Artificial Intelligence Based Controller for Micro Wind Energy Generation System for Power Quality Improvement

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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. Static Compensator (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality issues. The generated micro wind 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 ,which will synthesize the output waveform by injecting or absorbing reactive power and enable the real power flow required by the load. The system is simulated in MATLAB/SIMULINK and results are presented. The AI controller can very quickly and accurately detect momentary irregularity of equipment and feed back to control in real time. As well as enabling trend monitoring at the machine level, this also prevents quality defects that occur on high-speed production lines within a very short time.

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.

 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 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.
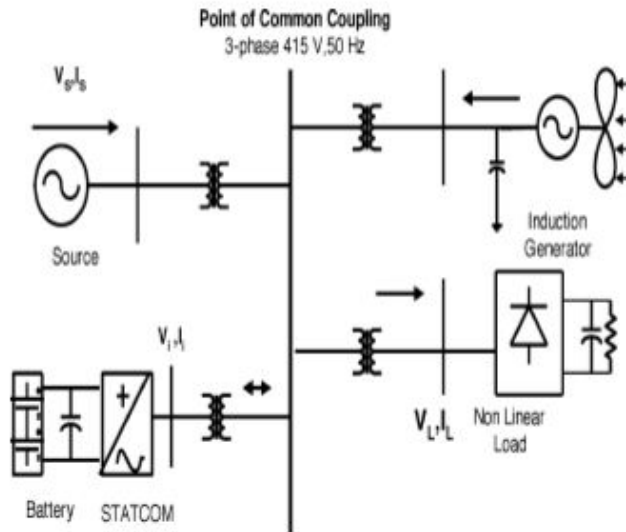
Fig. 1. Schematic diagram of micro-wind generator with battery storage sytem.

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

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

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

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)

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

By using the turbine rotational speed, ωturbine mechanical torque is shown in
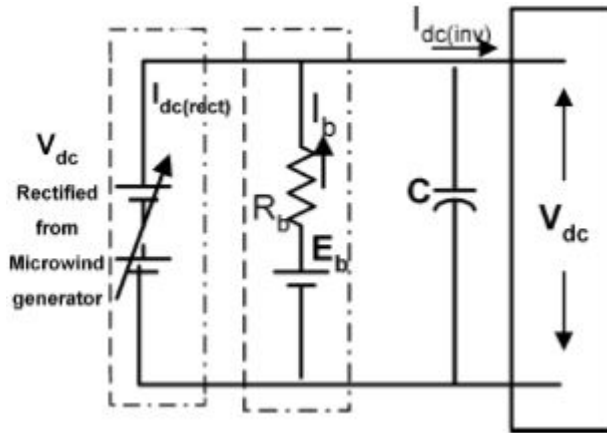
$$T_{mech} = \frac{P_{mech}}{\omega_{Turbine}}$$

Fig. 2. Dc link for battery storage and micro-wind generator.

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:

$$C\frac{dv}{dt} = I_{dc(rect)} - I_{dc(inv)} - I_b \tag{4}$$

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 resistanceR_b. The internal voltage varies with the charged status of the battery. The terminal voltage Vdc is given in

$$V_{dc} = E_b - I_b * R_b \tag{5}$$

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. 2. 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 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 $(V_{sa}\ V_{sb}, V_{sc})$

$$V_{sm} = \sqrt{\left\{\frac{2}{3}(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)\right\}} \tag{6}$$

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

$$u_{sa} = \frac{V_{sa}}{V_{sm}}, u_{sb} = \frac{V_{sb}}{V_{sm}}, u_{sc} = \frac{V_{sc}}{V_{sm}} \tag{7}$$

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

$$i_{sa}^* = i.u_{sa}, i_{sb}^* = i.u_{sb}\ , i_{sc}^* = i.u_{sc} \tag{8}$$

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:

$$i_{sa} > (i_{sa}^* + HB) \rightarrow S_A = 1 \qquad (9)$$

$$i_{sa} < (i_{sa}^* + HB) \rightarrow S_A = 1 \qquad (10)$$

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.

D.Artificial Intelligence based Contoller

Control Systems, particularly closed-loop control systems (CLCS), are frequently used in production machines, vehicles, and robots nowadays. CLCS are needed to actively align actual values of a process to a given reference or set values in real-time with a very high precession. Yet, artificial intelligence (AI) is not used to model, design, optimize, and tune CLCS. This paper will highlight potential AI-empowered and -based control system designs and designing procedures, gathering new opportunities and research direction in the field of control system engineering. Therefore, this paper illustrates which building blocks within the standard block diagram of CLCS can be replaced by AI, i.e., artificial neuronal networks (ANN). Having processes with real-time contains and functional safety in mind, it is discussed if AI-based controller blocks can cope with these demands. By finishing up the paper, the advantages and disadvantages of man-made intelligence engaged as well as - based CLCS plans are examined, and conceivable exploration bearings for presenting computer based intelligence in the space of control framework designing are given.

III. 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.
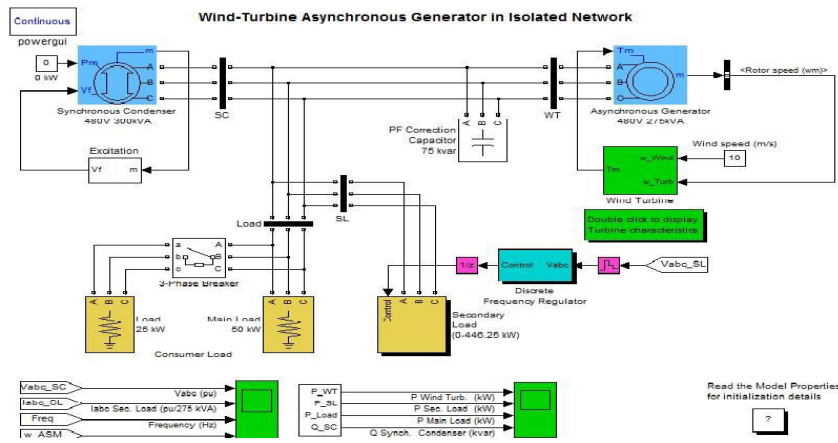
Fig.3 Wind turbine generator

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.
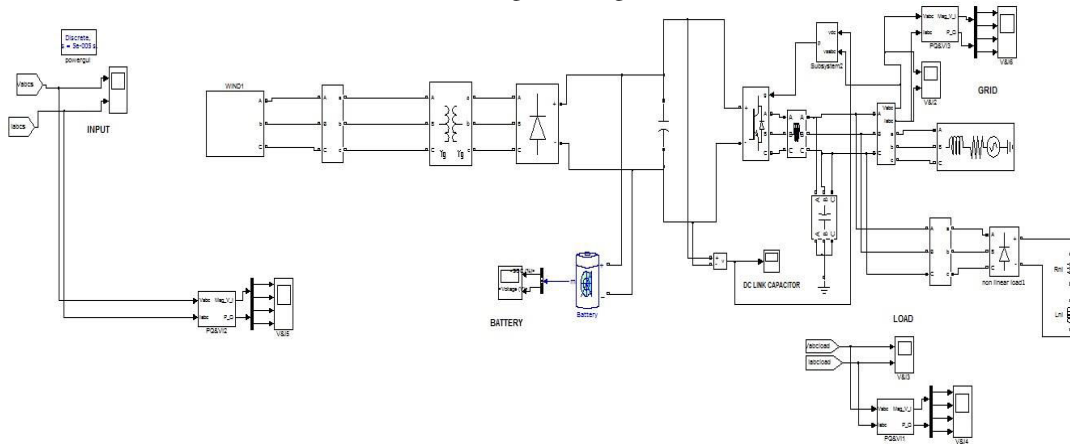

Fig.4 Micro WEGS under normal condition

The voltage and current waveform of the wind turbine generator operation is analyzed. The inverter output voltage under STATCOM operation with load variation is shown.The magnitude of input voltage,current,Real power and reactive power are shown below. 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.
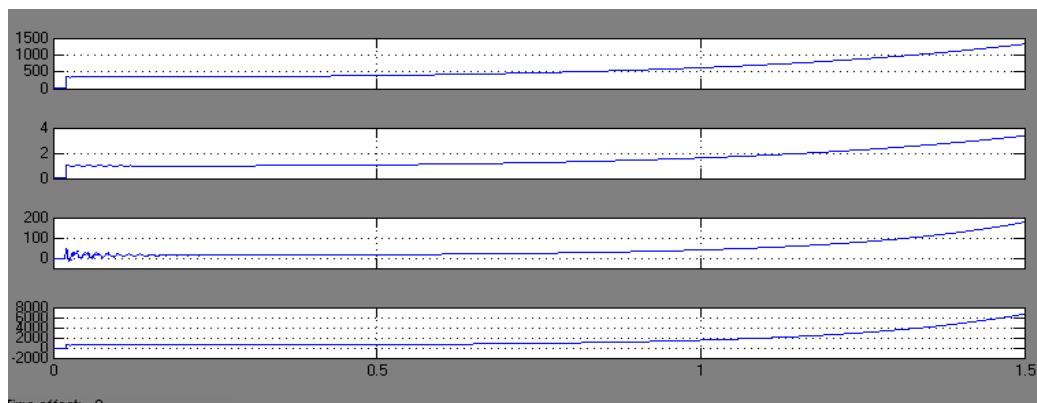

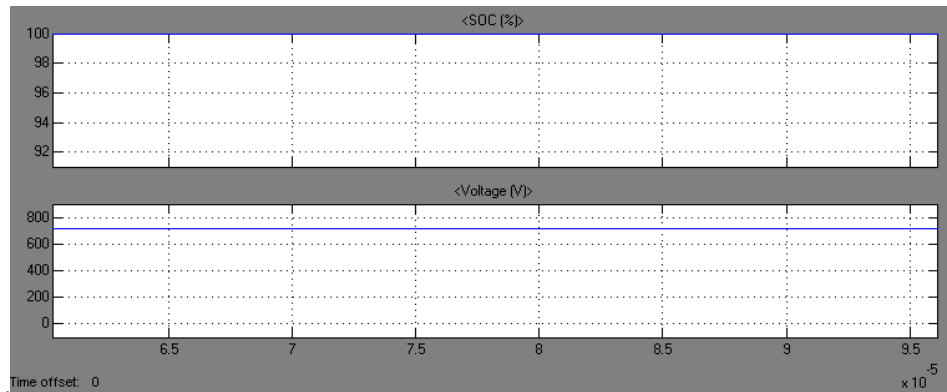Figure 6 Magnitude of V, I, Real & Reactive Power at input side

Fig.7 Battery SOC & Voltage

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.
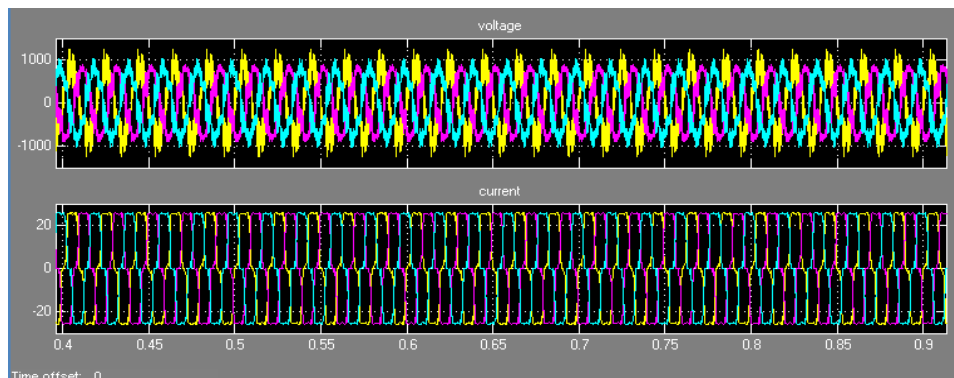

Fig.9 Voltage & Current at load side

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 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.
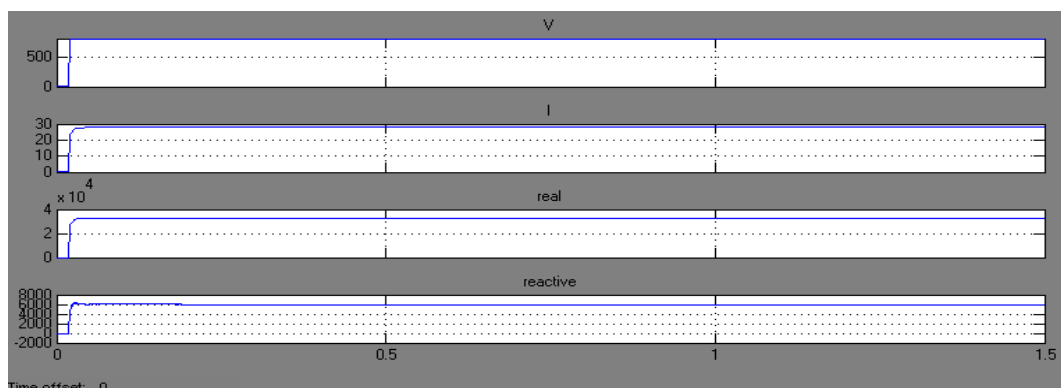

Fig.10 Magnitude of V, I, P, Q at load side

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 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.

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