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Simulation on Micro Wind Power Generator with Battery Energy Storage for Critical Load

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ABSTRACT

Supporting critical load without uninterrupted power supply is difficult in the micro-grid network. The proposed system with battery energy storage maintains the real and reactive power in the grid as per International Electro-Technical Commission IEC- 61400-21 at the point of common coupling. The combination of battery storage with micro-wind energy Generation system (μWEGS), which will synthesize the output waveform by injecting or absorbing reactive power and enable the real power flow required by the load.The system reduces the burden on conventional source and provides rapid response to critical loads. The system is simulated in ATLAB/SIMULINK and results are presented.

***Index Terms*—**Battery energy storage, micro-wind energy generating system, power quality

I. INTRODUCTION

Energy requirement is increasing with every passing day and the traditional fuels are depleting at a very fast rate and they produce a lot of pollution also.A renewable energy system using wind is found to be clean and inexhaustible and is becoming very popular . But the wind energy systemproduces fluctuating power which will definitely affect the operation in the distribution network. The utility system cannot accept new generation without strict condition of voltage regulation due to real power fluctuation and reactive power generation/absorption. The industrial and commercial customers often operate the sensitive electronic equipments or critical load that cannot tolerate voltage sags, voltage swells, or loss of power, which moreover cause interruption in life operating equipments or stoppage in industrial production. This requires some measure to mitigate the output fluctuation so as to keep the power quality in the distributed network. International Electro-Technical Commission IEC-61400-21 describes the norms for power quality of micro-wind generating system. The battery storage is used for critical load applications as it supplies power for a short period of time. The combination of battery energy storage and micro-wind generating system in distributed power system can provide the effective, reliable, and durable power system. The system also provides energy saving and un-interruptible power within distribution network [1]–[3]. In Japan, battery energy storage was used formitigation of variations in wind farm output to stabilize the short fluctuation of output power [4]. The parallel processing of wind energy generating system and battery storage will enhance the power flow in the distributed network. The microwind energy generating system is used to charge the battery as and when the wind power is available. The control method for the state of charge of battery unit was proposed in [5]. The battery storage provides a rapid response for either charging/discharging the battery and also acts as a constant voltage source for the critical load in the distributed network. The battery storage system utilizes flooded lead-acid battery cell for energy storage. For electrical energy storage application, a large number of cells are connected in series to produce the required operating voltage [6], [7]. In order to verify the effectiveness of proposed system, the current control mode of voltage source inverter is proposed to interface the battery storage with micro-wind energy generator into the distributed network. The proposed control system with battery storage has the following objectives:

1) unity power factor and power quality at the point of common coupling bus;
2) real and reactive power support from wind generator and batteries to the load;
3) stand-alone operation in case of grid failure.

This paper is organized as follows. Section II introduces the wind power extraction with batteries, Section III introduces the control scheme, Section IV describes the system performance, and Sections V and VI describe the experimental results and conclusion

II. Wind Power Extraction with Batteries

The proposed micro-wind energy extraction from wind generator and battery energy storage with distributed network is configured on its operating principle and is based on the control strategy for switching the inverter for critical load application as shown in Fig. 1.

A. Micro-Wind Energy Generating System

The micro-wind generating system (μWEGS) is connected with turbine, induction generator, interfacing transformer, and ac-dc converter to get dc bus voltage. The power flow is represented with dc bus current for constant dc bus voltage in inverter operation. The static characteristic of wind turbine can be described with the relationship in the wind as in

$$P_{\text{wind}} = \frac{1}{2}\rho \Pi R^2 V_{\text{wind}}^3 \tag{1}$$

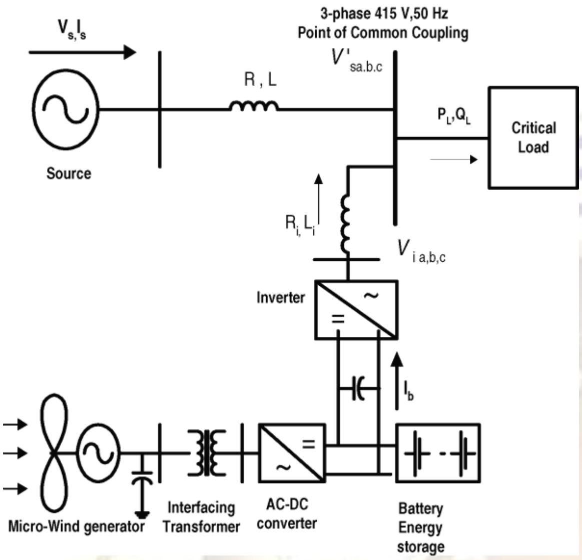


Fig. 1. Scheme of micro-wind generator with battery storage for critical load application.

where ρ is air density (1.225 kg/m3), R is the rotor radius in meters, and Vwind is the wind speed in m/s. It is not possible to extract all kinetic energy of wind and is called CP power coefficient. This power coefficient can be expressed as a function of tip speed ratio λ and pitch angle θ. The mechanical power can be written as (2)

$$P_{\text{mech}} = C_p P_{\text{wind}} \tag{2}$$

$$P_{\text{mech}} = \frac{1}{2}\rho \Pi R^2 V_{\text{wind}}^3 C_p. \tag{3}$$

By using the turbine rotational speed, ω turbine mechanical torque is shown in

$$T_{\text{mech}} = P_{\text{mech}} / \omega_{\text{turbine}}. \tag{4}$$

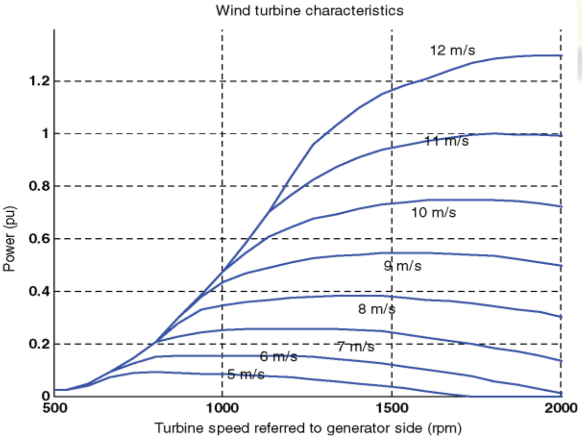


Fig. 2. Power-speed characteristic of turbine.

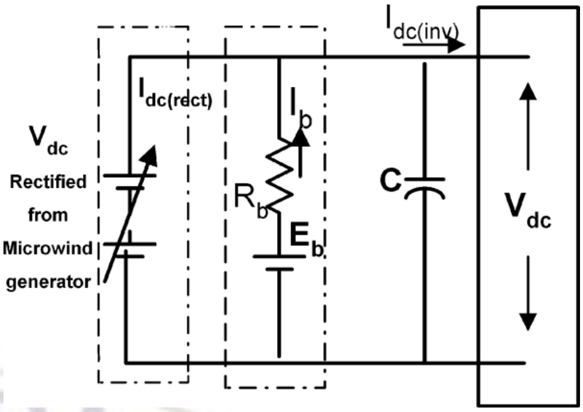


Fig. 3. Dc link for battery storage and micro-wind generator.

The speed-power characteristic of variable speed wind turbine is given in Fig. 2. *B. Dc Link for Battery Storage and Micro-Wind Energy Generator* The battery storage and μWEGS are connected across the

dc link as shown in Fig. 3. The dc link consists of capacitor which decouples the μwind generating system and ac source (grid) system [8], [9]. The battery storage will get charged with the help of μwind generator. The use of capacitor in dc link is more efficient, less expensive and is modeled as follows:

$$C\frac{d}{dt}V_{\text{dc}} = I_{\text{dc(rect)}} - I_{\text{dc(inv)}} - I_b \tag{5}$$

where C is dc link capacitance, Vdc is rectifier voltage, Idc(rect) is rectified dc-side current, Idc(inv) is inverter dc-side current, and Ib is the battery current. The battery storage is connected to dc link and is represented by a voltage source Eb connected in series with an internal resistance Rb. The internal voltage varies with the charged status of the battery. The terminal voltage Vdc is given in

$$V_{\text{dc}} = E_b - I_b * R_b \tag{6}$$

(4) where Ib represents the battery current.

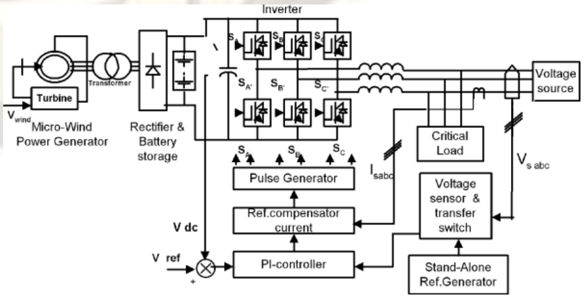


Fig. 4. Inverter interface with combination of battery storage with μWEGS

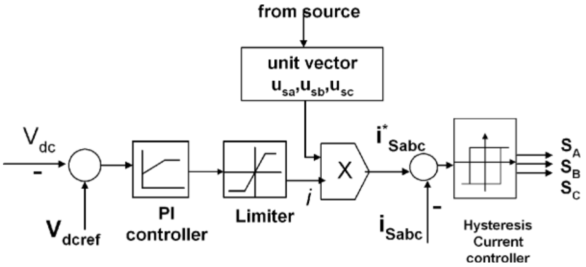


Fig. 5. Control scheme for switching the inverter circuit.

It is necessary to keep adequate dc link level to meet the inverter voltage [10] as in

$$V_{dc} \geq \frac{2\sqrt{2}}{M_a} V_{inv} \tag{7}$$

where *V*inv is the line-to-neutral rms voltage of inverter (240 Vrms), inverter output frequency 50 Hz, and *Ma* is modulation index (9). Thus, the dc link is designed for 800V.

III. Control Scheme of the System

The control scheme with battery storage and micro-wind generating system utilizes the dc link to extract the energy from the wind. The micro-wind generator is connected through a step up transformer and to the rectifier bridge so as to obtain the dc bus voltage. The battery is used for maintaining the dc bus voltage constant; therefore the inverter is implemented successfully in the distributed system [11]–[13]. The three-leg 6-pulse inverter is interfaced in distributed network and dual combination of battery storage with micro-wind generator for critical load application, as shown in Fig. 4. The control scheme approach is based on injecting the current into the grid using "hysteresis current controller." Using such techniques the controller keeps the control system variables between the boundaries of hysteresis area and gives correct switching signals for inverter operation.

The control scheme for generating the switching signals to the inverter is shown in Fig. 5. The control algorithm needs the measurement of several variables such as three-phase source current *i*Sabc for phases a, b, c, respectively, dc voltage *V*dc, inverter current *i*iabc with the help of sensors. The current control block receives an input of reference current *I* ∗ Sabc and actual current *i*Sabc is measured from source phase a, b, c, respectively, and are subtracted so as to activate the operation of the inverter in current control mode.

A. Grid Synchronization

In the three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage (*V*sa, *Vb*, *V*sc) and is expressed as sample template *V*sm [14], as in

$$V_{sm} = \left\{ \frac{2}{3}\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right) \right\}^{1/2}. \tag{8}$$

The in-phase unit vectors are obtained from ac source-phase voltage and the RMS value of unit vector *u*sa, *u*sb, *u*sc as shown in

$$u_{sa} = \frac{V_{Sa}}{V_{sm}}, u_{sb} = \frac{V_{Sb}}{V_{sm}}, u_{sc} = \frac{V_{Sc}}{V_{sm}}. \tag{9}$$

The in-phase generated reference currents are derived using the in-phase unit voltage template as in

$$i_{sa}^* = i.u_{sa}, i_{sb}^* = i.u_{sb}, i_{sc}^* = i.u_{sc} \tag{10}$$

where *i* is proportional to the magnitude of filtered source voltage for respective phases. It is the output taken from proportional-integral controller. This ensures that the source current is controlled to be sinusoidal. The unit vector implements the important function in the grid for the synchronization of inverter. This method is simple, robust and favorable as compared with other methods. When the grid voltage source fails the micro-wind generator acts as a stand-alone generator. Under such conditions the voltage sensors sense the condition and will transfer the micro-switches for the generation of reference voltage from micro-wind generator. The above generated reference under no source supply gets switched to the stand-alone reference generator after voltage sensing at the point of common coupling. This is a unit voltage vector which can be realized by using microcontroller or DSP. Thus, the inverter maintains the continuous power for the critical load.

B. Hysteresis Based Current Controller

Hysteresis based current controller is implemented in the current control scheme. The reference current is generated as in (10) and the actual current is detected by current sensors that are subtracted for obtaining current errors for a hysteresis based controller. The ON/OFF switching signals for IGBT of inverter are derived from hysteresis controller. When the actual (measured) current is higher than the reference current, it is necessary to commutate the corresponding switch to get negative inverter output voltage. This output voltage decreases the output current and reaches the reference current. On the other hand, if the measured current is less than the reference current, the switch commutated to obtain a positive inverter output voltage. Thus the output current increases and it goes to the reference current. As a result, the output current will be within a band around the reference one. The switching function *SA* for phase a is expressed as follows:

$$i_{sa} > (i_{sa}^* + HB) \rightarrow S_A = 1$$

$$i_{sa} < (i_{sa}^* - HB) \rightarrow S_A = 0 \tag{11}$$

TABLE I
SYSTEM PARAMETERS

Source voltage	3-phase, 415 V, 50 Hz
Source and line inductance	0.5 mH
Micro-wind generator parameter (induction generator)	150 kW, 415 V, 50 Hz, $P = 4$, Rs = 0.01 Ω, Rr = 0.015 Ω, Ls = 0.06 H, Lr = 0.06 H, wind velocity 5 m/s
DC link parameter	DC link-800 V, $C = 5\ \mu$F
Rectifier-bridge parameter (three arm bridge type)	Snubber $R = 100$ Ω, Ron = 0.01 Ω, snubber capacitance = 0.01e-3 F
IGBT device parameters (three arm bridge type)	Rated voltage 1200 V, Forward.Current 50 A, gate voltage +/-20 V, turn-ON delay 70 ns, turn-OFF delay 400 ns, power dissipation 300 W
Battery parameters	DC 800 V, cell capacity 500 Ah, type-lead acid
Interfacing transformer	Rating-1 KVA, Y-Y type, 415/800 V, 50 Hz
Critical load parameter	3-phase 415 V, non-linear load $R = 10$ Ω, $C = 1\ \mu$F

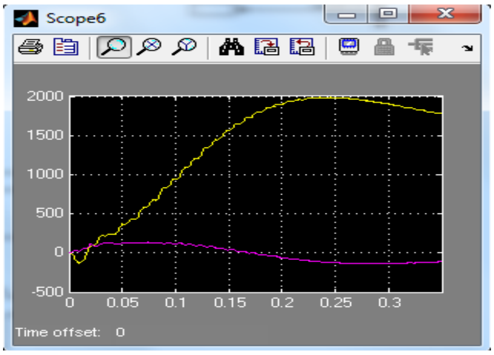
where HB is a hysteresis current-band, similarly the switching function *SB*, *SC* can be derived for phases "b" and "c," respectively. The current control mode of inverter injects the current into the grid in such a way that the source currents areharmonic free and their phase-angles are in-phase with respect to source voltage. Thus, the injected current will cancel out the reactive and harmonic part of load current. Thus, it improves the source current quality at the PCC. The power transfer takes place as soon as battery energy system is fully charged with the help of micro-wind generator. To achieve this goal, the source voltage is sensed and synchronized in generating the desired reference current command for the inverter operation. The implementation of the hysteresis band current control is not expensive. The control is excellent for a fast response of an inverter to rapid changes of reference current, since current control has negligible inertia and delay.

IV. System Performance

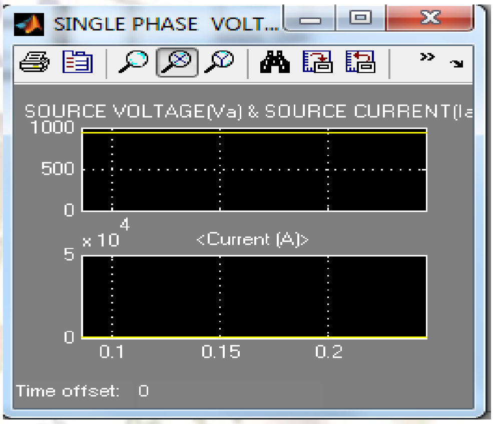
The scheme of micro-wind generator with battery energy storage for extraction of wind energy for critical load application is shown in Fig. 1 and is simulated in MATLAB/ SIMULINK with power system block set. A simulink model library includes the model of converter, induction generator, critical load, and others that has been constructed for simulation .The model has been designed to assess the system in absence and presence of fault.

V. Simulation

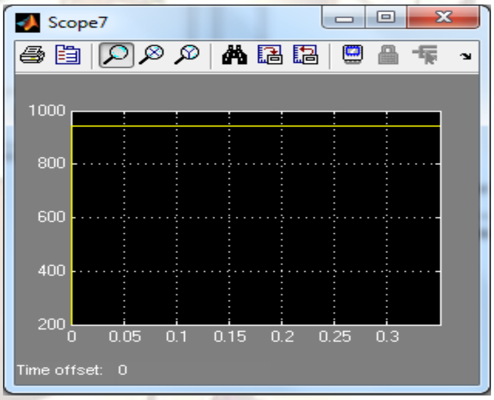
a) Microwind system without fault



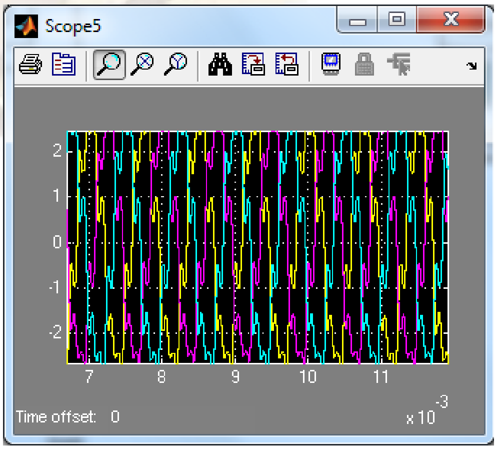
Active and Reactive Power at the Input Side



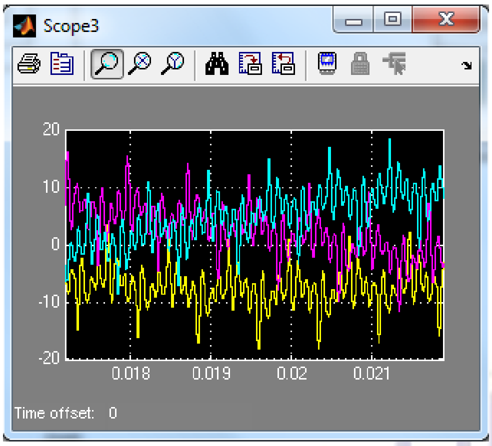
Source Voltage and Source current at Input Side



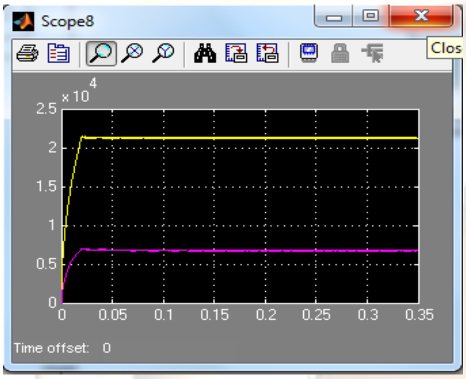
Capacitor Voltage



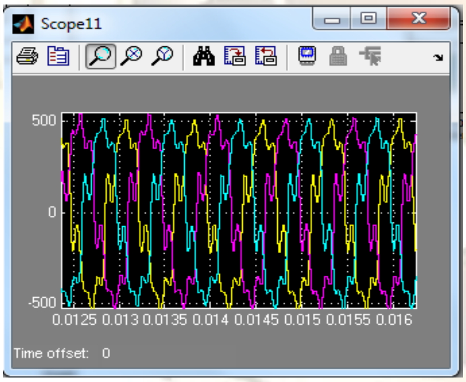
Three Phase Voltage at Load



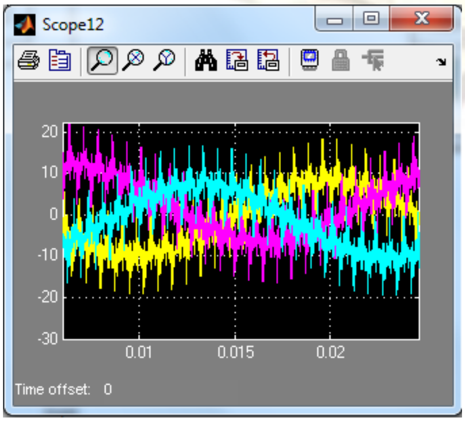
Three Phase Current at Load



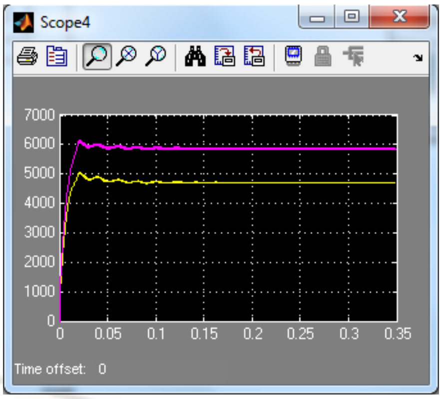
Active And Reactive Power at Load Side



Three phase voltage at grid side

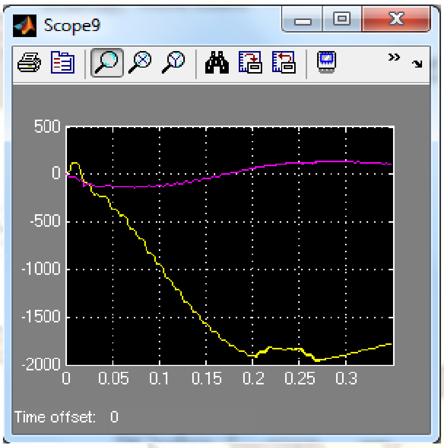


Three Phase Current at Grid side

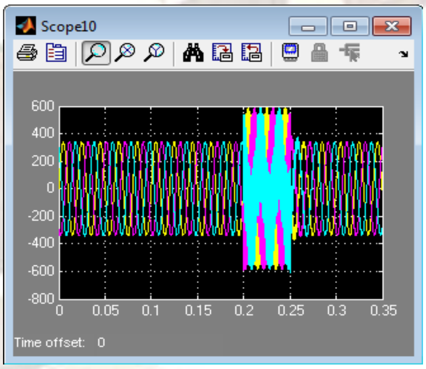


Active and Reactive Power at Grid

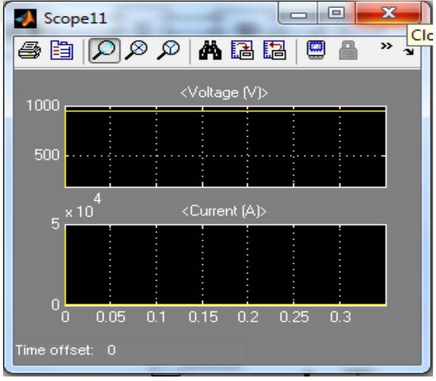
b) Microwind system with fault



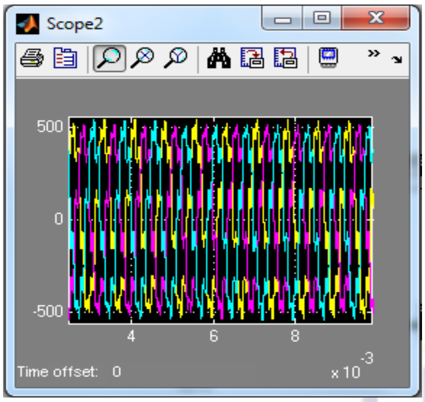
Active and Reactive Power at Input Side



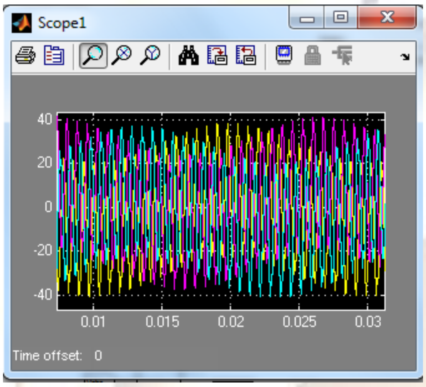
Voltage at input side



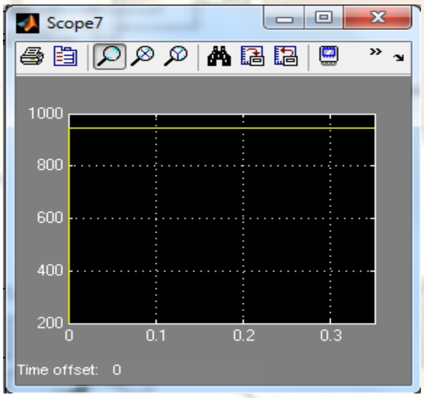
Source Voltage and Current



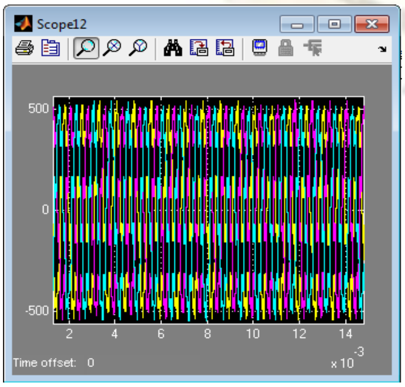
Three phase voltage at Load



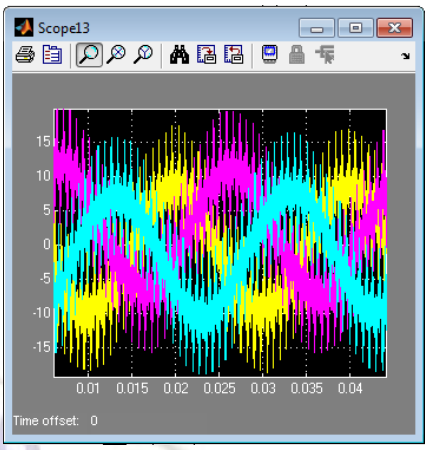
Three Phase Currrent at Load Side



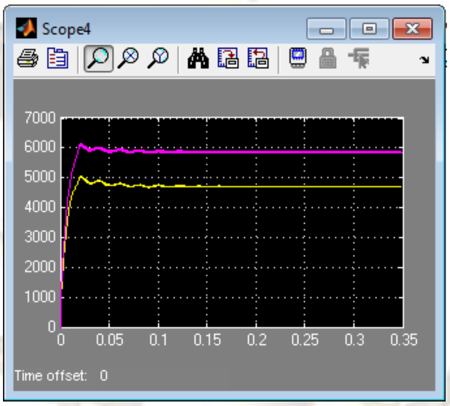
Capacitor Voltage



Three Phase Voltage at Grid Side



Three Phase Current at grid Side



Active Reactive Power at Grid Side

VI. Conclusion

The paper proposed micro-wind energy conversion scheme with battery energy storage, with an interface of inverter in current controlled mode for exchange of real and reactive power support to the critical load. The hysteresis current controller is used to generate the switching signal for inverter in such a way that it will cancel the harmonic current in the system. The scheme maintains unity power factor and also harmonic free source current at the point of common Connection in the distributed network. The suggested control system is suited for rapid injection or absorption of reactive/real power flow in the power system. The battery energy storage provides rapid response and enhances the performance under the fluctuation of wind turbine output and improves the voltage stability of the system. This scheme is providing a choice to select the most economical real power for the load amongst the available wind-battery-conventional resources and the system operates in power quality mode as well as in a stand-alone mode.

References

[1] D. Graovac, V. A. Katic, and A. Rufer, “Power quality problems compensation with universal power quality conditioning

system,” *IEEE Trans. Power Delivery*, vol. 22, no. 2, pp. 968–997, Apr. 2007.

[2] Z. Chen and E. Spooner, “Grid power quality with variable speed wind turbin es,” *IEEE Trans. Energy Conversion*, vol. 16, no. 2, pp. 148–154,Jun. 2008.

[3] Z. Yang, C. Shen, and L. Zhang, “Integration of stat COM and battery energy storage,” *IEEE Trans. Power Syst.*, vol. 16, no. 2, pp. 254–262, May 2001.

[4] K. Yoshimoto, T. Nanahara, and G. Koshimizu, “Analysis of data obtained in demonstration test about battery energy storage system to mitigate output fluctuation of wind farm,” in *Proc. CIGREE*, Jul. 2009, p. 1.

[5] L. Maharjan, S. Inoue, H. Akagi, and J. Asakur, “State-of-charge (SoC)- balancing control of a battery energy storage system based on a cascade PWM converter,” *IEEE Trans. Power Electron*, vol. 24, no. 6, pp. 1628– 1636, Jun. 2009.

[6] P. C. Loh, M. J. Newman, D. N. Zmood, and D. G. Holmes, “A comparative analysis of a multiloop voltage regulation strategies for single and three phase UPS system,” *IEEE Trans. Power Electron*, vol. 18, no. 5, pp. 1176–1185, Sep. 2003.

[7] Z. Jiang, “Adaptive control strategy for active power sharing in hybrid fuel cell/battery power source,” *IEEE Trans. Energy Conversion*, vol. 22, no. 2, pp. 507–515, Jun. 2007.

[8] B. S. Borowy and Z. M. Salameh, “Dynamic response of a stand-alone wind energy conversion system with battery energy storage to a wind gust,” *IEEE Trans. Energy Conversion*, vol. 12, no. 1, pp. 73–78, Mar. 1997.

[9] P. F. Ribeiro, B. K. Johnson, M. L. Crow, A. Arsoy, and Y. Liu, “Energy storage system for advance power applications,” *Proc. IEEE*, vol. 89, no. 12, pp. 1744–1756, Dec. 2001.

[10] B. Singh, S. S. Murthy, and S. Gupta, “Analysis and design of STATCOM-based voltage regulator for self-excited induction generator,” *IEEE Trans. Energy Conversion*, vol. 19, no. 4, pp. 783–791, Dec. 2004.

[11] S. Teleke, M. E. Baran, A. Q. Huang, S. Bhattacharya, and L. Anderson, “Control strategy for battery energy storage for wind farms dispatching,” *IEEE Trans Energy Conversion*, vol. 24, no. 3, pp. 725–731, Sep. 2009.

[12] N. M. Ahdel-Rahim and J. E. Quaicoe, “Analysis and design of a multiple feedback control strategy for a single-phase voltage-source ups inverter,” *IEEE Trans. Power Electron*, vol. 11, no. 4, pp. 532–541, Jul. 2006.

[13] G. Tapia, “Proportional-integral regulator based application to wind farm reactive power management for secondary voltage control,” *IEEE Trans. Energy Conversion*, vol. 22, no. 2, pp. 488–498, Jun. 2007

[14] Y. Chauhan, S. Jain, and B. Sing, “Static volt-ampere reactive compensator for self-excited induction generator feeding dynamic load,” *Electric Power Compon. Syst. J.*, vol. 36, no. 10, pp. 1080–1101, Oct. 2008.

[15] F. S. Pai and S.-I. Hung, “Design and operation of power converter for microturbine powered distributed generator with capacity expansion capability,” *IEEE Trans. Energy Conversion*, vol. 3, no. 1, pp. 110–116, Mar. 2008.

[16] J. M. Carrasco, “Power-electronic system for grid integration of renewable energy source: A survey,” *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1002–1014, Jun. 2006.

[17] S. W. Mohod and M. V. Aware, “Grid power quality with variable speed wind energy conversion,” in *Proc. IEEE PEDES*, Dec. 2006, pp. 1–6. [18] S. W. Mohod and M. V. Aware, “Power quality issues and its mitigation technique in wind energy conversion,” in *Proc. IEEE ICQPH*, Sep.–Oct. 2008, pp. 1–6.

[19] S. W. Mohod and M. V. Aware, “A STATCOM-control scheme for grid connected wind energy system for power quality improvement,” *IEEE Syst. J.*, vol. 2, no. 3, pp. 346–352, Sep. 2010.

[20] *MATLAB/SIMULINK User Guide*, MathWorks, Inc., Natick, MA, 1995.