Efficient Control of Stand Alone Self-Excited Induction Generator by Using Statcom

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Abstract: This paper presents an energy storage unit supported Static Synchronous Compensator (STATCOM) for voltage and frequency control of wind turbine driven Self Excited Induction Generator (SEIG) system. The battery energy storage unit is integrated to the STATCOM to maintain the continuity of power supply during the unavailability of wind blow. The proposed control scheme extracts reference current signal and controls the voltage and frequency of the SEIG system. This system offers coordinating logic meant for effective power utilization and handles different state of the situation with continuation of clean power supply to the load. The STATCOM that can handle various sorts of loads can enumerate the effectiveness of the system under stable and non stable situation. The simulation results are validated to ensure the performance of the proposed renewable energy utilization system for uninterrupted clean power supply.

Key words: DC-DC converter · Self-Excited Induction Generator · Voltage and frequency control · Total harmonic distortion

INTRODUCTION

Day by day availability of non- renewable energy source is rapidly decreasing as technological growth focuses on its usage. This has resulted severe scarcity of coal, petroleum and natural gas. It is mandatory to extract energy from renewable energy source such as solar, wind, tidal, biogas, etc. Moreover the environment is greatly affected by conventional energy source. Erecting the equipment and infrastructure for power generation through conventional energy source is also expensive due to transportation and maintenance of established structure in the remote areas such as hill stations, island and the places where grid station is not available. In this paper power generation is produced from wind energy through SEIG. The power quality can be ensured with the help of custom power devices. So, that voltage and frequency are confined to specified magnitude [1, 2]. This would enable the end user to enjoy the disturbance free power supply. The turbine run by resources like bio-gas, tidal and gasoline can be operated at a constant speed. Though SEIG is employed with a stable speed turbine, the power disturbance factor such as voltage fluctuations occurs due to changes in load to SEIG [3-5]. Whenever SEIG meets the variable load, a huge reactive power is required by SEIG. Hence fluctuation in the system would become very larger. In order to overcome the power fluctuation due to the reactive power requirement, the compensators such as SVC, STATCOM has been equipped with the power generation system [6, 7]. Some applications use the electronic controller to rid of the reactive power compensation problem. The SEIG supported by a wind turbine is forced to an interrupted power generation as wind blow is not constant all the time. The voltage amplitude and frequency of generated power could not be constant in the SEIG run by wind energy under a dynamic change in speed and load [8-11].

The various topologies and frequency and voltage controller are already designed by experts all over the world for the smooth rhythm of frequency and voltage in induction generators of types such as wound rotor and squirrel cage. A SEIG can be used as a stand alone system or the power generated through this can also be connected to a grid which offering supply to various loads. Like synchronous in frequency and voltage (linear loads), improper proportion in voltage and frequency (non-linear loads) and dynamic loads. The stable and variable state analysis of SEIG had already been performed with these loads [12-17]. In the place, where stand alone power generating system is the only source

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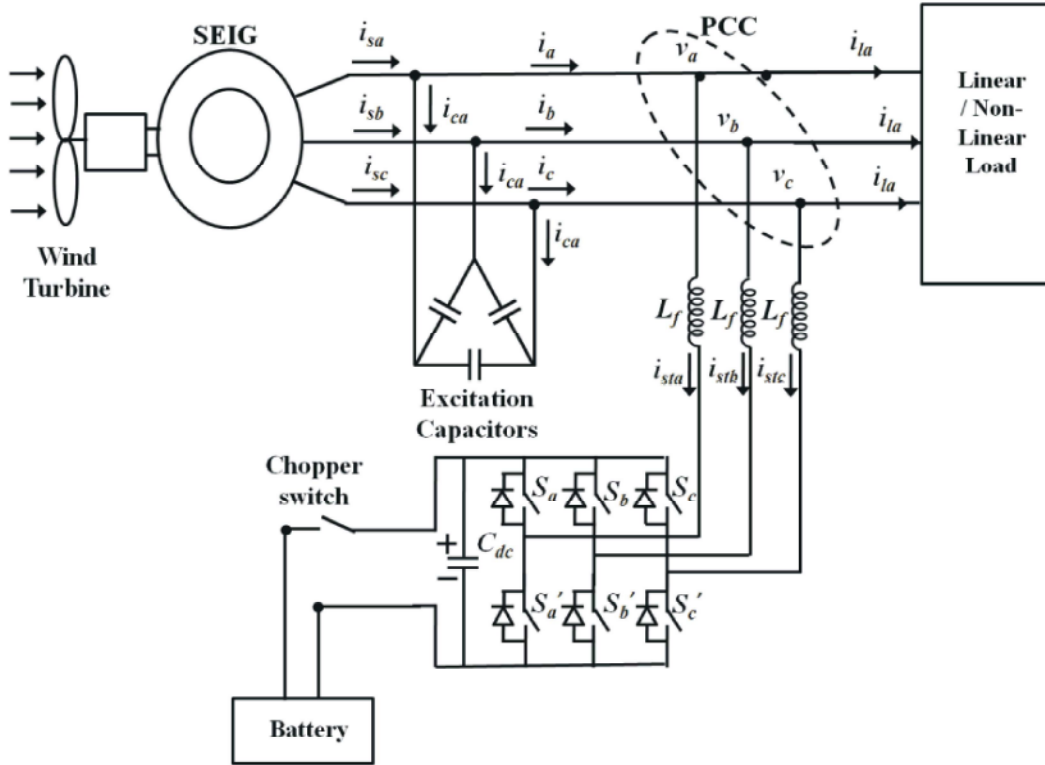
Fig. 1: Schematic diagram of proposed wind energy conversion system with STATCOM

to fulfill the supply power to the loads like running an induction motor for small cottage industries (sawmill, flour mill, rice mill etc.) and mandatory power supply for lighting houses and street lamp. As these loads have non linear characteristics, regulation of voltage has become as essential task in the stand alone power generating system. To overcome the voltage regulation problem and harmonics in the nonlinear load, the SEIG system is equipped with a voltage regulator and the system's performance is tested under dynamic load conditions [18-20].

Whenever power fluctuation occurs, an active power is supplied by the voltage regulator to withstand the voltage on its constant state. However the STATCOM can perform the voltage regulation for a certain limit of active power. To strengthen its ability further some conventional energy storage devices such as battery or condenser are used [21- 23]. In order to extend its ability to perform compensation for a long period, an additional energy storage device is required to support the DC link of STATCOM. The SEIG is made work more effectively with the coordinating logic, which focuses on frequency and voltage regulation and uninterrupted clean power supply at different states of condition dynamically faced by the power generator.

System Description: The SEIG system with bateery supported STATCOM is shown in Fig. 1. The topology of the proposed system the VSI is linked to the Point of Common Coupling (PCC) through the interfacing inductor. The SEIG power generating system consisting of the wind turbine, SEIG and excitation capacitors. Battery baink is utilized to maintain the DC link voltage of the STATCOM in long term. When the excessive power generated by SEIG system is identified, the chopper switch is initiating the task of storing this excessive electrical energy via battery. This stored energy is utilized to maintain the DC link voltage of STATCOM. The SEIG systemis supported by the STATCOM to provide the voltage and frequency regulation and harmonic compensation.

Modeling of the Self-excited Induction Generator: The 3 phase SEIG dynamic model is designed with the help of the stable dq axes reference frame and the volt ampere associated with reference frame is shown in the below expressions [24].

$$[V] = [R][I] + [L]p[I] + w_r[G][I] \qquad (1)$$

The current derivative can be formulated as:

$$p[I] = [L]^{-1}\{[V] - [R][I] - w_r[G][I]\} \qquad (2)$$

The matrices of voltage, current and resistance are expressed as mentioned in the expressions.

$$[V] = [V_{ds} \, V_{qs} \, V_{dr} \, V_{qr}]^T \qquad (3)$$

$$[I] = [I_{ds} \, I_{qs} \, I_{dr} \, I_{qr}]^T \qquad (4)$$

$$[R] = \text{diag}[R_s \, R_s \, R_r \, R_r] \qquad (5)$$

$$L = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \qquad (6)$$

$$G = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & L_m & 0 & 0 \\ -L_m & 0 & -L_r & 0 \end{bmatrix} \qquad (7)$$

The SEIG operated in the saturation zone, it's magnetization characteristics are not order with respect to current changes. Because of this nature, the magnetizing current is to be calculated every now and then considering stator and rotor currents. The magnetising current calculated as;

$$I_m = \sqrt{(I_{ds} + I_{dr})^2 + (I_{qs} + I_{qr})^2} \qquad (8)$$

The torque to generated by the SEIGis written in the expression (9)

$$T_e = (3P/4) L_m (I_{qs}I_{dr} - I_{ds}I_{qr}) \qquad (9)$$

The torque balance is identified by using the expression (10)

$$T_{shaft} = T_e + J(2/P) p\omega_r \qquad (10)$$

The rotor speed is calculated from torque equation and expressed as in Equation (11)

$$p\omega_r = (2/P)(T_{shaft} - T_e)/J \qquad (11)$$

Control Scheme of the STATCOM Supported SEIG System: The functional sketch of implementing the proposed control approach is depicted in Fig. 2. In this control approach Synchronous Reference Frame (SRF) theory is adopted for calculation of source reference current [25, 26]. The load currents and source voltage are taken as a feedback signal. The load currents are transformed d-q-0 frame from a-b-c frame with aid of unit vectors as denoted in Equation (12).

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2p}{3}) & \cos(\theta + \frac{2p}{3}) \\ -\sin\theta & -\sin(\theta - \frac{2p}{3}) & -\sin(\theta + \frac{2p}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \qquad (12)$$

The three-phase Phase Locked Loop (PLL) fetches the values for the unit vectors ($\sin\theta$, $\cos\theta$). The d and q axis currents have fundamental and harmonic components together. After the attainment of d-q-0 frame of load currents, DC component (i_{Ld}) obtained from the d-axis component with the help of Low Pass Filter (LPF). This extraction leads to the separation of non-DC quantities from the reference signal.

After the conversion of d-q-0 frame component of load currents, DC component (i_{Ld}) extracted from the d-axis component through the Low Pass Filter (LPF). Hence, non-DC quantities (harmonics) separate from the reference signal.

$$i_{Ld} = i_{ddc} + i_{dac} \qquad (13)$$

Computation of D-Axis Current for Source Currents Using: The frequency is sensed by giving three-phase source voltage as input to the PLL. The sensed system frequency is matched with the reference frequency magnitude and the error in frequency is fed into PI controller. The frequency regulator assisted with PI controller can generate i_{db} to produce the gate pulses for the VSI of -STATCOM.

The frequency error is notified as;

$$f_{e(n)} = f_{ref} - f(n) \qquad (14)$$

where, f_{ref} is the reference frequency, $f_{(n)}$ is the sensed frequency of the load voltage.

Fig. 2: Block diagram of the proposed controller for STATCOM

The value identified for $f_{e(n)}$ through expression (14) is given as input for PI controller. The i_{db} value received from PI controller by the process of identification is used to find the three-phase source reference current.

The output of the frequency regulator is measured as the active current to be taken by the VSI.

$$i_{db(n)} = i_{db(n-1)} + K_{pd}(f_{e(n)} - f_{e(n-1)}) + K_{id} f_{e(n)} \quad (15)$$

The d-axis source reference current is determined by the Equation (16).

$$i_d^* = i_{ddc} - i_{db} \quad (16)$$

Computation of Q-Axis Current for Source Currents:
The voltage regulator calculates reactive component of the supply current. The STATCOM control scheme houses the to improve the voltage regulation of the system. The expression denoted in the Equation (17) can estimate the magnitude of AC voltage (V_S) at the load point.

$$V_s = \sqrt{2/3} \sqrt{V_{sa}^2 + V_{sb}^2 + V_{sc}^2} \quad (17)$$

Then, a PI controller is used to regulate this voltage to a reference value as,

$$i_{qr(n)} = i_{qr(n-1)} + K_{pq}(V_{se(n)} - V_{se(n-1)}) + K_{iq} v_{te(n)} \quad (18)$$

where, $V_{se(n)} = V_S - V_{s(n)}$ denotes the error between reference (V_S^*) and actual ($V_{s(n)}$) terminal voltage amplitudes at the nth sampling instant. Kpq and Kiq are the proportional and the integral gains of the voltage PI controller. The AC regulator assisted with PI controller can generate i_{qr} to produce the gate pulses for the VSI of STATCOM. The value identified for $V_{se(n)}$ is given as input for PI controller. The i_{qr} value received from frequency regulator by the process of identification is used to find the three-phase source reference current. The performance of the PI controller to regulate load voltage rely on i_q^* (quadrature axis reference current) and the same is identified using the following expression.

$$i_q^* = i_{qdc} - i_{dr} \quad (19)$$

Estimation of Reference Source Current and PWM Generator: The values (i_{db} and i_{qr}) obtained from frequency and voltage regulator are used to identify reference quantities (i_d^* and i $^*)_q$ These reference quantities are given as input to reference current estimator in order to find out reference source current. The d and q-axis reference frame quantities are translated to a-b-c reference frame quantities based on the theory of park's transformation.
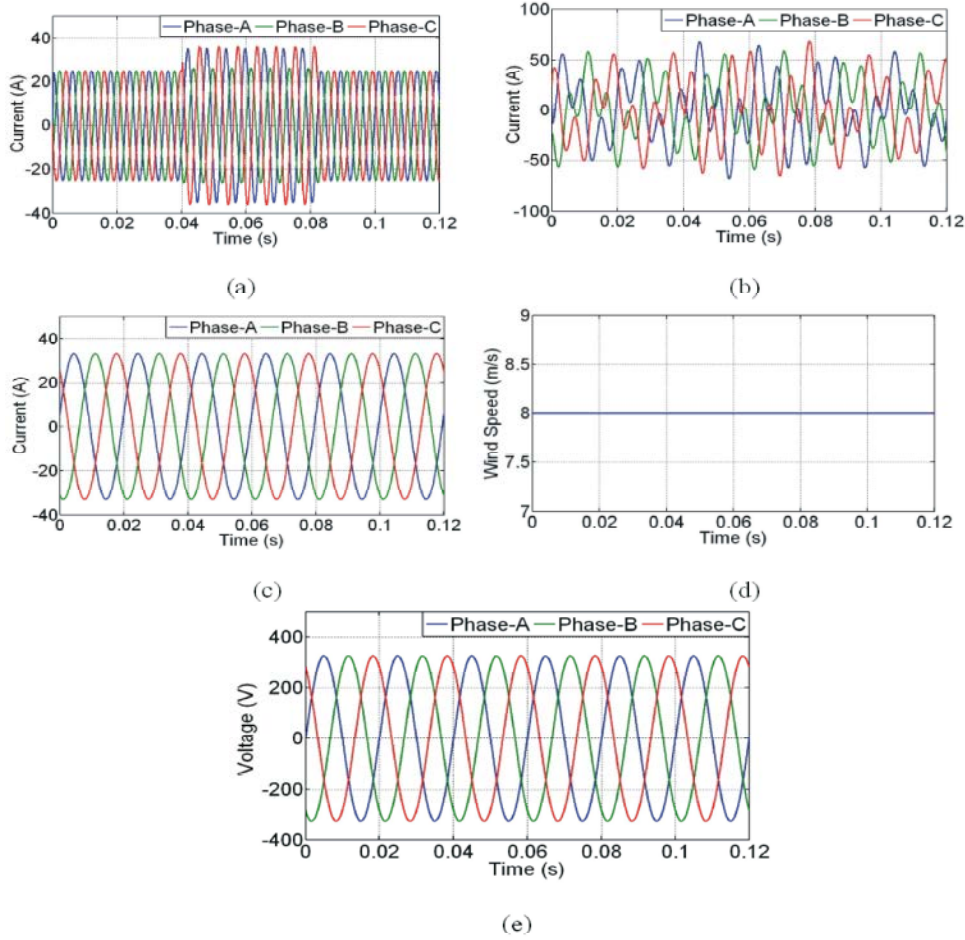
Fig. 3: Simulation results under balanced /unbalanced linear loads at stable wind speed: (a) load currents (i_{labc}) before implementing -STATCOM (b) injected current for compensation (c) source currents (i_{sabc}) after implementing -STATCOM (d) wind speed (V_w) (e) generator voltage after implementing -STATCOM

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos(\theta - \frac{2p}{3}) & -\sin(\theta - \frac{2p}{3}) & 1 \\ \cos(\theta + \frac{2p}{3}) & -\sin(\theta + \frac{2p}{3}) & 1 \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \\ i_0^* \end{bmatrix}$$

(20)

After the process gets over at the reference current estimator, switching comments are established with the help of reference and actual quantities by following hysteresis band current control method.

The proposed STATCOM employed PWM current generator produces the firing pulses by comparing reference and sensed source current (i^*_{sabc} & i_{sabc}).

Simulation Results: The proposed STATCOM incorporating features yielded by SRF theory uses

MATLAB / Simulink software to asses the performance under unbalanced and distorted load current and source voltage conditions. The simulation study shows the result of SEIG power generating system before and after installation of STATCOM. The effectiveness of the system implemented in this paper has been analysed under various load conditions. They are as follows case1: balanced /unbalanced linear loads at constant wind speed case2: balanced non-linear loads at varying wind speed and case3: unbalanced non-linear loads at varying wind speed. The precise simulation results are narrated in the following sections for above cited load conditions.

Balanced /Unbalanced Linear Loads at Constant Wind Speed: In this scenario the load currents are made unbalanced by circuiting a single-phase diode rectifier linked between two phases. Fig. 3 displays the digital simulation results of load currents (i_{labc}) before
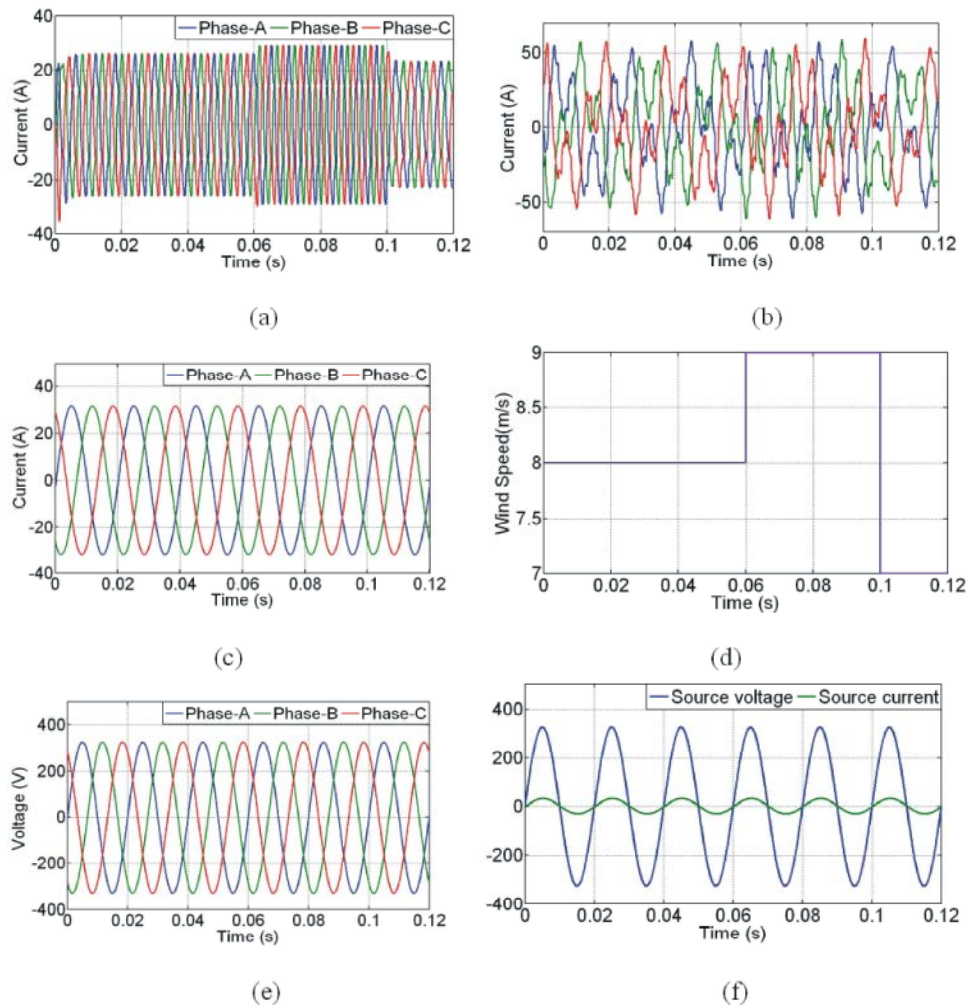
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Fig. 4: Simulation results under Balanced non-linear loads at varying wind speed: (a) load currents (i_{labc}) before compensation (b) injected current for compensation (c) source currents (i_{sabc}) after compensation (d) wind speed (V_w) (e) generator voltage after compensation (f) source voltage (e_{sa}) superimposed by the source current (i_{sa})

implementing STATCOM, injected current for compensation, source currents (i_{sabc}) after implementing STATCOM, wind speed (V_w) and generator voltage after implementing -STATCOM. Results in this case is verified on applying linear different quantum of load from the phases a, b and c. The system has the capability of maintaining balance in voltage and current though it is suffering from the linear unbalanced load.

Balanced Non-Linear Loads at Varying Wind Speed:
Fig. 4 portrays digital simulation waveforms for balanced, non linear loads with variable wind blowing. It is noticed that the voltage and frequency remain balanced, though fluctuation in wind blow various abruptly. In Fig. 4 (a) up to the time limit 0.06 sec wind blow was as expected (8m/s)

after that wind blow varied that lasted 0.1sec, whenever wind blow increases, the contribution of the system is limited because sufficient energy is generated from wind energy conversion system itself. During the period 0.1sec the wind blow is reduced to 7m/s from 9m/s the system gets ready to offer its contribution as usual.

Unbalanced non Linear Loads at Varying Wind Speed:
The impact on performance of the system under unbalanced non-linear load at rapid change in wind speed is analyzed. Unbalanced load is created during the period between 0.04 to 0.08sec. The system is able to identify the condition and with stands to compensate the current which results in maintaining the balanced current and voltage at the generator terminal.
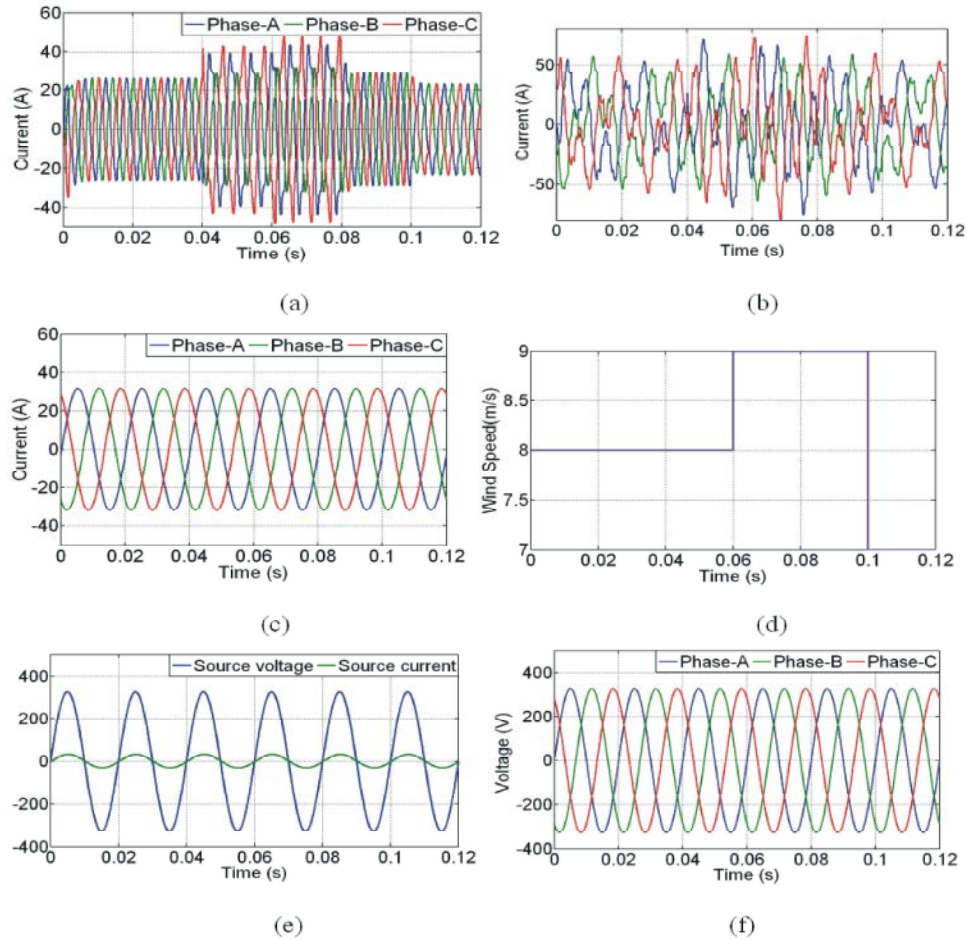
Fig. 5: Simulation results under unbalanced non linear loads at varying wind speed: (a) load currents (i_{labc}) before compensation (b) injected current for compensation (c) source currents (i_{sabc}) after compensation (d) wind speed (V_w) (e) generator voltage after compensation (f) source voltage (e_{sa}) superimposed by the source current (i_{sa})
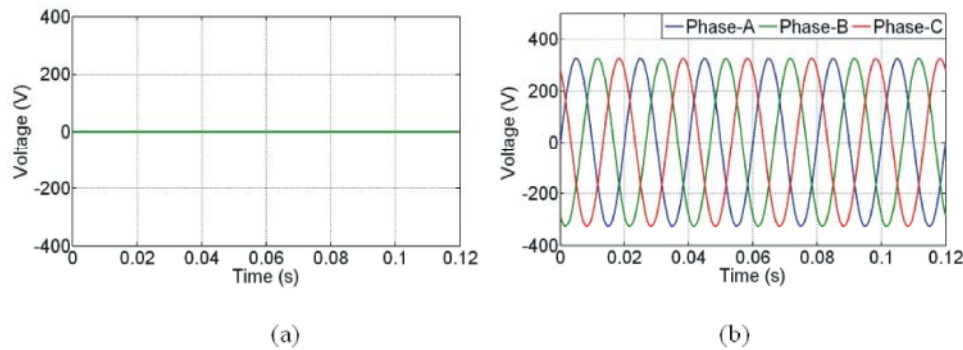

Fig. 6: Voltage interruption compensation during absence of wind blow: (a) generator voltage before compensation (b) load voltage after compensation

Fig. 5 shows the load currents (i_{labc}) before compensation, injected current for compensation, source currents (i_{sabc}) after compensation, wind speed (V_w), source voltage after compensation and source voltage (e_{sa}) overlayed by the source current (i_{sa}). The system provides features that offering uninterrupted balanced power supply to the load, even at the time of unavailability of wind blow naturally and at the time maintenance work is
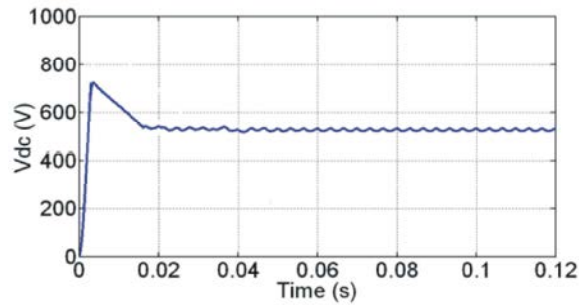
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Fig. 7: DC link voltage of the STATCOM

being carried out. During these times supply are made available to the load through the power generating system. Fig. 6 depicts the voltage during the lack of wind blow and load voltage after implementing STATCOM.

Fig. 7 displays the DC link voltage of the - STATCOM. THD experienced in the system before installing STATCOM showing values 22.5%, 26.5% and 27.2% have been diminished to 2.23%, 3.25% and 2.65% after smooth compensation done by -STATCOM. After the compensation it is noticed that the value of THD falls under the limit standardized by IEEE STD 519-1992 [27]. Digital simulation results clearly study that based STATCOM is able to get rid of harmonic components and bias in load current with sound enough to eliminate voltage distortions..

CONCLUSION

This paper has proposed the SEIG system incorporated with STATCOM that focuses on compensating voltage and frequency. The SEIG can be erected at remote places where the utility grid cannot be easily deployed or in the area isolated from the service of the grid. The performance of the system has been ensured with the help of control algorithm implemented in the controller under the conditions of balanced/unbalanced linear loads with instability in wind blown. The combination of hybrid renewable energy source proposed in the system can reduce the harmonics related to voltage and current fluctuation. The system with provision of the energy storage unit can ensure the effective utilization of energy source available, though they are in different form. The compensation at the terminal is done by establishing a co-ordinating logic among wind mill and the battery. The performance of the system has been analyzed with the help of simulation results.

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