IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

Impact Factor: 6.252

Volume 2, Issue 2, July 2022

Synchronization and Control of Battery Based Wind Energy Conversion System

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Abstract: *In this proposed work, a battery based wind energy conversion system is developed for voltage and frequency regulation for isolated locations for 3-phase 4-wire system. The isolated system consists of wind turbine, self excited induction generator (SEIG), capacitor bank, voltage source converter (VSC), battery system and nonlinear load. A modified least mean square (MLMS) control is utilized to extract the fundamental component from load current and generate switching pulses for VSC. The proposed control with VSC provides voltage/frequency regulation, harmonics suppression, power support, load balancing and enhances the overall power quality of the isolated system. A battery system is developed at dc-side of the VSC to consume extra power under minimum load demand and maintain the power balance at point of common coupling (PCC) between power generation and load. The proposed system is designed in MATLAB/Simulink environment under different operating conditions.*

Keywords: Point of Common Coupling, Self Excited Induction Generator, VSC

I. INTRODUCTION

A voltage regulator for parallel operated isolated asynchronous generators (IAGs) supplying three-phase four-wire loads driven by constant speed prime mover like diesel engine, bio-mass, gasoline, etc. The proposed voltage regulator is realised using a static compensator (STATCOM) for providing the reactive power compensation, harmonic elimination and load balancing. Three single-phase insulated gate bipolar transistors (IGBTs) based VSCs along-with three single-phase transformers and self-supporting DC bus are used as a voltage controller for supplying three-phase four-wire loads. The neutral point of the load is achieved using the neutral point of the excitation capacitors and primary windings terminal of the transformers [1]. An analysis and design of an electronic load controller (ELC) for three-phase self-excited induction generators (SEIGs) suitable for standalone pico-hydro power generation with constant input power. Here, the SEIG can be used to generate constant voltage and frequency if the electrical load is maintained constant at its terminals. Moreover, under such operation, SEIG requires constant capacitance for excitation resulting in a fixed-point operation. For this purpose, a suitable control scheme has to be developed such that the load on the SEIG remains constant despite change in the consumer load is described [2]. In this work, a renewable energy based microgrid (MG) for standalone operation is developed. The places, where renewable energy sources such as wind, solar, hydro, etc., are in abundance, use them to generate electricity by developing wind-hydro based MG. The main control unit of MG is voltage source inverter (VSI) in which an indirect current control is applied. This VSI is used for power quality improvements through harmonics suppression of nonlinear loads; voltage regulation during contingencies such as load unbalance; and reactive power compensation at point of common coupling according to the system requirement [3]. This paper presents a new controller for voltage and frequency control (VFC) of two-winding single-phase induction generator. It provides coordinated control of battery energy storage system (BESS) and dump load during the mismatch of power between loads and generator using VFC loop. It provides protection against overcharging of BESS. For this purpose adaptive vectorial filter (AVF) is implemented to operate single-phase induction generator in standalone mode of operation for power quality features is discussed [4]. This paper describes about implementation of phase-locked loop (PLL)–based control algorithms for distribution static compensator (DSTATCOM) used to mitigate power quality issues due to unbalanced and non-linear load. Three control algorithms based on moving average filter PLL (MAF-PLL), double second order generalized integrator PLL (DSOGI-PLL), and adaptive filter with frequency estimation loop PLL (AFFEL-PLL) are used in this paper. These are more suitable to mitigate the power quality problems created by non-linear and unbalanced loads in distribution system [5]. These controllers are basically load controllers which maintain the load power constant at generator terminals which in turns maintain the system frequency constant [6]. In this study, a control algorithm based on non-linear adaptive second-order Volterra filter (NLVF) is utilised to operate the voltage-source converter (VSC). The main role of VSC is to supply compensating current to improve the power quality in wind-based off-grid distributed power generation system. This off-grid system consists of three-phase induction generator, VSC and non-linear loads. The proposed control algorithm is adaptive as well as non-linear in nature. The characteristic of Volterra series is exploited to generate the reference source current for VSC operation. The NLVF estimates the active and reactive weights of fundamental load current for reference current generation. It mitigates the power quality problems created by disturbances in non-linear load or wind oscillations on off-grid system. The solution of power quality problems such as the presence of harmonics in supply current, load unbalance and reactive power compensation is obtained [7]. This paper proposes a cost-effective compensator to suppress harmonics and compensate the power factor of all-electric shipboard power systems (SPSs). This compensator, which is based on a fixed capacitor-thyristor controlled reactor (FC-TCR), behaves as a low-pass filter and therefore can reject both low and high-order harmonics. Moreover, the FC-TCR compensator is featured by the low switching losses; hence, it can effectively be implemented for low and medium voltage applications [8]. This paper addresses the compensation of power quality problems such as balancing of load, compensation of neutral current, and distortions of the load current in a wind-based renewable energy system working at an isolated location for small consumers. For this purpose, an adaptive theory based momentum least mean square (MLMS) algorithm is used to operate the voltage source converter, which enhances the power quality in the system [9]. Sudden start of an IM load and frequent change of nonlinear load in a standalone distributed generation system (DGS) cause the dip in ac voltage and frequency. Moreover, these loads distort DGS currents. Therefore, in this paper, an improved-reweighted zero-attracting quaternion-valued least mean square (I-RZA-LMS)-algorithm-based voltage source converter (VSG) control is proposed for voltage and frequency regulation, and power quality improvement in DGS. Moreover, the control algorithm of dc-dc bidirectional converter (BDC) is used for dc link voltage regulation and MPPT of the solar photovoltaic array at IM starting and nonlinear loading is presented [10]. A procedure based on genetic algorithm (GA) has been formulated for the performance predetermination of wind-driven self-excited induction generators (SEIGs) operating in parallel and supplying common loads. Both static and induction motor (IM) loads have been considered. The GA technique has also been applied for the evaluation of the excitation capacitor required for obtaining a desired terminal voltage for a given speed and load is discussed [11].

II. SYSTEM CONFIGURATION

In this proposed work, a battery based wind energy conversion system is developed for voltage and frequency regulation for isolated locations for 3-phase 3 wire system. This dissertation defines the performance analysis of static compensator (STATCOM) based voltage regulator for self-excited induction generators (SEIGs) supplying non-linear loads. In practice, a number of loads are non-linear in nature and therefore they inject harmonics in the generating systems. The SEIG being a weak isolated system, its performance is very much affected by these harmonics. The additional drawbacks of SEIG are poor voltage regulation and it requires adjustable reactive power source with varying load to maintain constant terminal voltage. A three-phase insulated gate bipolar transistor (IGBT) based current controlled voltage source inverter known as STATCOM is used for harmonic elimination and it provides required reactive power for the SEIG with varying loads to maintain constant terminal voltage. This standalone system consists of a wind driven self-excited induction generator (SEIG) and battery system. This control approach is used for generating the reference source currents which are used to generate the pulses of VSC (Voltage Source Converter). The advantage of this system is that the voltage is maintained by VSC without automatic voltage regulator of the wind-driven SEIG. The main objective of this work is to maintain voltage and frequency of standalone system for remote locations.

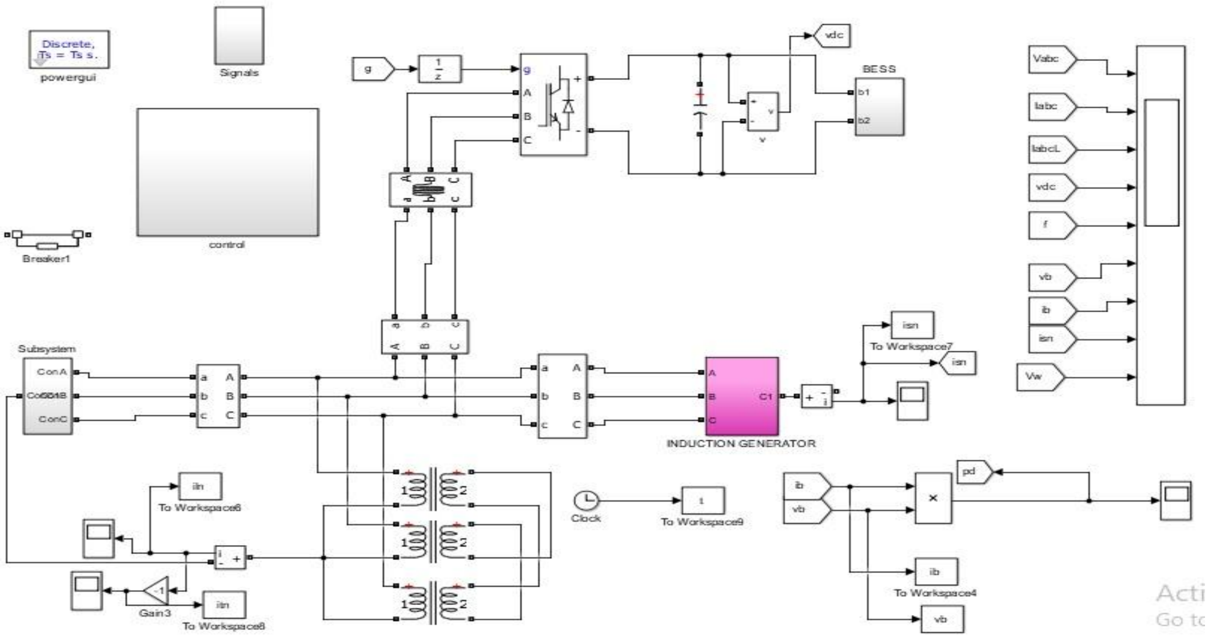

Fig. 1 System Configuration

Fig. 1 represents the system configuration of isolated system. The proposed system is constructed using wind turbine, self excited induction generator, insulated gate bipolar transistor based voltage source converter, nonlinear load, battery system and interfacing inductors. The SEIG can work under variable wind speed and generate power. The interfacing inductors are used to reduce the ripples from compensator current. Moreover, the VSC is used to provide active and reactive power compensation under different operating conditions. Further, VSC is also provide harmonic reduction and load balancing.

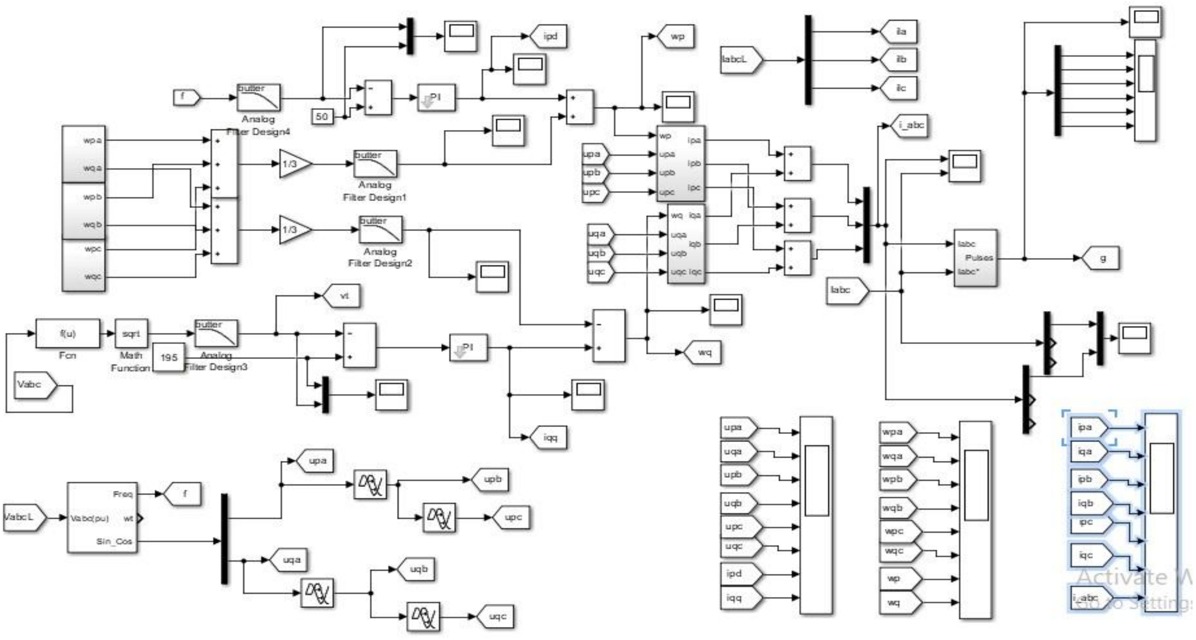

Fig. 2 MLMS Control Algorithm

Fig. 2 The MLMS based control is used to extract fundamental load current component under unbalanced nonlinear load condition. Basically, the comparison of sensed current and extracted reference current using MLMS control algorithm is used to generate switching pulses for VSC. The proposed control is able to extract fundamental component under worst condition of load. Moreover, two PI controllers are utilized to extract the active and reactive current component.

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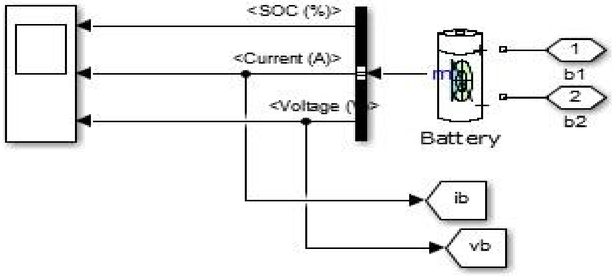


Fig. 3 Battery Energy Storage System

Fig. 3 represents the schematic diagram of battery energy storage system. A lithium ion based battery rating 400V, 7.5Ah is used in the proposed system. The battery system is utilized to consume the extra power and to supply power at point of common coupling under variable load demand.

Evaluation of peak value of voltage and in-phase/quadrature unit vectors

The peak value (V_m) of the wind driven SEIG is evaluated as

$$V_m = \left(\sqrt{2(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)/_3}\right) \quad (1)$$

v_{sa}, v_{sb} and v_{sc} are the instantaneous phase voltages at common point of interfacing (CPI). The in-phase and quadrature unit vectors are determined as

$$p_{ua} = \frac{v_{sa}}{V_m}, p_{ub} = \frac{v_{sb}}{V_m}, p_{uc} = \frac{v_{sc}}{V_m} \quad (2)$$

$$\begin{bmatrix} q_{ua} \\ q_{ub} \\ q_{uc} \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} -1 & 0 & 1 \\ \sqrt{3} & 1 & -1 \\ \frac{-\sqrt{3}}{2} & \frac{1}{2} & \frac{-1}{2} \end{bmatrix} \quad (3)$$

Where, p_{ua}, p_{ub} and p_{uc} are the in-phase unit vector and q_{ua}, q_{ub} and q_{uc} are the quadrature phase vectors of the 3-phase voltages of the system.

Generation of reference source current for VSC

A new modified MLMS control algorithm is implemented for the generation of VSC switching pulses; this modified control depends on the equation [3].

$$\omega(n) = \omega(n-1) + \frac{1}{p_{uabc}^T(n)U(n)+\beta} e_{rr}(n) p_{uabc}(n) \quad (4)$$

In this modified algorithm, the value of variable regularization factor (β) is (β>0) [21].

The modified MLMS control algorithm is used to modify the fundamental in-phase (p_{ua}, p_{ub} *and* p_{uc}) and quadrature (q_{ua}, q_{ub} *and* q_{uc}) unit vectors of the load current. The MLMS based control modifies the in-phase and quadrature weight components of 3-phase templates (w_{pa}, w_{pb} *and* w_{pc}) and (w_{qa}, w_{qb} *and* w_{qc}). The source frequency and the reference frequency are fed to the DC PI controller, which generates PI controller current. The summation of PI controller current and fundamental active average components generates the active reference current. Similarly, the evaluated peak voltage and reference voltage are fed to the AC PI controller current, which generates PI controller current. The fundamental reactive weight component and PI controller current are used generate quadrature reference current.

$$i_{La}^* = i_{La} \times p_{uabc} \quad (5)$$

$$i_{Lq}^* = i_{Lq} \times q_{uabc} \quad (6)$$

The summation of eq. (4) and (5) gives extracted reference source current and the extracted current is purely sinusoidal under nonlinear load condition. The extracted current and reference current of source is fed to the PWM controller for the generation of switching pluses of VSC.

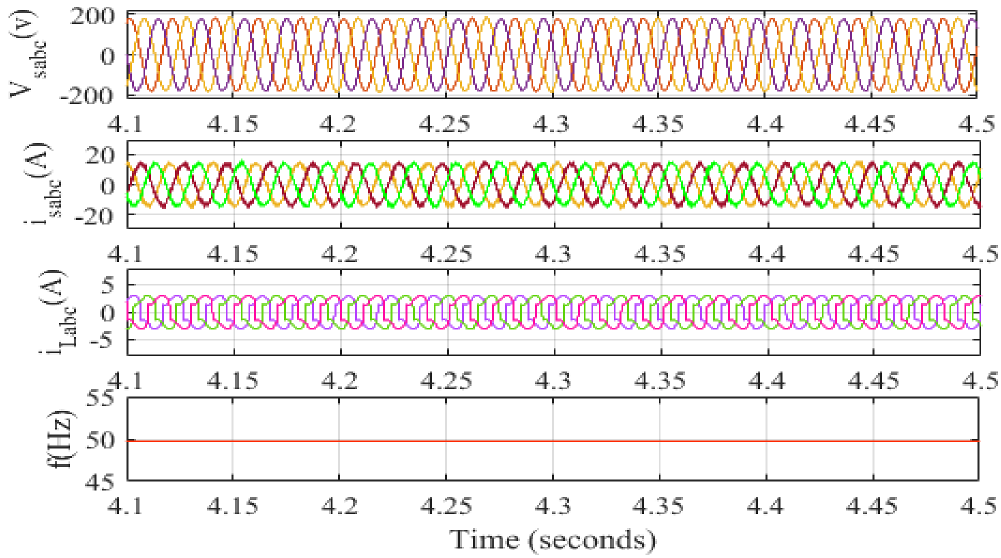
$$i_{sabc}^* = i_{La}^* + i_{Lq}^* \quad (7)$$

III. RESULTS AND DISCUSSION

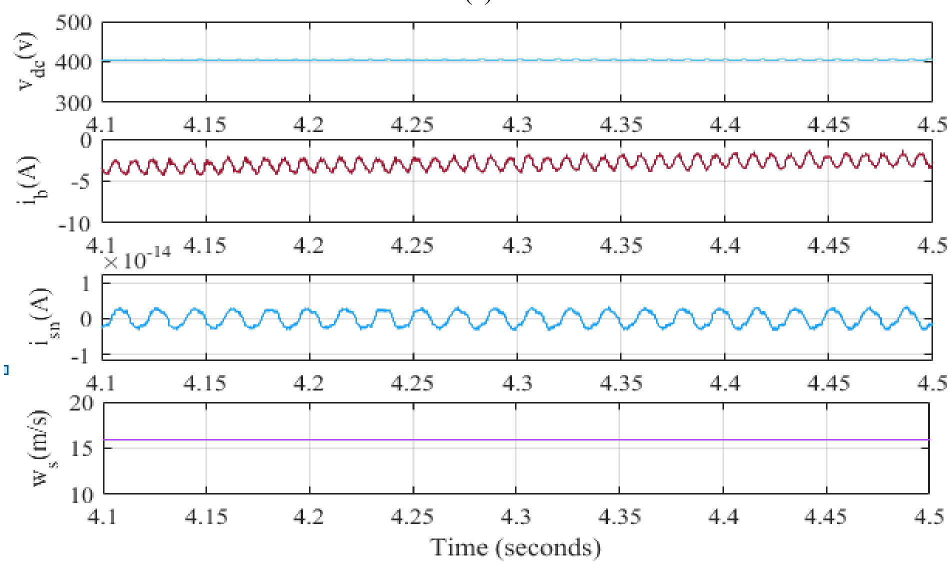
The Entire proposed system is developed in MATLAB/Simulink environment and results are taken under different operating conditions such as varying wind speed and unbalanced load. The proposed system consists of wind turbine, self excited induction generator, battery bank and nonlinear load.

3.1 Steady State Response of Isolated System under fixed wind speed feeding balanced load

Fig. 4(a) and (b) Shows the steady state analysis of isolated system under fixed wind speed feeding balanced load. Fig 4(a) shows the source voltage, source current, load current and frequency of the isolated system. The proposed controller maintains all the parameters stable of the isolated system while feeding balanced nonlinear load. Fig 4(b) shows dc link voltage, battery current, neutral current and wind speed of the isolated system. The wind speed is fixed at 16 m/s. The controller maintains the dc-link voltage under nonlinear load. The extra power is supplied to the battery and the battery is shifted to the charging mode. The MLMS control with VSC provides voltage/frequency regulation, power support, harmonic suppression, load balancing and enhances the power quality of the isolated system. Moreover, the MLMS control successfully extracts the fundamental load current component under nonlinear load condition.



(a)



(b)

Fig. 4(a) and (b) Steady state response of isolated system under fixed wind speed feeding balanced load

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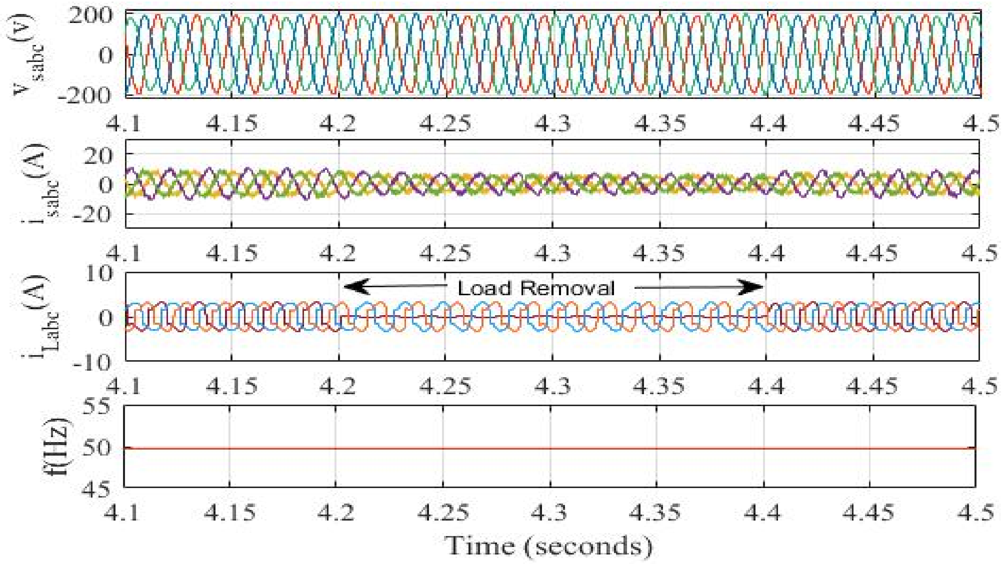
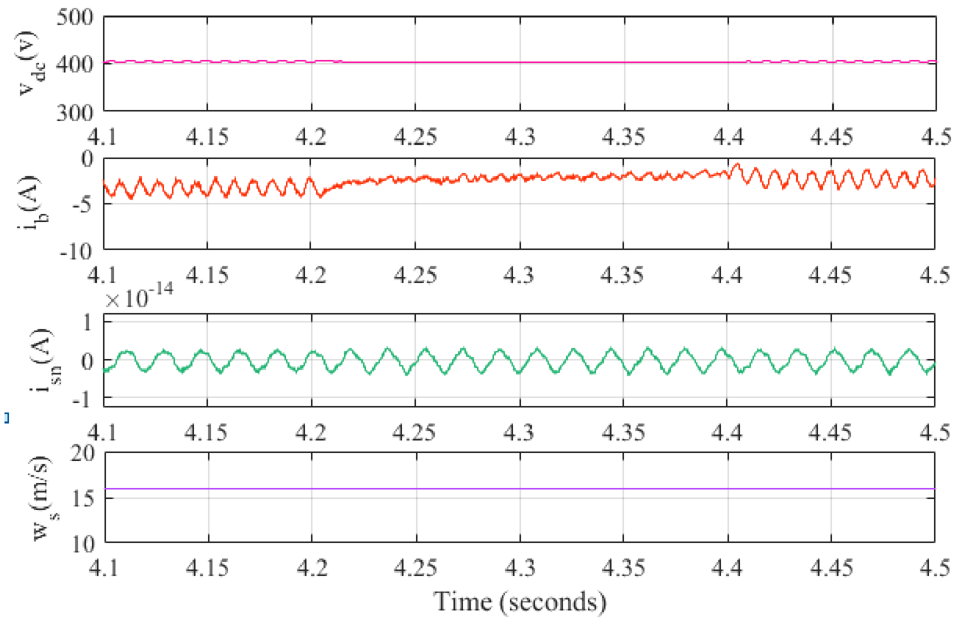
3.2 Dynamic Response of Isolated System under fixed wind speed feeding Unbalanced Load

Fig. 5(a) and (b) shows the dynamic response of isolated system under fixed wind speed while feeding unbalanced load. Fig. 5(a) shows the load of phase 'a' is removed at t=4.2s and injected at t=4.4s and wind speed is fixed at 16 m/s. During the load removal duration, the controller maintains the source voltage and frequency of the isolated system. The source current and load current are reduced due to load removal. Fig. 5(b) shows dc link voltage, battery current, neutral current and wind speed. The proposed control maintains the dc link voltage and provides neutral current compensation during dynamic conditions of nonlinear load. The extra power is supplied to the battery during transient condition of load.



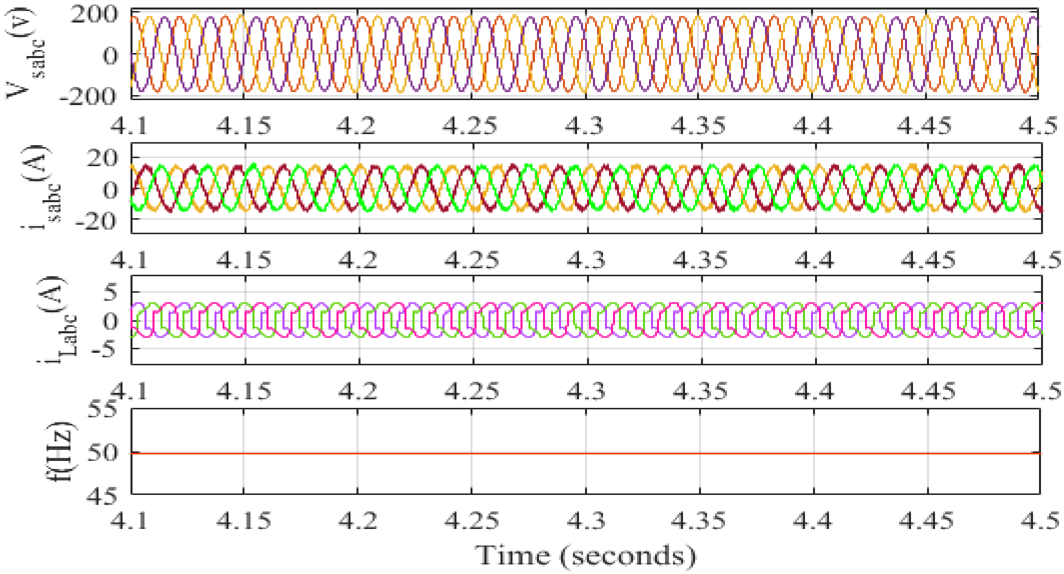
(a)



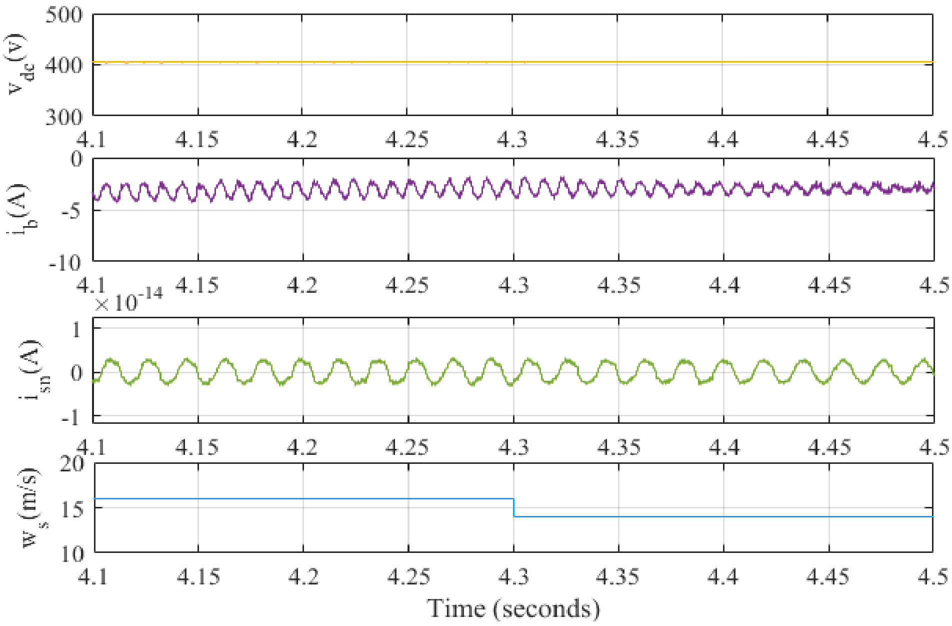
(b)

3.3 Dynamic Response of Isolated System under Varying Wind Speed feeding balanced load

Fig. 6(a) and (b) dynamic response of isolated system under varying wind speed feed balanced non linear load. Fig. 6(a) shows source voltage, source current, load current and frequency of the isolated system. During the variation in wind speed, the controller maintains all the parameters of the isolated system. Fig. 6(b) shows the controller maintains dc link voltage stable and compensate the neutral current during the variation in wind speed and wind speed is changed 16 m/s to 14 m/s. The extra power is supplied by the battery at point of common coupling to maintain the power balance during dynamic condition of wind speed.



(a)



(b)

Fig. 6(a) and (b) Dynamic response of isolated system under varying wind speed feeding balanced load

IV. CONCLUSION AND FUTURE SCOPE

The three phase four wire induction generator had been employed for power generation in the isolated system. The different aspects related to control of point of common coupling point variables such as voltage and frequency are considered for the study. For regulation of voltage and frequency with power quality aspects, the modified least mean square based adaptive filter is used. The other problems of three phase four wire system such as load balancing, neutral current compensation, harmonics mitigation and compensation of load reactive power are also solved. The entire isolated system has been simulated in MATLAB and results are analyzed under different operating conditions.

Isolated system can help deploy more zero-emissions energy sources, make use of waste heat, reduce energy lost through transmission lines, help manage power supply and demand, and improve grid resilience to extreme weather. In future, it can be used for electrical vehicle battery charging and supply to single phase loads for standalone applications in rural areas, where grid supply is not available.

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