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Power Quality Improvement in a Micro WECS with Battery Storage under Critical Load Condition

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Abstract- In the micro-grid system, it is particularly complicated to maintain the critical load with continuous power supply. 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 sustain the power quality norms at the point of common coupling. The generated microwind power can be stored in the batteries at low power demand hours. In this scheme, inverter control is executed with hysteresis current control mode to achieve the faster dynamic switchover for the support of critical load. 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 the conventional source and utilizes µWEGS and battery storage power under critical load constraints. The system provides rapid response to support the critical loads. The scheme can also be operated as a stand-alone system in case of grid failure like a uninterrupted power supply. The system is simulated in MATLAB/SIMULINK and results are presented.

Index Terms- Battery energy storage, Micro-wind energy generating system, Power quality.

I. INTRODUCTION

WITH HIGH population growth and economic development in the world, there is a very high demand for energy. Traditional fossil sources such as oil, coal are costly and have a serious pollution to the environment. As a renewable energy, wind energy generation has been focused as a clean and inexhaustible energy providing a feasible solution to energy shortage. 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 microwind 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. 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. 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. In Japan, battery energy storage was used for mitigation of variations in wind farm output to stabilize the short fluctuation of output power . 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 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. 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.

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

$$Pwind = \tfrac{1}{2}\rho \text{Л}R^{2}V^{3}wind \qquad (1)$$

whereρ 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)

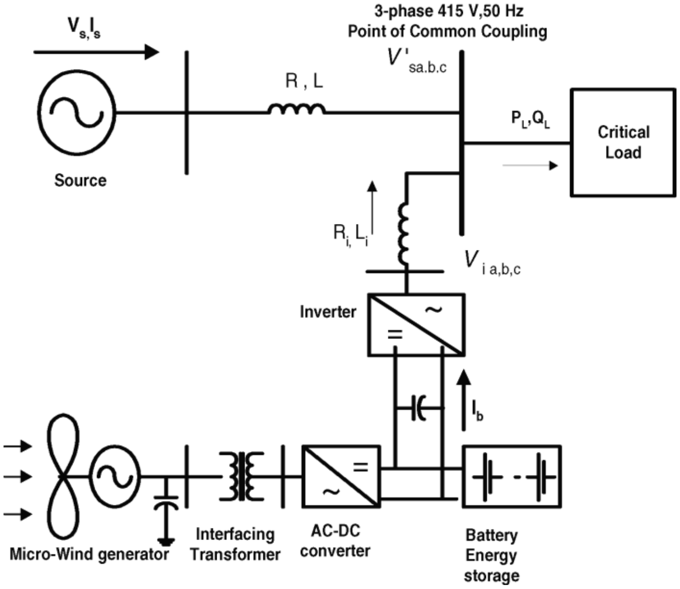

Fig. 1.Scheme of micro-wind generator with battery storage for critical load application.

$$P\text{mech} = CpP\text{wind} \quad (2)$$

$$P\text{mech} = \tfrac{1}{2}\rho JIR^{2}V^{3}\text{wind}Cp. \quad (3)$$

By using the turbine rotational speed, ωturbinemechanicaltorque is shown in

$$T\text{mech} = P\text{mech}/\omega\text{turbine}. \quad (4)$$

B. Dc Link for Battery Storage and Micro-Wind Energy Generator

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

$$Cd/dtV_{\text{dc}} = I_{\text{dc(rect)}} - I_{\text{dc(inv)}} - I_b \quad (5)$$

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 Ebconnected in series with aninternal resistance Rb. The internal voltage varies with the charged status of the battery. The terminal voltage Vdc is given in

$$V\text{dc} = Eb - Ib*Rb \quad (6)$$

whereIbrepresents the battery current.

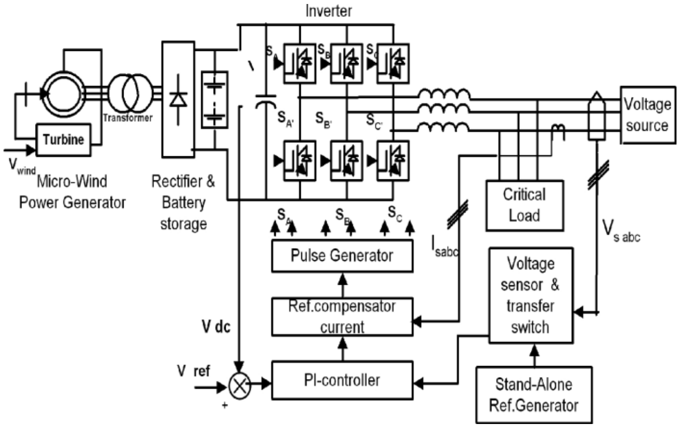

Fig. 2. Inverter interface with combination of battery storage with μWEGS.

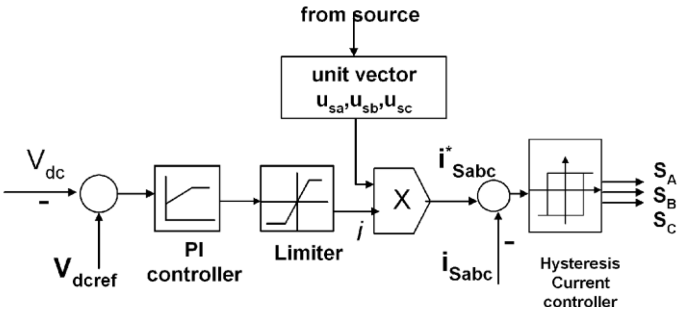

Fig. 3. Control scheme for switching the inverter circuit.

C. 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:

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

$$i_{\text{sa}} < (i^*_{\text{sa}} - HB) \rightarrow S_A = 0 \quad (7)$$

The simulation parameters for the given system are given in Table I.

TABLE I
System Parameters

Source voltage	3-phase, 415V, 50 Hz
Source and line inductance	0.5mH
Micro-wind generator parameter (induction generator)	150kW, 415V, 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-800V, $C = 5\mu$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 1200V, Forward.Current 50 A, gate voltage +/-20V, turn-ON delay 70 ns, turn-OFF delay 400 ns, power dissipation 300W
Battery parameters	DC 800V, cell capacity 500 Ah, type-lead acid
Interfacing transformer	Rating-1KVA, Y-Y type, 415/800V, 50 Hz
Critical load parameter	3-phase 415V, non-linear load R = 10_, $C = 1\mu$F

D. Dynamic Performance Under Power Quality Mode

A critical load is considered as a nonlinear load for the simulation of the system. The performance of the system is observed for the power quality improvement of critical load. The inverter is switched “on” at 0.2 s. The source current *Is*, inverter injected current *I*inv, and load current *IL* are measured with and without controller operation. The current supplied from the source is made sinusoidal, harmonics-free as soon as controller is in operation and is shown in Fig. 4(a). The injected current supplied from the inverter is shown in Fig.4(b). The critical load current in the system is shown in Fig. 4(c). During this interval, the load current will be the source current and inverter current.

E. Performance of PI Controller

The proportional-integral type controller is used in the control system and its response is very fast. It corrects the error between measured variable and a desired set value. The *Kp*determine amplification to the current error and *Ki* process the corrected error. The PI controller used to increase the overshoot increases the change in the settling time and eliminates the steady state error in the system. The increase in the loop gain *Kp*improves the steady state tracking accuracy, disturbance signal rejection, the relative stability and also makes the system less sensitive to the parameter variations. The integral controller reduces the steady state error without the need for manual reset. The transfer function for the simulation is considered as in eqn(8).

$$G(s) = \frac{10}{0.008s + 1} \qquad (8)$$

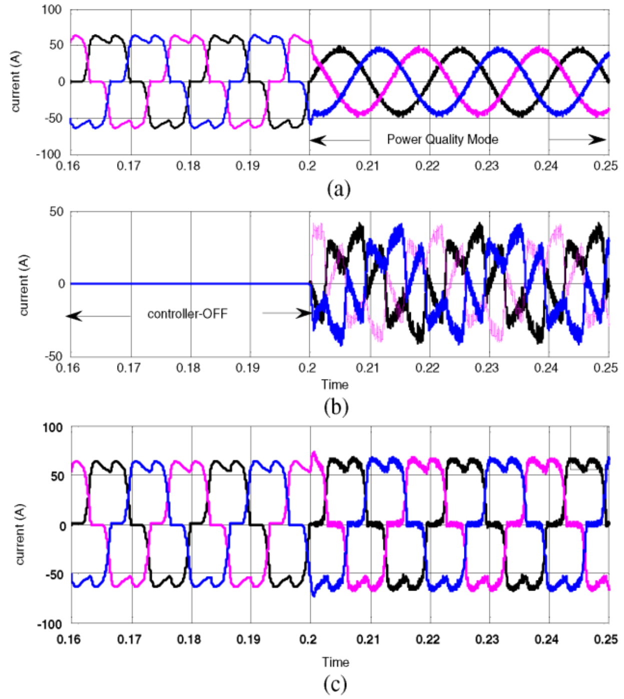

Fig. 4(a). The injected current supplied from the inverter (b). The critical load current in the system(c). During this interval, the load current will be the source current and inverter current.

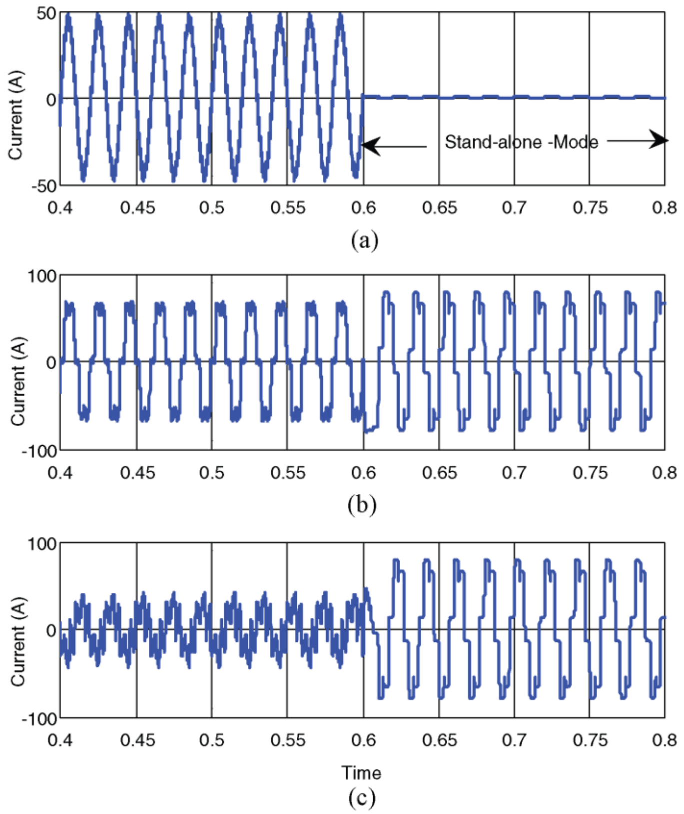

Fig. 5. (a) Source current. (b) Load current. (c) Inverter-injected current.

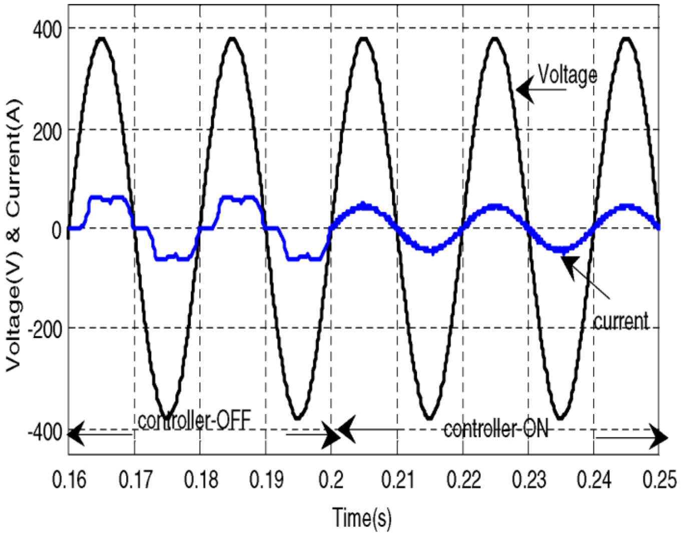

Fig. 6.Source current and source voltage at PCC.

The performance of controller is used to stabilize the voltage in the distributed network. The source current is maintained in phase with the source voltage, indicating the unity power factor at point of common coupling and satisfies power quality norms. The results of in-phase source current and source voltage are shown in Fig.6.

The current waveform before and after the inverter operation is analyzed for power quality measures. The Fourier analysis of the waveform is expressed without the inverter-controller in the system and the THD of the source current signal is shown in Fig. 7(a), the measured THD and its harmonics order is shown in Fig. 7(b).

III. EXPERIMENTAL RESULTS OF THE CONTROLLER

In order to validate the viability of the control scheme for switching the inverter, a laboratory prototype of the system is designed and fabricated.

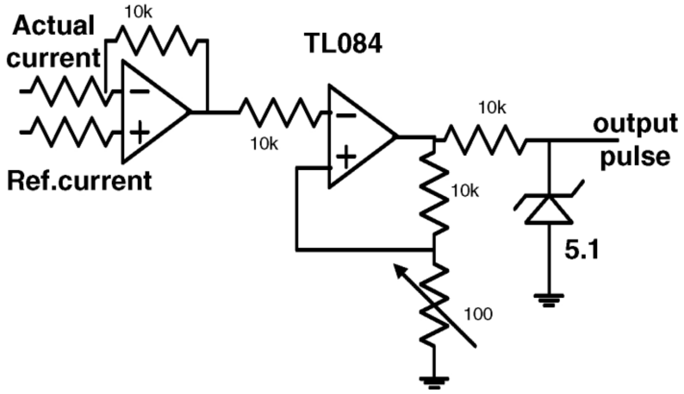

Fig. 7.Hysteresis controller.

A. Hysteresis Band Controller

The hysteresis band current controller circuit is developed as shown in Fig. 7. The reference and actual currents are the input to this circuit. These currents are compared within a hysteresis band which can be adjusted by potentiometer. The output of this controller is given to the delay circuit through opto-coupler and wave shaping circuits.

IV. 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 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.

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