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Extarction of wind power with battery energy storage for critical load condition in grid connected system

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***Abstract*— In the grid, renewable resources are connected to extract more power. This adds more problems to grid, such as voltage fluctuations and distortions. The proposed micro wind energy conversion system with battery energy storage is used to exchange the controllable real and reactive power in the grid and to maintain power quality at the point of common coupling (PCC). In this scheme inverter is controlled by the hysteresis current controller to achieve the faster dynamic switch over for the support of critical load. The reference signals are derived from one of the phase voltage.**

The main objective of the proposed control is the three phase supply currents both in its waveform, magnitude and phase to follow three phase reference signals. When this is achieved, ideally the supply current will then be always sinusoidal, with robust control over its magnitude and phase, irrespective of the harmonics and unbalance of the load demand or the supply voltage system. This confirms nearly unity power factor on supply side with active and reactive power support from the wind turbine side. The battery storage with micro wind energy generation system will obtain the output waveform by injecting (or) absorbing reactive power and enable the real power flow required by the load. The generated power can be stored in the batteries at low power demand hours. This scheme can be operated as a standalone system in case of grid failure like a uninterrupted power supply.

***Index Terms*— Battery energy storage system(BESS), micro-wind energy generating system, power quality, Hysteresis current controller, Point of common coupling(PCC).**

I. Introduction

Renewable sources often produce power and voltage varying with natural conditions (wind speed, sun light etc.,) and grid connection of these sources is essential if they are ever to realize their potential to significantly alleviate the present day problems of atmospheric pollution and global warming. The micro wind power generation system with battery energy storage is becoming more prominent with the increasing demand of power generation. It also reduces the environment pollution. However the output power of micro- wind generator is fluctuating and will 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. In the fixed-speed wind turbine operation, all the fluctuation in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations.

During the normal operation, wind turbine produces a continuous variable output power. These power variations are mainly caused by the effect of turbulence, wind shear, and tower-shadow and of control system in the power system. Thus, the network needs to manage for such fluctuations. The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag, swells, flickers, harmonics etc. However the wind generator introduces disturbances in to the distribution network .One of the simple methods of running a wind generating system is to use the induction generator connected directly to the grid system. The induction generator has inherent advantages of cost effectiveness and robust- ness. However; induction generators require reactive power for magnetization. When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly affected. A proper control scheme in wind energy generation system is required under normal operating condition to allow the proper control over the active power production. In the event of increasing grid disturbance, a battery energy storage system for wind energy generating system is generally required to compensate the fluctuation generated by wind turbine. It used for sensitive load applications as it supplies the power for a short period of time. The wind energy generation system is response for either charging/discharging the battery and also acts as a constant voltage output for the critical load in the distribution system

The proposed control system with battery storage has the following objectives:

1) Unity power factor and power quality at the point of

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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.

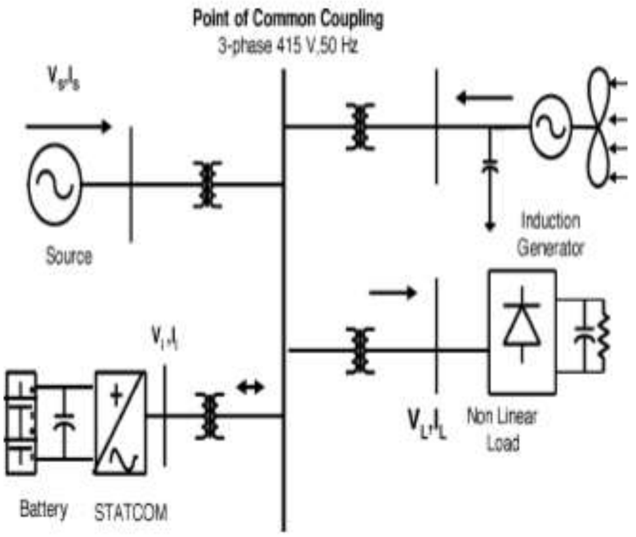


Fig. 1. Schematic diagram of micro-wind generator with battery storage for critical load application.

II. EXTRACTION OF WIND POWER 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

$$P_{Wind} = \frac{1}{2}\rho \pi R^2 V_{wind}^3$$

where ρ is air density (1.225kg/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)

$$P_{mech} = c_P P_{wind}$$

$$P_{mech} = \frac{1}{2}\rho \pi R^2 v_{wind}^3$$

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

$$T_{mech} = \frac{P_{mech}}{\omega_{Turbine}}$$

Wind Turbine Characteristics

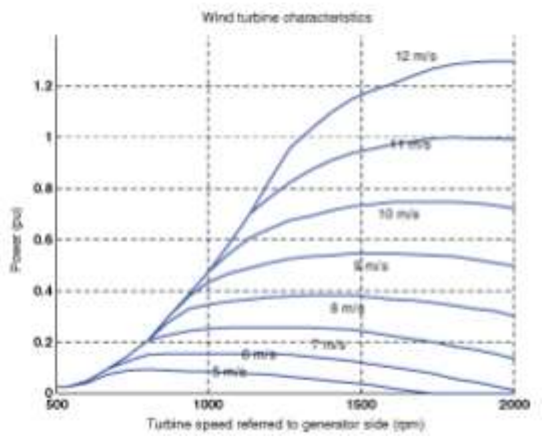


Fig. 2. Power-speed characteristic of turbine

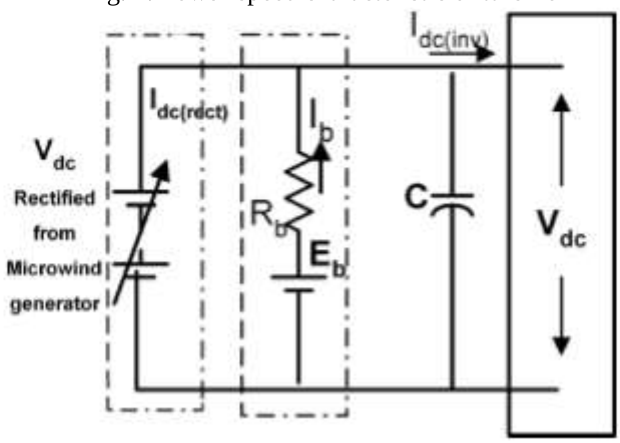


Fig. 3. Dc link for battery storage and micro-wind generator.

The speed-power characteristic of variable speed wind turbine is given in Fig. 2.

B. Dc link for battery storage and micro-wind 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:

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

where C is dc link capacitance, V_{dc} is rectifier voltage, $I_{dc(rect)}$ is rectified dc-side current, $I_{dc(inv)}$ 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 E_b connected in series with an internal resistance R_b. The internal voltage varies with the charged status of the battery. The terminal voltage Vdc is given in

$$V_{dc} = E_b - I_b * R_b$$

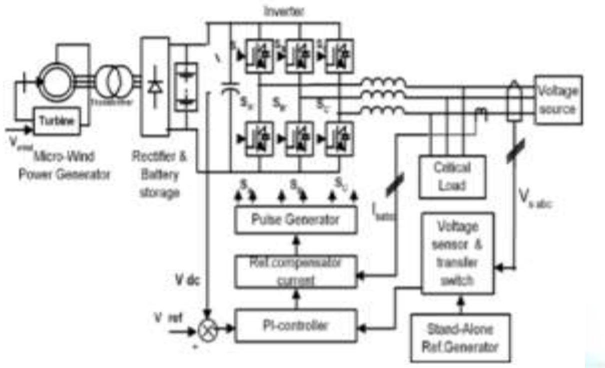


Fig. 4. Inverter interface with combination of battery storage with µWEGS

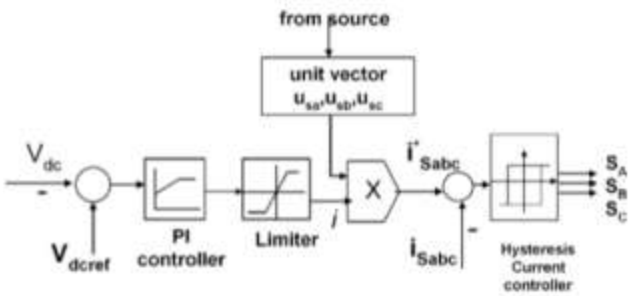


Fig. 5. Control scheme for switching the inverter circuit.

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

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

where V_{inv} is the line-to-neutral rms voltage of inverter (240Vrms), inverter output frequency 50Hz, and M_a 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 iSabc for phases a, b, c, respectively, dc voltage Vdc, inverter current iiabc with the help of sensors. The current control block receives an input of reference current i∗Sabc and actual current iSabc 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} V_{sb}, V_{sc}) and is expressed as sample template Vsm [14], as in

$$V_{sm} = \sqrt{\left\{\frac{2}{3}(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)\right\}}$$

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

$$u_{sa} = \frac{V_{sa}}{V_{sm}}, u_{sb} = \frac{V_{sb}}{V_{sm}}, u_{sc} = \frac{V_{sc}}{V_{sm}}$$

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

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

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:

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

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

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 are harmonic 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.

C. *Statcom Performance under Load Variations:*

The wind energy generating system is connected with grid having the nonlinear load. The performance of the system is measured by switching the STATCOM. The STATCOM responds to the step change command for increase in additional load. When STATCOM controller is made ON, without change in any other load condition parameters, it starts to mitigate reactive demand as well as harmonic current. The dynamic performance is also carried out by step change in a load. This additional demand is fulfilled by STATCOM compensator. Thus, STATCOM can regulate the available real power from source.

IV. SIMULATION RESULTS

A. *System Performance*:

The Simulink model library includes the model of Conventional Source, Asynchronous Generator, STATCOM, Non-Linear Load, Inverter, Grid Voltage, Battery, Line Series Inductance and others that has been constructed for simulation. The simulation parameter values for the given system are given in Table 1.

Table 1. *System Parameters*

S.NO	Parameters	Ratings
1.	Grid voltage	3-phase,415V,50Hz
2.	Asynchronous generator	275kVA, 415V, P = 4, Rs = 0.01 , Rr = 0.015 , Ls = 0.06H, Lr = 0.06H
3.	Three phase source	110KVA,50HZ
4.	Line series inductance	0.05mH
5.	Inverter parameters	DC link Voltage = 800V, DC link Capacitance = 100µF, Switching frequency = 2kHz
6.	IGBT Rating	Collector Voltage = 1200V, Forward Current = 50A, Gate Voltage = 20V 7
7.	Load parameter	Non linear load=25KW
8.	Battery	800V,50A

The effectiveness of the proposed method is demonstrated through simulation result of grid voltage and current shown in Figure 6. This is due to the reference derived from the grid voltage.

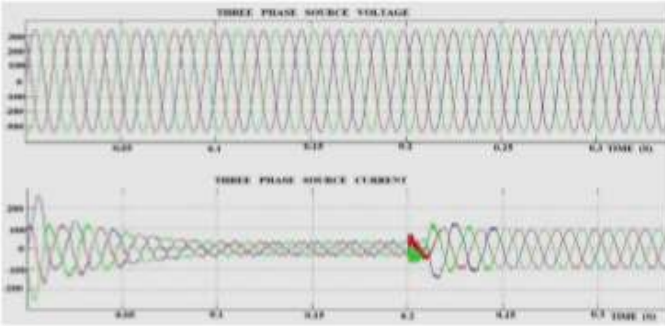


Figure 6. Grid Voltage and Current

The voltage and current waveform Ia, Ib, Ic for before 0.21s and after 0.21s of the STATCOM operation is analyzed. The inverter output voltage under STATCOM operation with load variation is shown in Figure 7

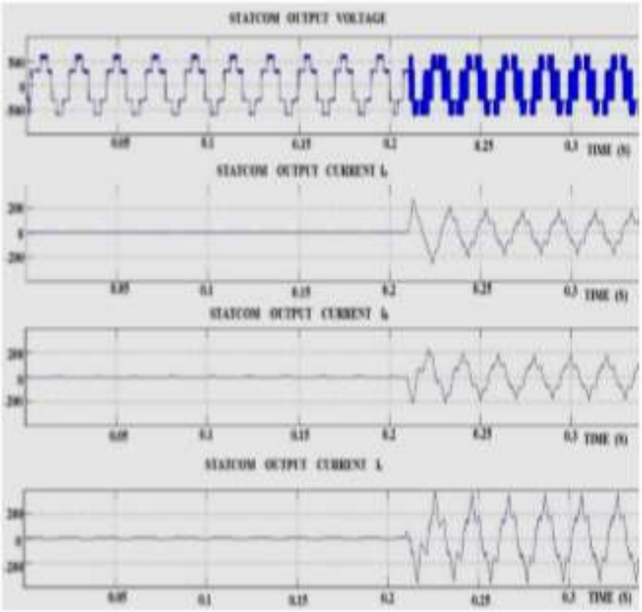


Figure 7.STATCOM voltage and current I_a,I_b,I_c

The source current is maintained in phase with the source voltage indicating the 0.89 power factor at point of common coupling and satisfies power quality norm. The result of in-phase source current and source voltage are shown in Figure 8.This is due to the reference derived from the grid voltage. The dynamic load does affect the inverter output voltage.

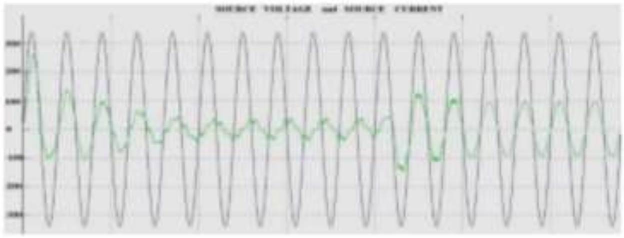


Figure 8. Power Factor

The source current on the grid is affected due to the effect of non-linear load and wind generator, this purity of wave form is lost on both sides in the system. The dynamic performance is also carried out by step change in a load, when applied at 0.21s. The load current is shown in Figure 9.

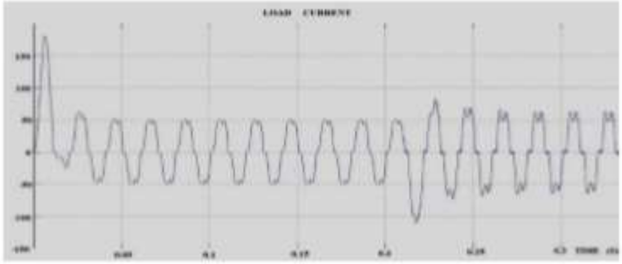


Figure 9. Load Current

Load voltage regulation is defined by the drop in voltage when going from a no load to full load condition on a power source. In more practical terms, it is often measured when going from a typical steady state load to a maximum load condition, realized under normal operating conditions. Load voltage regulation is used to evaluate the performance of an isolation transformer and distribution system under heavy step load changes. Load voltage regulation is critical before 0.21s and after the 0.21s voltage regulation" is the stand-by mode of operation is shown in Figure 10.

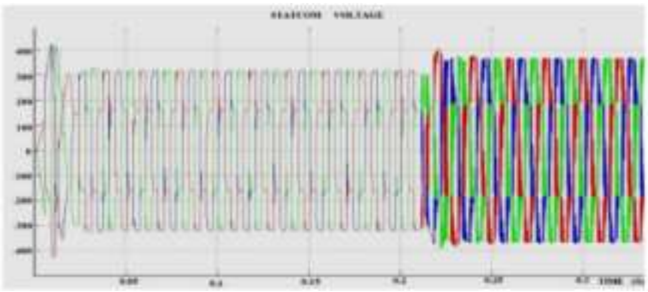
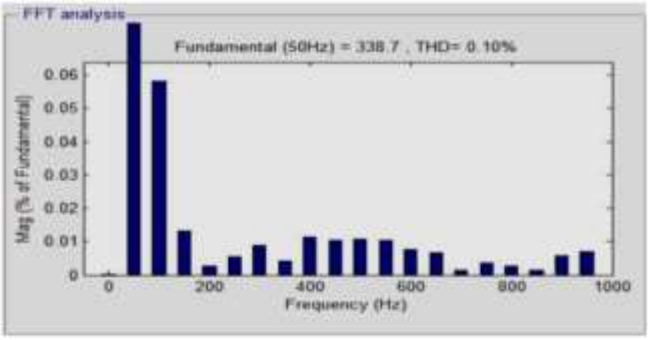


Figure 10. Load Voltage

The power quality improvement is observed at the point of common coupling, when the controller is in ON condition. The inverter is placed in the operation and source current waveform The Fourier analysis of this waveform is expressed; the THD has been improved with in the standard level. The result of THD 0.10% is shown in Figure 11. The above scheme for critical load application has not only power quality improvement but it also supports the critical load with the energy storage through the batteries.



V. 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 exchange of wind power is regulated across the dc bus having energy storage and is made available under the steady state condition. This also allows the real power flow during the instantaneous demand of the load. 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 ofthe 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.

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