamic power of the wind turbine can be expressed as,

P-O.5pCpAV (11)

Cpis a function of tip speed ratio (A),and A is obtained as,

$$\lambda = \omega R / V \tag{12}$$

where, OJ is the angular speed of the turbine with radius R. The OJ is obtained from the speed of the wind turbine. The polynomial relation between the power coefficient, Cp and the tip speed ratio, Aat a particular pitch angle for the turbine is represented as [1],

$$C_p = C_1\{(C_2/\lambda i) - C_3\beta - C_4\}e^{-(C_5/\lambda i)} + C_6\lambda \tag{13}$$

4.2 Modeling of the PM Generator

The electrical system consists of a permanent magnet synchronous generator (PMSG) driven by the wind turbine. The PMSG has been modeled in the rotor reference frame. [f one considers zero sequence quantities are not present in the machine and on applying Park's transformation, the terminal voltage of the PMSG in the rotor reference frame can be expressed as [15]

$$v_d^{\,g} = -Ri_d - Lpi_d + \omega Li_q \qquad (14)$$

$$v_q^{\,g} = -Ri_q - Lpi_q - \omega Li_d + \omega\psi \qquad (15)$$

where, p is the derivative operator(), I is the quadrature axis current (A), i_d is the direct axis current (A), R is the stator phase winding resistance (n), L is the stator inductance (H), co is the rotor angular velocity of generator (rad/s) and \If is flux linkage (volt-slrad).

4.3 Modeling of the Scott-transformer

The transformer model available in the MATLAB power system blockset (PSB) toolbox is used for modeling the Scott- transformer.

4.4 Modeling of the VF Controller

The VF controller consists of a three-leg VSC with a BESS at its dc link. The Thevenin's equivalent circuit of the BESS is shown in Fig. 2. The capacitor Cb represents the energy storage in the battery and is obtained as,

$$C_b = (kWh*3600*1000)/(0.5(V_{ocmax}^{\,2} - V_{ocmin}^{\,2})) \qquad (16)$$

where, Voemax and Voemin are the maximum and minimum voltages of the battery and the kWh is the total energy available from the battery. The resistance, Rb in parallel with the Cb represents the self discharging of the battery and as the self discharge current of a battery is small, the Rb is large. The resistance, Rs is the equivalant resistance (internal + external) of the parallel/series combination of cells in a battery, which is a small value. The parameters of the BESS are given in the Appendix.

4.5 Modeling of the Consumer loads

The three-phase four-wire consumer linear and nonlinear loads are modeled using the available resistance, inductance, diodes etc in the power system block set toolboxes of the MATLAB.

5. RESULTS AND DISCUSSION

The proposed isolated WECS with neural network controller is simulated and are analyzed at various operating conditions such as varying loads, varying wind speed and unbalanced linear Inon-linear load conditions. The performance of the system is described in the following sections.

5.1 Dynamic Performance of isolated WECS with neural network based VF controller at varying Loads

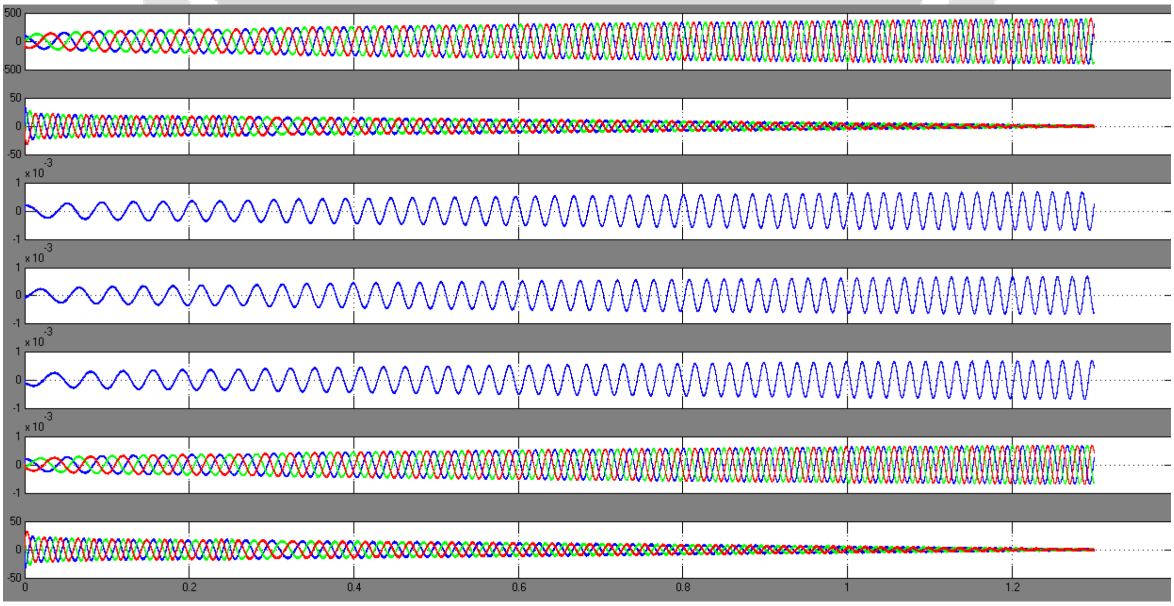

Fig: 3-dynamic performance of WECS at varying loads

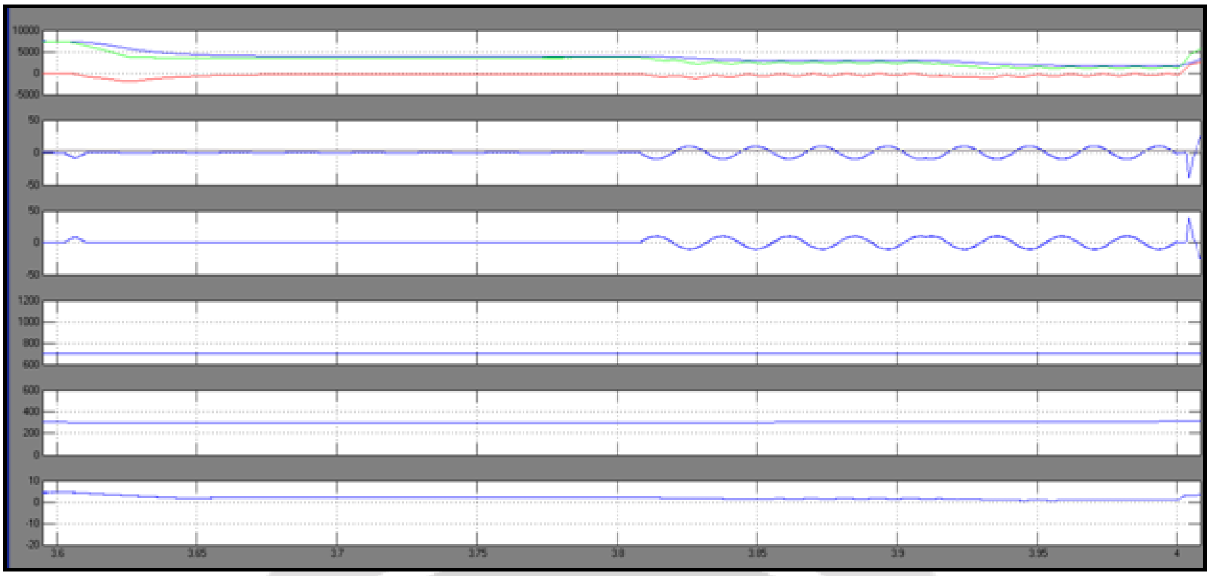

Fig: 4-dynamic performance of WECS at varying loads

The dynamic performance of the WECS with PMSG and V-F controller under linear lagging power factor load condition is shown in Fig. 3 and 4. At 0.75 s, the load is included and then the load is increased at 0.95 s. The part of the load is removed a l.15 s and the load is completely withdrawn at 1.25 s. The terminal voltages (vs), supply currents (is), load currents (id, controller currents (ie), system frequency (t), amplitude of terminal voltage (Vs),dc bus voltage (Vde), wind speed (V), battery current (ib) ,wind power (Pw), battery power (Pb) and load power (PL) are depicted in Fig. 3 and 4. The amplitude of terminal voltage is maintained at the reference value under various load disturbances. The system frequency is also regulated to the reference value during all load disturbances.

5.2 Performance of isolated WECS with neural network based VF controller at varying wind speeds

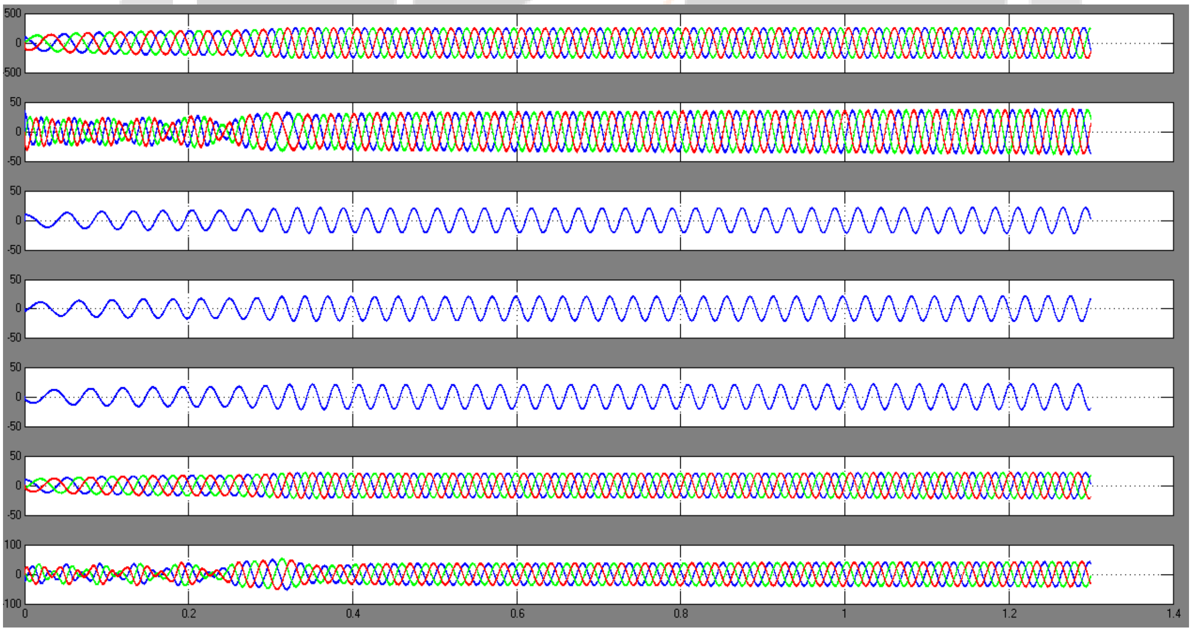

Fig:5- dynamic performance of WECS at varying wind speeds

The dynamic performance of the WECS with PMSG and V-F controller under varying wind speed with constant linear lagging power factor load condition is shown in Fig. 5& 6. At 0.9 m s, the wind speed is raised from 7 m/s to 10 mls and the wind speed is decreased from 10 m/s to 8 m/s at 1.15 s. The terminal voltages (Vs), supply currents (Is), load currents (Id), controller currents (Ic), system frequency (t), amplitude of terminal voltage (Vs),dc bus voltage (Vde), wind speed (V), battery current (Ib) ,wind power (Pw), battery power (Pb) and load power (PL) are depicted in Fig. 5& 6. It is observed that the change in supply power due to the change in wind speed is absorbed by the controller to maintain the system frequency to the reference value. The amplitude of terminal voltage is maintained at the reference value under various load disturbances. The supply currents are balanced under all unbalanced load conditions.

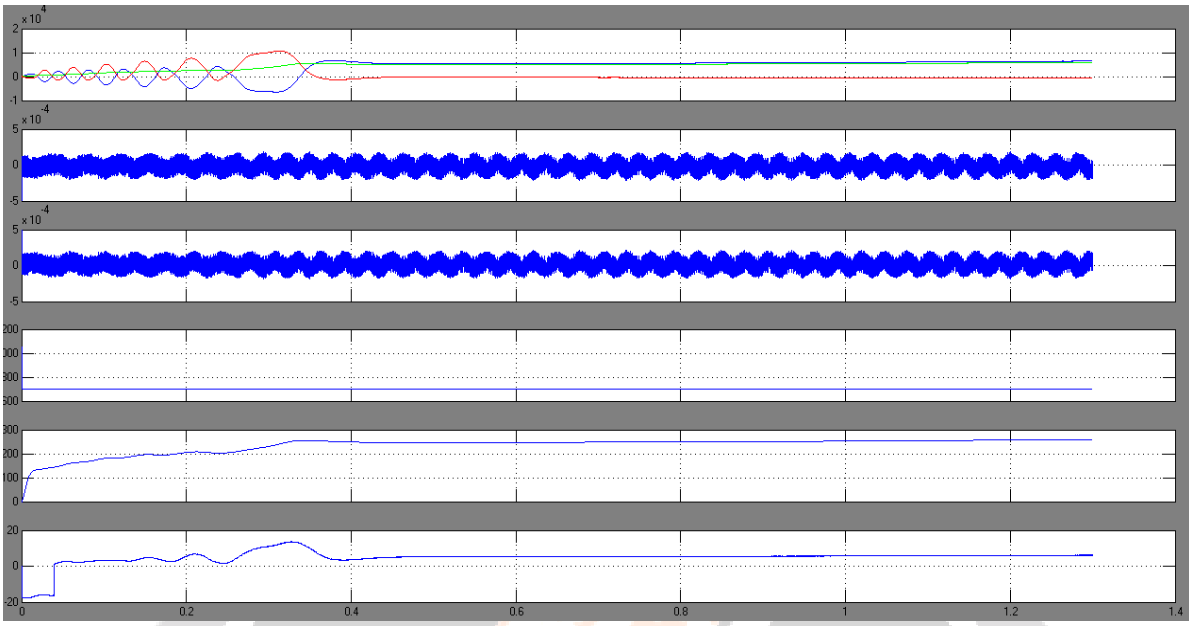

Fig: 6- dynamic performance of WECS at varying wind speeds

5.3 Performance of isolated WECS with neural network based VF controller at unbalanced linear/non-linear Loads

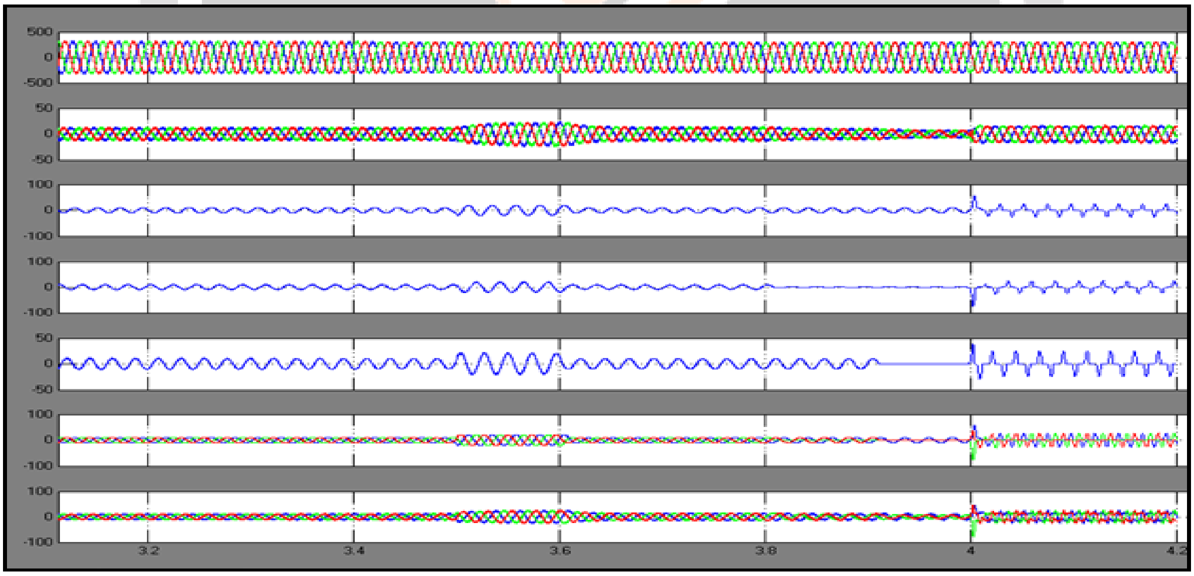

Fig: 7- Dynamic performance of the WECS with balanced/ unbalanced linear/nonlinear loads.

The dynamic performance of the WECS with PMSG and VF controller under linear/non-linear balanced/unbalanced load condition is shown in Fig. 7& 8. Initially a linear load is included and it is changed to two-phase load and then to single- phase load at 0.85 s and 0.95 s respectively. The linear load is completely withdrawn at [.0s, and then the balanced non linear load is included. The terminal voltages (vs), supply currents (is), load currents (iLa, iLb, iLc), controller currents (ic), dc bus voltage (Vde), system frequency (t), amplitude of terminal voltage (Vs), wind speed (V), load neutral current (iLn), transformer neutral current (izn), wind power (Pw), battery power (Pb) and load power (Pd are depicted in Fig. 7. The supply currents are balanced under all unbalanced load conditions. The harmonics in the supply currents is eliminated by proper harmonic current injection by the VF controller. The amplitude of terminal voltage is maintained at the reference value under various load disturbances. The system frequency is also regulated to the reference value during all load disturbances.

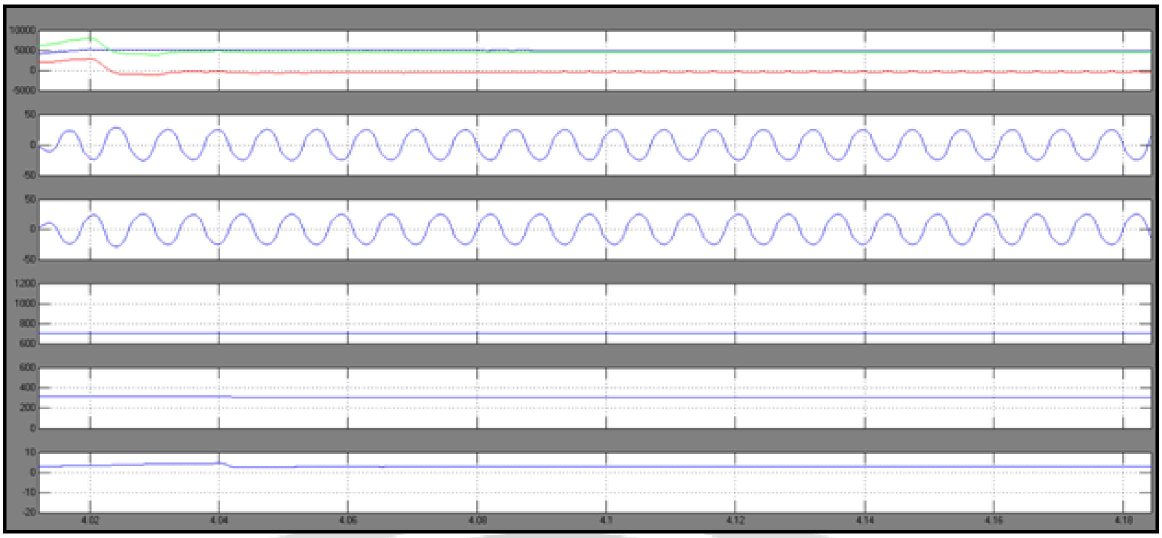

Fig: 8- Dynamic performance of the WECS with balanced/ unbalanced linear/nonlinear loads.

6. CONCLUSION

A stand alone wind energy conversion system based on a permanent magnet synchronous generator with an Adaline (adaptive linear element) controlled voltage and frequency(VF) controller has been found suitable for three-phase four-wire system. The VF controller has used a VSC with a battery energy storage system (BESS) at its dc link.. The proposed electro-mechanical system along with its controller and Scott connected transformer has been modelled and its behaviour is simulated using MATLAB with its Sirnulink and Power system blockset tool boxes. The Scott connected transformer requires only two single phase transformers. The performance of WECS has been demonstrated under varying wind speeds and varying electrical load conditions. The VF controller has been found suitable to regulate the voltage and frequency of the system. Moreover, the VF controller has also functioned as a harmonic compensator and a load balancer. The neutral current in the three-phase four-wire distribution system has been circulated locally using a Scott transformer.

APPENDICES

A. Turbine

$C_p$max=0.48, Am=S.I, R=6m, C1=0.5176, C2=116, C3=OA, C4=5, C_5=21, C_6=0.006S, C_7=0.OS, Cg =0.035, OJ=103 rpm

B. Permanent Magnet Synchronous Generator 30kVA, 415V, 50Hz, 4pole

C. Loads

(i) Linear: 20 kVA, O.SO pf lag

(ii) Non-linear: Three single-phase bridge rectifier with R= 25 Q and C= 470flF

D. Ripple Filter R f= 5 Q, Cf= 5 flF

E. VF Controller Parameters DC bus capacitance, Cdc : 1000 flF AC inductor Lg: 6.1 mH PWM switching Frequency: 10 kHz

F. Battery specification Cb=15000F, Rb=lOk Q, Rs=O.Ol Q, Voc=700 V

G. Scott-connected transformer Two single-phase transformers of rating 5kVA, 240V1120V, 5kVA, 207V/207V.

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