Voltage and Frequency Control of Asynchronous Generator for an Isolated Wind Energy Conversion System

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Abstract: ***This paper deals with a battery energy storage system (BESS) and an IGBT (Insulated Gate Bipolar Junction Transistor) based 4 leg voltage source converters. Three legs of the converter are connected to each phase of the generator while the fourth leg is used to compensate the source neutral current. A star connected three phase capacitor bank is used for the generator excitation and the value of the excitation capacitor is selected to generate the rated voltage at no load. The proposed controller is having capability for harmonic elimination, load balancing , bidirectional flow capability of active power and reactive power by which it can control the system voltage and frequency with variation of consumer loads and the speed of the wind. The proposed generating system is modeled and simulated in MATLAB along with Simulink and power system blockset (PSB) toolboxes. The simulated results are presented to demonstrate the capability of an isolated generating system for feeding three-phase four-wire loads with the neutral current compensation.***

Keywords: Asynchronous generator, BESS, isolated generating system, neutral current compensations

1. Introduction

The increasing interest in renewable energy sources , simple constructible machine (Induction Generator), power quality improvement, uncertainty in power output, isolated system integration , induction generator poor voltage regulation , induction generator reactive power requirement, and uncertainty in consumer load give attention to power engineer about the maximum power tracking, reactive power supply of generator , interconnection of network, voltage and frequency control of load and storage of power. Also ancillary services, power system restructuring constraint give more attention to think about load and frequency control system with proper control strategy [1],[3]. On view of these here we are selecting proposed load and frequency control system. Renewable energy sources have attracted attention worldwide due to soaring prices of fossil fuels. Renewable energy sources are considered to be important in improving the security of energy supplies by decreasing the dependency on fossil fuels and in reducing the emissions of greenhouse gases (GHG). The viability of isolated systems using renewable energy sources depends largely on regulations and stimulation measures. Renewable energy sources are the natural energy resources that are inexhaustible: for example, wind, solar, geothermal, biomass and small-hydro generation [2]. Amongst renewable energy sources, small-hydro and wind energy have ability to complement each other [2]. For power generation by small or micro–hydro as well as wind systems, the use of squirrel cage induction generators (SCIGs) has been reported in literature [4]-[16].

Although the potential for small hydroelectric systems depends on the availability of suitable water flow, where the resource exists it can provide cheap, clean, reliable electricity [6]. Hydroelectric plants convert the kinetic energy of a waterfall into electric energy. The power available in a flow of water depends on the vertical distance the water falls (i.e., head) and the volume of flow of water in unit time (i.e., discharge). The water powers a turbine, and its rotation movement is transferred through a shaft to an electric generator [7]. When SCIG is used for small wind power applications, its reactive power requirement is met by a capacitor bank at its stator terminals [8]. The SCIG has advantages like simplicity, low cost, rugged, maintenance free, absence of DC, brushless etc. [7].

As regards wind turbine-generators, these can be built either as constant-speed machines, which rotate at a fixed speed regardless of wind speed, or as variable-speed machines in which rotational speed varies in accordance with wind speed. For fixed speed wind turbines, energy conversion efficiency is very low for widely varying wind speeds. In recent years, wind turbine technology has switched from fixed-speed to variable-speed. The variable speed machines have several advantages. They reduce mechanical stresses, dynamically compensate for torque and power pulsations, improve power quality, and system efficiency [7]. The grid connected variable speed wind energy conversion system based on SCIG use back to back connected power converters [9]. In such systems, the power converter decouples the SCIG from the grid, resulting in an improved reliability. Flux oriented control of induction generator has been demonstrated in [9] as vector control of induction generator for wind power. Voltage and frequency control of load has been reported by different way [11, 12 and 13]. Battery based load voltage and frequency controller has been given in [17, 18 and 19]. Self excitation capacitance calculation has been reported in [5, and 6]. Charging battery mathematical model has been demonstrated in [14, and 15]. Electronic load voltage controller by IGBT has been reported in [3]. Proposed electronic load controller acts as a reactive power controller, load balancer and load controller.

2. System configuration and control scheme

Figure 1 & Figure 2 shows the system configuration and a control strategy of an asynchronous generator. The control scheme of the STATCOM to regulate the terminal voltage of the generator is based on the generation of reference source currents, which have two components, in-phase and quadrature, with the ac voltage. The in-phase unit templates (Ua, Ub and Uc) are three-phase sinusoidal functions, computed by dividing the ac voltages (Vla, Vlb and Vlc) by their amplitude. Another set of quadrature unit templates (Wa, Wb and Wc) are sinusoidal functions obtained from in-phase templates (Ua, Ub and Uc). To regulate the ac terminal voltage Vtm , it is sensed and compared with the reference voltage. The voltage error is processed in the proportional integral (PI) controller.

The output of the PI controller ($i^r{}_{smq}$) for an ac voltage control loop decides the amplitude of reactive current to be generated by the STATCOM. Multiplication of quadrature unit templates (Wa, Wb and Wc) with the output of the PI-based ac voltage controller $i^r{}_{smq}$ yields the quadrature component of the reference source currents ($i^r{}_{saw} i^r{}_{sbw}$ and $i^r{}_{scw}$). The amplitude of active power component of the source current (Idm) is estimated by dividing the difference of filtered load power (PLfilter) and output of PI frequency controller (Pc) to the amplitude of the terminal voltage (Vtm). Multiplication of Idm with in-phase unit templates (Ua, Ub and Uc) yields the in-phase component of reference source currents. The instantaneous sum of quadrature and in-phase components provides the reference source currents ($i^r{}_{sa}, i^r{}_{sb}$ and $i^r{}_{sc}$), which are compared with the sensed line currents (i_{sa}, i_{sb} and i_{sc}). These current error signals are amplified and compared with the hysteresis controller to generate the gating signals for IGBTs of the VSC. Fourth leg of the STATCOM is used to compensate the source neutral current (i_{sn}) that is maintained at zero reference value ($i^r{}_{sn}$) through switching of the IGBTs of this leg.

3. Control algorithm

Basic equations of the control scheme of the proposed controller for an asynchronous generator are developed in this section.

3.1 Control Algorithm for the STATCOM

Different components of the STATCOM used in asynchronous generator-system shown in Figure 1 & Figure 2 are modeled as follows.

Three line voltages at the generator terminals (Vla, Vlb and Vlc) are considered sinusoidal, and hence their amplitude is computed as

$$V_{tm} = \{(2/3)(V_{la}{}^2 + V_{lb}{}^2 + V_{lc}{}^2)\}^{1/2}$$

The unit template in phase with (Vla, Vlb and Vlc) are derived as

$$U_a = V_{la}/V_{tm}; U_b = V_{lb}/V_{tm}; U_c = V_{lc}/V_{tm}$$

The unit template in quadrature with (Vla, Vlb and Vlc) may be derived using a quadrature transformation of the in-phase unit template (Ua, Ub and Uc) as

$$W_a = -U_b/\sqrt{3} + U_c/\sqrt{3}$$
$$W_b = \sqrt{3}U_a/2 + (U_b - U_c)/2\sqrt{3}$$
$$Wc = -\sqrt{3}U_a/2 + (U_b - U_c)/2\sqrt{3}$$

3.1.1 Quadrature Component of Reference Source Currents

The ac voltage error $V_{er(n)}$ at the nth sampling instant is

$$V_{er(n)} = V_{tref(n)} - V_{t(n)}$$

where $V_{tref(n)}$ is the amplitude of reference ac terminal voltage and $V_{t(n)}$ is the amplitude of the sensed three-phase ac voltage at the generator terminals at nth instant.

The output of the PI controller ($i^r{}_{smq(n)}$) for maintaining the ac terminal voltage constant at the nth sampling instant is expressed as

$$i^r{}_{smq(n)} = i^r{}_{smq(n-1)} + K_{pa}\{V_{er(n)} - V_{er(n-1)}\} + K_{ia}V_{er(n)}$$

where K_{pa} and K_{ia} are the proportional and integral gain constants of the PI controller. $V_{er(n)}$ and $V_{er(n-1)}$ are the voltage errors in nth and (n-1)th instants and $i^r{}_{smq(n-1)}$ is the amplitude of quadrature component of the reference source current at (n-1)th instant.

The quadrature components of reference source currents are computed as

$$i^r{}_{saw} = i^r{}_{smq}.w_a; i^r{}_{sbw} = i^r{}_{smq}.w_b; i^r{}_{scw} = i^r{}_{smq}.w_c$$

3.1.2 In Phase Component of Reference Source Currents

Active component of reference source current is estimated by dividing the difference of filtered instantaneous load power (PLfilter) and output of the PI frequency controller to the terminal voltage Vtm . The load power PL is estimated as by taking three phases to two phase transmitter.

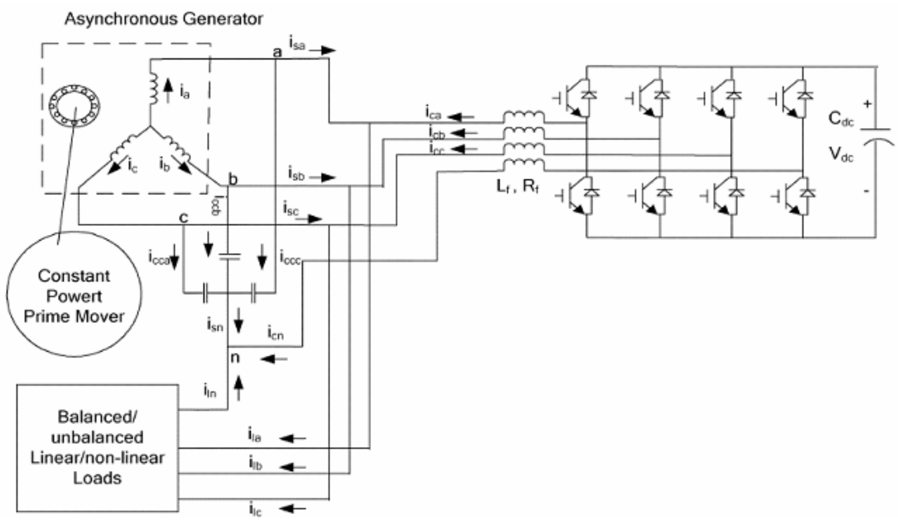

Figure 1: Schematic diagram of BESS based VF controller for isolated wind energy conversion system

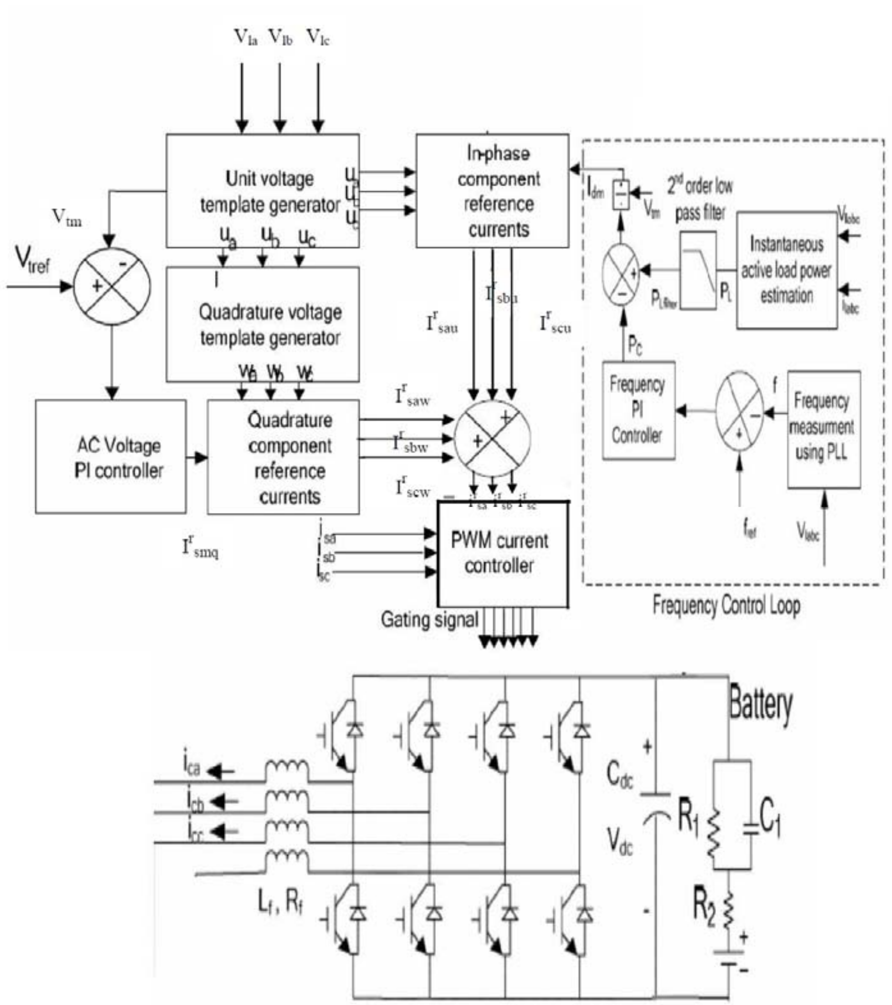

Figure 2: Schematic diagram of control scheme for VSC based VF Controller

$$V_1 = (\sqrt{2/3})(V_{la} - 1/2V_{lb} - 1/2V_{lc})$$
$$V_2 = (\sqrt{2/3})(\sqrt{3/2}V_{lb} - \sqrt{3/2}V_{lc})$$
$$i_1 = (\sqrt{2/3})(i_{la} - 1/2i_{lb} - 1/2i_{lc})$$
$$i_2 = (\sqrt{2/3})(\sqrt{3/2}i_{lb} - \sqrt{3/2}i_{lc})$$

Instantaneous active power is estimated as

PL =V1i1 + V2i2

It is filtered to achieve its DC component (PLfilter).

Then active component of reference source current Idm is calculated as

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

The instantaneous line voltage is at the terminal of an asynchronous generator (Vla, Vlb and Vlc) are considered sinusoidal and their amplitude is computed as

$$V_{tm} = \{(2/3)(V_{la}^{\ 2} + V_{lb}^{\ 2} + V_{lc}^{\ 2})\}^{1/2}$$

The unity amplitude templates are having instantaneous value in phase with instantaneous voltage (Vla, Vlb and Vlc) which are derived as

$$U_a = V_{la} / V_{tm}; U_b = V_{lb} / V_{tm}; U_c = V_{lc} / V_{tm}$$

Instantaneous values of in phase component of reference source currents are estimated as

$$i^r{}_{sau} = I_{dm}U_a; i^r{}_{sbu} = I_{dm}U_b; i^r{}_{scu} = I_{dm}U_c$$

3.1.3 Reference Source Currents

Total reference source currents are a sum of in-phase and quadrature components of the reference source currents, as follows:

$$i^r{}_{sa} = i^r{}_{saw} + i^r{}_{sau}$$
$$i^r{}_{sb} = i^r{}_{sbw} + i^r{}_{sbu}$$
$$i^r{}_{sc} = i^r{}_{scw} + i^r{}_{scu}$$

3.1.4 Neutral Current Compensation

The fourth leg of the VSC of the STATCOM is used to compensate the source neutral current and is controlled at the reference value ($i^r{}_{sn}$). The source neutral current (i_{sn}) which is sum of source phase currents is compared with its reference value ($i^r{}_{sn}$).

$$i^r{}_{sn} = 0; i_{sn} = i_{sa} + i_{sb} + i_{sc}; i_{snerr} = i^r{}_{sn} - i_{sn}$$

The current error signal i_{snerr} is amplified and compared using a hysteresis current controller for generating the PWM signal for switching of the fourth leg of the VSC. For making source neutral current (i_{sn}) "zero", the compensating current should be equal and opposite in direction of sum of load currents.

3.1.5 PWM Current Controller

The reference currents ($i^r{}_{sa}$, $i^r{}_{sb}$ and $i^r{}_{sc}$) are compared with the sensed source currents (i_{sa} , i_{sb} and i_{sc}). The ON/OFF switching patterns of the gate drive signals to the IGBTs are generated from the PWM current controller. The current errors are computed as

$$i_{saerr} = i^r{}_{sa} - i_{sa}$$
$$i_{sberr} = i^r{}_{sb} - i_{sb}$$
$$i_{scerr} = i^r{}_{sc} - i_{sc}$$

These current error signals are amplified and then compared in the PWM hysteresis controller for switching of the IGBT of the VSC of the STATCOM.

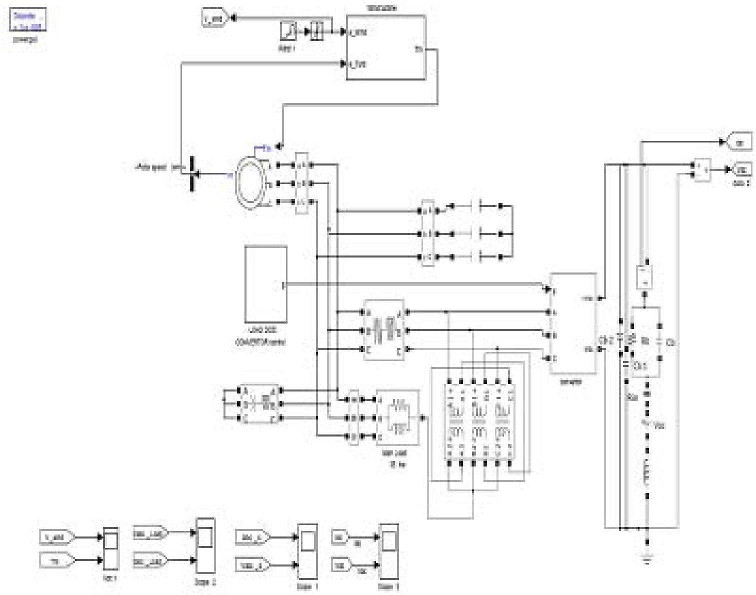

Figure 3: MATLAB Based Simulation model of the asynchronous generator with STATCOM Based VFC.

4. Results and discussion

The performance of the proposed controller is demonstrated under different electrical and mechanical dynamic condition Fig. 4 shows the performance of the controller for supplying balanced / unbalanced non-linear loads under the condition of varying wind speeds and it is observed that in all such conditions the controller response in a desirable manner . Simulated transient wave forms of the generator voltage (Vabc), generator current (iabc), load currents (ilabc) speed of the wind (vw), battery current (ib), battery voltage (vb) are given in different dynamic conditions.

5. Conclusion

The performance of an isolated asynchronous generator based voltage and frequency controller for isolated wind energy conversion system has been demonstrated for load leveling, voltage and frequency regulation. The proposed controller is having good capability for harmonic elimination, load balancing, and load leveling and voltage and frequency control. MATLAB based simulation results have shown the satisfactory performance for the proposed electrical distribution system feeding linear and non-linear loads.

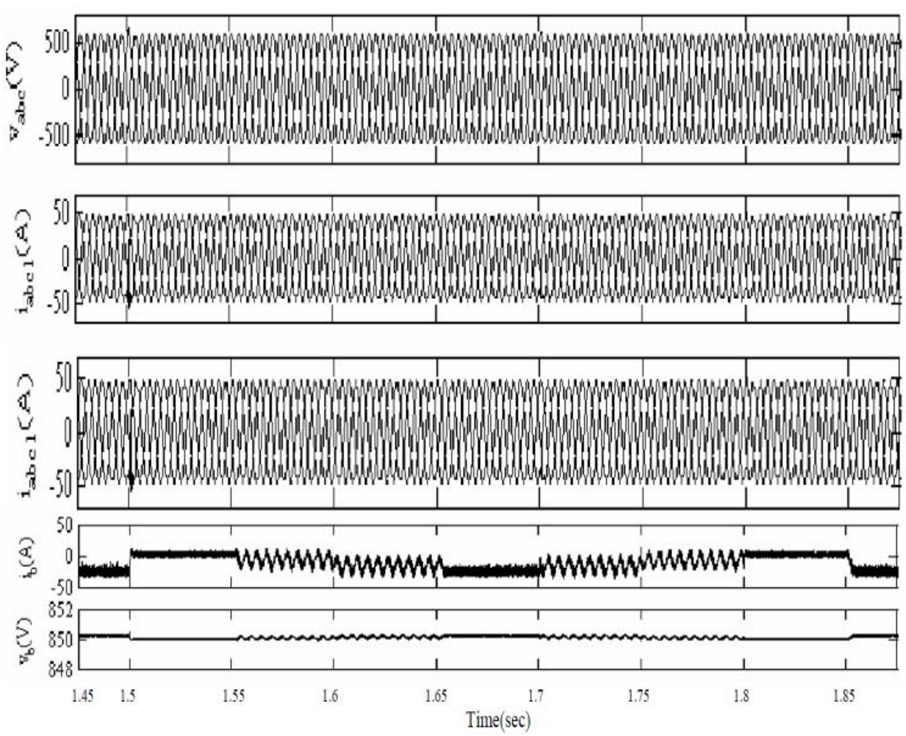

Figure 4: Performance of the controller under the condition of varying wind speed and load

6. Appendix

1) Parameters of 40-kW 415-V 50-Hz Y-connected four-pole:
Rs = 0.09961 Ω
Ls = 0.867 mH
Rr = 0.058 Ω
Lr = 0.867 mH
Lm = 0.030369 H
Inertia = 0.4 kg •.

2) Parameters of 40-kW wind turbine:

Wind-speed range = 6.0−11.2 m/s
Speed range = 43−81 r/min
I = 13.5 kg •
r = 7.5 m
= 0.4412
λ^* = 5.66

3) PI Controllers: Voltage controller:
= 15
= 0.05.

4) Transformer Specifications:

Three single-phase transformers of 15 kVA 138/138 V, connected in zigzag manner

5) Battery Specifications:
= 43 156 F
= 10 kΩ
= 0.2 Ω
= 750 V
= 680 V
Storage = 600 kW • h
L = 1 mH.

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