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Isolated Wind Energy Conversion System with Asynchronous Generator Incorporating Voltage and Frequency Control

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Abstract—*This paper deals with the voltage and frequency control aspect of isolated self excited induction generator with the help of power electronics technology. The shunt connected PWM controlled IGBT based three leg VSC with battery at its dc link is used to regulate both voltage and frequency by controlling real and reactive power respectively during sudden change in load, wind speed and unbalanced loading. Sinusoidal pulse width modulation technique is used to generate switching pulses for six IGBT switches. Drawbacks of induction generator in isolated mode are verified in results section. The proposed controller is implemented in MATLAB/SIMULINK environment and results shows that controller efficiently improve the power quality of system.*

Keywords: *Insulated gate bipolar transistor, voltage and frequency controller, battery energy storage system, self excited asynchronous generator, pulse width modulation*

1. INTRODUCTION

Power electronics switches such as IGBT, MOSFET, BJT , Thyristors plays an important role in control of almost all renewable and non renewable energy sources . Because of the advantages offered by the IGBT such as its excellent forward and reverse blocking capabilities, small chip size and low cost, low on state voltage drop, superior on state current density and easily controllable nature than other switches it is the mostly used in control application. The main limitation of self excited asynchronous generator in isolated operation is its poor voltage and frequency regulation because of varying rotor speed , load demand and characteristics of load .For successful operation asynchronous generator during these abnormal condition require continuous supply of reactive power whether from grid(grid connected mode) or from suitable capacitor bank (isolated mode).Power electronics components have vast potential for making asynchronous generator a suitable candidate for wind energy conversion system. In literature number of control schemes [1, 3, 12, 13, 14] found to control the voltage and frequency of isolated asynchronous generator using power electronics components. Electronic load controller (ELC) based on current controlled VSI is reported in [1].In this scheme real and reactive power is controlled via three leg igbt based VSI in order to maintain frequency and voltage level constant respectively. The main drawback of this scheme is that the excess generated power is wasted in dump load . The another scheme [2] utilizes combination of STATCOM and ELC(electronic load controller) for controlling voltage and frequency respectively. This scheme has same drawback as of above because excess generated power is wasted in auxiliary load connected to the ELC terminal so that generated power at generator terminal remains constant. The control scheme [3] implements a star delta transformer in addition with three leg VSC having battery at its dc terminal. In this scheme Instantaneous symmetric component theory is used for extraction of reference source current. The main advantage of this scheme is that the excess generated power is used to charge the battery and can be utilized during peak load period and star delta transformer is used to circulate zero sequence current hence works as load balancer. The other schemes includes AC-DC-AC PWM converter, shunt active filters[15], series capacitor compensation[16] are also found in literature. This paper presents the analysis of pwm controlled three leg VSC with battery at its dc terminal for controlling the voltage and frequency of isolated asynchronous generator.

2. SYSTEM CONFIGURATION

The proposed system model is shown in the fig.1. It consists asynchronous machine modeled in d-q axis reference frame with squirrel cage rotor working as asynchronous generator, delta connected capacitor bank of adequate size for self excitation, VSC with battery connected at its dc terminal for exchange of real and reactive power and consumer load which may be linear/nonlinear/static/dynamic in nature. The parameter of asynchronous generators are computed using conventional test(no load , dc test and synchronous speed test). VSC is connected to the generator terminal at the point of common coupling.

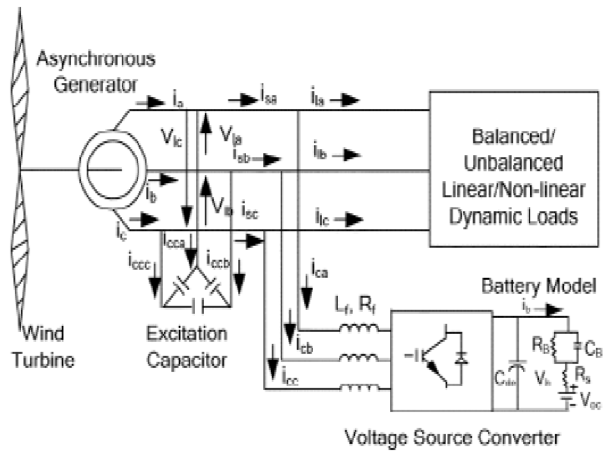

Fig. 1: Overall system configuration

3. MODELING OF INDUCTION GENERATOR

Generally two models (per phase equivalent circuit model and D-Q axis model) are used for performance analysis of induction generator. Per phase equivalent circuit model is used to for steady state analysis while DQ axis model is used for steady state as well as transient state analysis of induction generator. Performance of induction machine can be described in any of three reference frames viz. stationary($\omega = 0$), rotor ($\omega = \omega r$) and synchronous reference frame ($\omega = \omega s$) Here DQ axis model of induction generator with stationary reference frame is used.

Voltage equations for DQ axis induction machine model can be written as-

[V]=[R][I]+[L]p[I]+ω_r[G][I]

where [V] is the transpose $[Vqs\ Vds\ Vqr\ Vdr]$, [I] is transpose of $[Iqs\ Ids\ Iqr\ Idr]$, [R], [L] and [G] represents 4×4 matrices of resistance,inductance and conductance.

$$[G]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & L_m & 0 & L_r \\ -L_m & 0 & -L_r & 0 \end{bmatrix};$$

$$[L]=\begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix}$$

Here where Vds, Vqs, Vdr, Vqr are the d- and q-axis of the stator and rotor voltages; $Ids, Iqs\ , Idr, Iqr$ are the d- and q-axis of the stator and rotor currents; ωs is the angular velocity of the synchronously rotating reference frame; ωr is the rotor angular velocity; Rs, Rr are the stator and rotor resistances and Ls, Lr, and Lm are the stator, rotor and mutual inductances, respectively.

Lm is the main factor in the dynamics of voltage build up and stabilization. Relation between Lm and Im can be found from synchronous speed test. Magnetizing characteristics of SEIG is highly non linear. Also relation between Lm and Im can be written as:

Lm=$\Psi m/Im$

Where Ψm , im are magnetizing flux linkage and magnetizing current.

magnitude of magnetizing current can be found as

$$Im= \sqrt{(ids + idr)^2 + (iqr + iqs)^2}$$

electromagnetic torque is

$$Te = \frac{3}{2}\frac{P}{2} Lm(iqs * idr - ids * iqr)$$

Positive value of Te means motoring operation and negative value means generating mode.

Torque -speed equation can be written as :

$$Tshaft = Te\ +\ j(2/p)\ p\omega r$$

During simulation the residual magnetism in the machine is considered which is necessary for induction machine to self excite.

4. CONTROL STRATEGY

Control strategy is based on the principal of generation of reference source currents .Voltage and frequency control loops are used for computing the reactive and real components of reference source currents respectively. In phase unit vectors (da, db, dc) are computed by dividing the ac voltages by their magnitude (Vtm) and 90 degree phase shift of in phase unit vectors give quadrature unit vectors$(qa\ qb\ qc)$. Now the output of voltage control loop is multiplied with quadrature unit vectors to compute reactive component of reference source current for controlling voltage and the output of frequency control loop is multiplied with in phase unit vectors to compute active component of reference source current for controlling the frequency.

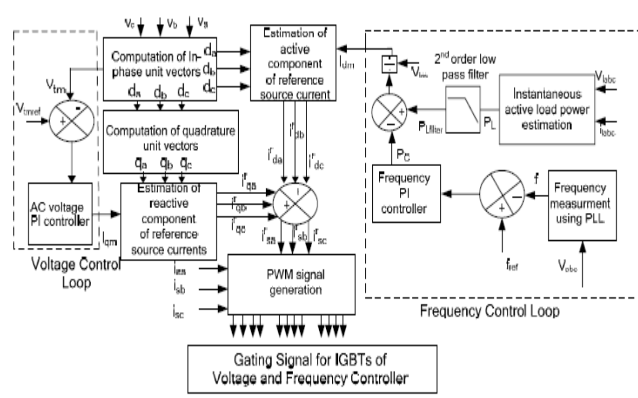

Fig. 2: Schematic block diagram of control scheme

In the next stage these active and reactive components are summed to generate reference source currents which are compared with sensed source currents The error signal is amplified and then sine triangle pwm technique is used to generate appropriate sequence of pulses for IGBT switches. Fig.2 shows the block schematic block diagram of control scheme.

5. MODELING OF CONTROL SCHEME

Basic equations on which control schemes relies is as follows.

5.1 Computation of active component of reference source current

The active component of reference source current is described by the given equation.

$$Idm = 2(PLfilter - Pc)/3 * Vtm$$

Where

PL is computed by taking the clark's (alpha-beta) transformation of generated voltage and current and Pc is the output of the frequency PI controller. The calculated frequency of the generated voltage computed by phase locked loop is subtracted from reference set frequency and frequency error is given as input to the PI controller.

The frequency error can be defined as:

$$f_{er\,(n)} = f_{ref\,(n)} - f_{(n)}$$

The output of frequency PI controller (Pc) at any instant can be computed by following equation.

$$P_{c(n)} = P_{c(n-1)} + K_{pf}\{f_{er\,(n)} - f_{er\,(n-1)}\} + K_{if}\, f_{er\,(n)}$$

Where

K_{pf} and K_{if} are proportional and integral gain of frequency PI controller.

Vtm is amplitude of instantaneous line voltages at generator terminal.

$$Vtm = sqrt\{\, (2/3) * (Va^2 + Vb^2 + Vc^2)\}$$

The instantaneous value of in-phase component of reference source current is computed as:

$$Irda = Idm * da;\ Irdb = Idm * db\ ;\ Irdc = Idm * dc.$$

Where da, db, dc are in phase unit vectors derived from following relationship:

$$da = Va/Vtm\ ;\ db = Vb/Vtm\ ;\ dc = Vc/Vtm$$

5.2. Computation of reactive component of reference source current

First quadrature unit vectors are computed from in phase unit vectors as:

$$qa = \frac{-db}{\sqrt{3}} + \frac{dc}{\sqrt{3}};$$

$$qb = \sqrt{3} * \frac{da}{2} + \frac{(db - dc)}{2*\sqrt{3}};$$

$$qc = \frac{-\sqrt{3} * da}{2} + \frac{(db - dc)}{2 * \sqrt{3}};$$

Then instantaneous quadrature component of reference source currents are computed by multiplying these unit vectors with the output(Iqm) of voltage PI controller as:

$$Irqa = Iqm * qa\ ;\ Irqb = Iqm * qb\ ;\ Irqc = Iqm * qc$$

Where Iqm is amplitude of quadrature component of reference source current derieved from error between amplitude of reference ac terminal voltage and amplitude of sensed three phase ac voltage.

The voltage error can be expressed by following equation;

$$V_{er\,(n)} = V_{tmref\,(n)} - V_{tm\,(n)}$$

And the output of voltage PI controller can be expressed at any instant of time as:

$$I_{qm\,(n)} = I_{qm\,(n-1)} + K_{pa}\{V_{er\,(n)} - V_{er\,(n-1)}\} + K_{ia} V_{er\,(n)}$$

Where

K_{pa} and K_{ia} are proportional and integral gain of voltage PI controller.

5.3. Computation of reference source currents

In phase and quadrature components of reference source currents are added to compute total reference source currents.

$$Irsa = Irqa + Irda, Irsb = Irqb + Irdb, Irsc = Irqc + Irdc$$

5.4. PWM signal generation

In order to generate pwm signal reference source currents are($Irsa, Irsb, Irsc$) are compared with sensed source currents (Isa, Isb, Isc) as follows.

$$Isaerr = Irsa - Isa \quad Isberr = Irsb - Isb \quad Iscerr = Irsc - Isc$$

These current errors is amplified and compared with triangular carrier wave in order to generate gating pulses for the switches of three leg VSC.

6. DESIGNING OF CONTROLLER COMPONENTS

6.1. DC Voltage source

The value of DC voltage source of VSI depends upon instantaneous energy available to controller. DC link voltage can be defined as:

$$Vdc = \frac{2*\sqrt{2}*VLL}{m*\sqrt{3}}$$

Where 'm' is modulation index and VLL is the line to line voltage.

6.2. AC Inductor

AC inductor can be calculated with the given equation :

$$Lf = \frac{\sqrt{3} * m * Vdc}{12 * \alpha * Fs * IL(ripple)}$$

Where Fs is switching frequency, IL(ripple) is ripple current.

6.3. Battery

When capacitor is used to model the battery unit, capacitance can be calculated from the following equation as follow[11]:

$$Cbat. = \frac{2(Kwh*3600*1000)}{(Voc_{max}^2 - Voc_{min}^2)}$$

In the proposed model resistance Rb (represents self discharging) is used in parallel with Cb to describe the stored energy and voltage during charging/discharging.

7. MATLAB/SIMULINK IMPLIMENTATION

The overall system including wind turbine, asynchronous generator, VF controller is implemented using simpower system toolbox of MATLAB/SIMULINK software. Simulink diagram is shown in fig.

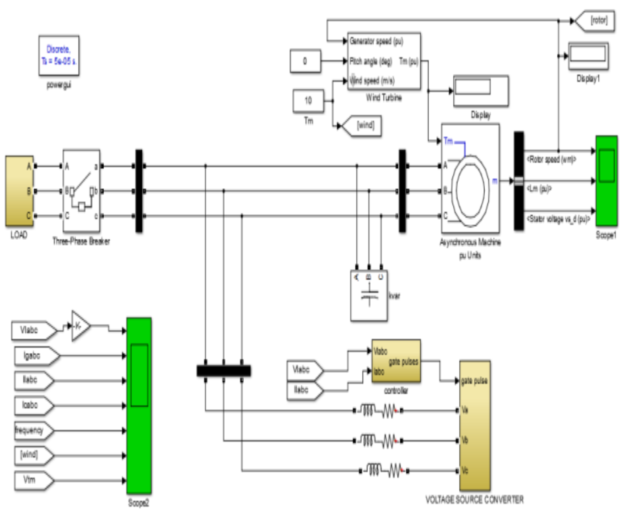

Fig. 3: Simulink implementation of SEIG with V/F control scheme

8. RESULT AND DISCUSSION

8.1 Verification of drawbacks of induction generator

The two major drawbacks (voltage and frequency variation) of induction generator in isolated mode can be easily understood with the help of simulation waveform. In order to generate constant frequency at fixed speed , the total generated power at generator terminal must be consumed by the connected load otherwise the this additional generated power might be stored in revolving component of machine which results in increase in machine speed thereby increasing frequency[6]. From fig. 5 we can see that induction generator voltage fully build upto 1 sec. at no load condition but frequency is very high. Now at 2 sec. we apply a load of such a value that all generated power is being consumed by load. As a result our voltage level and rotor speed decreases because of sudden change in load but our frequency comes in nominal range . This waveform verifies the statement made in [6] about principal of frequency regulation.

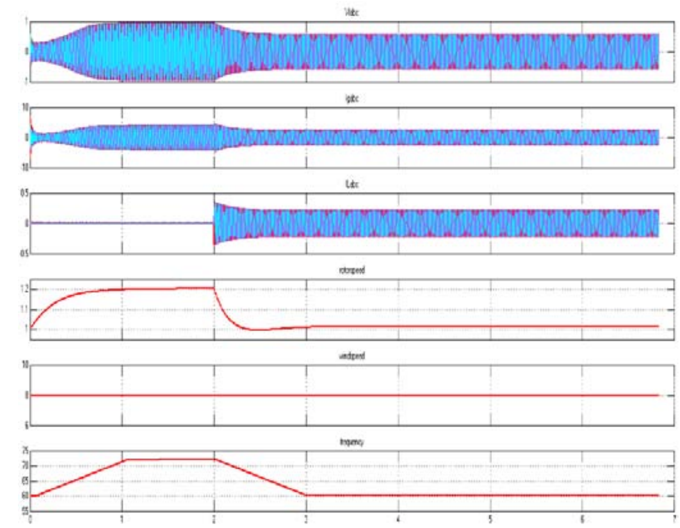

Fig. 4: Waveforms of voltage,current, rotor speed, frequency without using controller

8.2. Performance of wecs employing VF controller

8.2.1.Constant wind speed but changing load condition.

From fig.5 we can analyze the performance of wind energy conversion system employing voltage and frequency controller during fixed wind speed(10m/s). At 3 sec. when we apply a load (3kw) at generator terminal the load current increases. It is observed that terminal voltage slightly drops but achieve its steady state in very small time. Also very small fluctuation is being noticed in frequency but that vanishes in very small time.

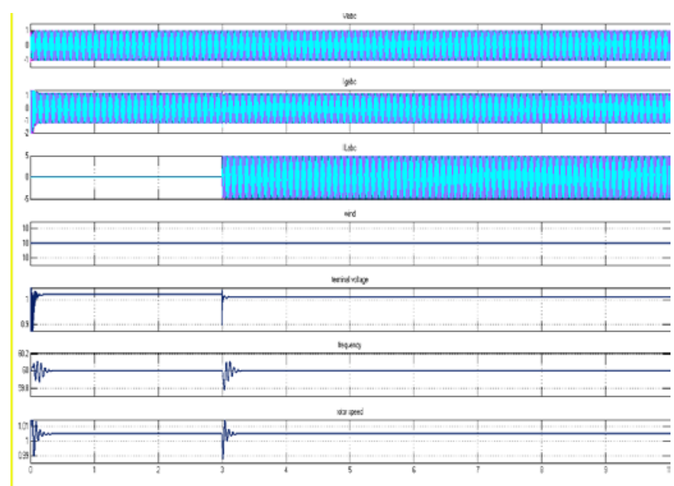

Fig. 5: Waveforms of variables during constant wind speed

8.2.2.Changing wind speed. Fig.5, In this case when the wind speed changes at 4 sec. (from 10m/s to 14m/s), the rotor speed increases therefore generated current increases but our voltage and frequency remains in stable point after very small disturbance.

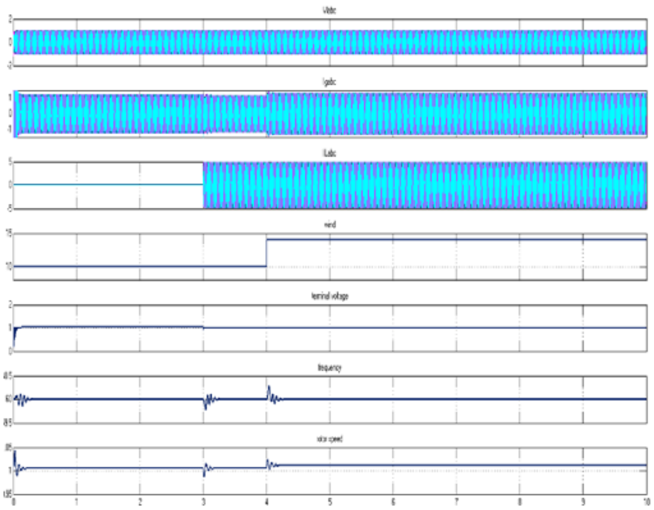

Fig. 6: Waveforms of variables during variable wind speed

8.2.3.Unbalanced loading. from fig. 6 it is observed that when at time 4 sec. one phase of load is open together with the change in wind speed , load current becomes unbalanced but still our voltage and frequency are unchanged.

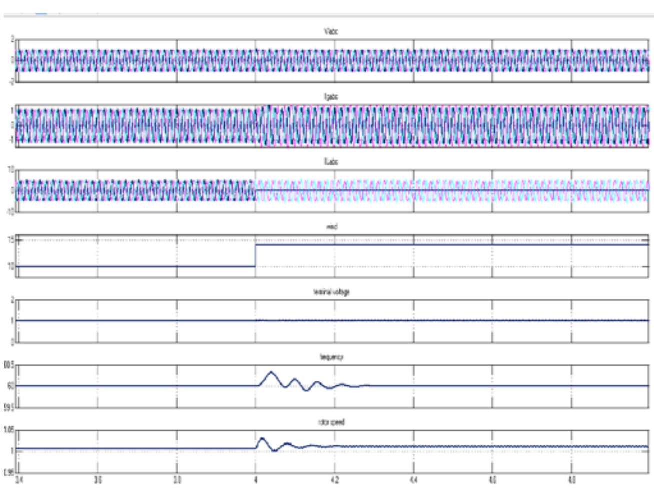

Fig. 7: Waveforms of variables during unbalanced loading

9. CONCLUSION

The performance of voltage and frequency controller has been analyzed in conjunction with isolated induction generator for three different cases(variable wind, variable load, unbalanced load) and it is observed that VF controller worked in desirable manner .The ultimate goal of improving voltage and frequency regulation of wind energy conversion system employing induction generator is achieved .

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APPENDIX

The parameter of 3.7 KVA ,460V,60 Hz,4 pole induction machine is as follows.

Rotor type	**Squirrel cage**
Reference frame	Rotor
Rs, Rr	0.01965,0.01909
Ls,Lr	0.0397, 0.0397
unit	p.u

Wind turbine specification

Rating 3KW, $Cpmax$ = 0.48, λm = 8.1

C1= 0.5176, C2= 116, C3=0.4, C4= 5, C5= 21, C6= 0.0068,

C7= 0.08, C8= 0.035.