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Grid Interfaced Wind power generator with battery Energy Storage System for Critical Load

M.H.V.Murali Krishna, M.Seshu

Abstract— **In the grid, renewable resources are connected to extract more power. This adds more problems to grid, such as voltage fluctuations and distortions. Here the micro wind energy conversion system with battery energy storage is used to interchange the controllable real and reactive power in the grid and power quality is maintained 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 attained, ideally the supply current would be sinusoidal always, with robust control over its magnitude and phase, despite of the harmonics and imbalance of the load demand and imbalance of supply voltage system. This endorse almost unity power factor on source side with active and reactive power support from the wind turbine side. The output waveform will be obtained with the battery storage with micro wind energy generation system by injecting (or) consuming reactive power and the real power flow required by the load is allowed. The generated power can be stored in the batteries at low power demand hours. In case of grid failure this system can be operated as a standalone system like a uninterrupted power supply.**

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

I. Introduction

Highlight 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 small scale wind power generation framework with battery energy storage is winding up more conspicuous with the extending power generation request. 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 framework can't allow 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 usual action, 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. Still the wind generator brings disruptions into the distribution network. The basic techniques of running a wind generating system are to utilize the induction generator associated directly to the grid system. The induction generator has inalienable points of interest of cost viability and robust-ness. Be that as it may; induction generators require reactive power for magnetization. At the point when the generated active power of an induction generator is fluctuated because of wind, absorbed reactive power and terminal voltage of an induction generator can be significantly influenced. An appropriate control scheme in wind energy generation system is required under usual operating condition to permit the proper control over the dynamic power production. If there should be an occurrence 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 framework with battery storage has the following objectives:

1) Unity power factor and power quality at the point of common coupling bus.

2) The real and reactive power support from wind generator and batteries to the load.

3) Stand-alone operation in case of grid collapse.

This paper is sorted out as takes after. Segment II presents the wind power extraction with batteries, Segment III presents the control scheme, Segment IV depicts the system

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M.H.V.Murali Krishna, *EEE Department, Prasad V.Potluri Siddhartha institute of technology, Vijayawada, India,*

M.Seshu, *EEE Department , Prasad V.Potluri Siddhartha institute of technology , Vijayawada, India.*

performance, and Segments V and VI portray the experimental outcomes and conclusion.

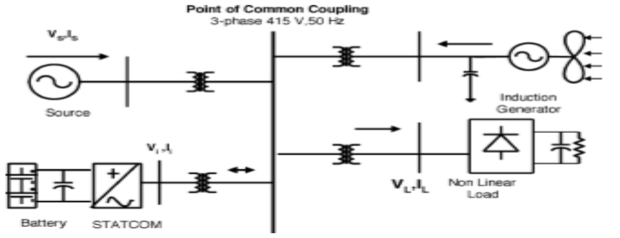


Fig. 1. Schematic diagram of micro-wind generator with battery storage for critical load application.

II. EXTRACTION OF WIND POWER WITH BATTERIES

A. *Micro-wind energy generating system*

The wind generating system (WEGS) is associated with turbine, induction generator, interfacing transformer, and ac-dc converter to obtain dc bus voltage. The power flow is depicted 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 C_P 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 ω , turbine mechanical torque is shown in

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

B. *Dc link for Battery Storage and Micro-Wind Generator*

The battery storage and WEGS are associated over the dc link as appeared in Fig. 3. The dc link comprises 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 wind generator. The utilization of capacitor in dc link is more efficient, less expensive and is demonstrated 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 I_b 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

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

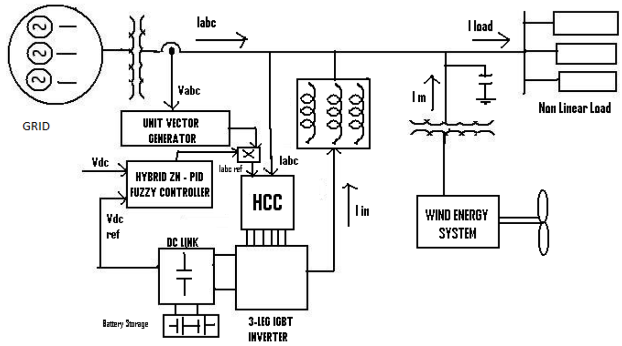


Fig. 2. Inverter interface with combination of battery storage with WEGS

It is important to keep satisfactory 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 wind generating system uses the dc link to extract the energy from the wind. The 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 utilized for keeping the dc bus voltage constant; consequently 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 conspire approach relies upon imbuing the current into the grid utilizing “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 estimation of few factors,for example,three-phase source current iSabc for phases a, b, c, respectively, dc voltage Vdc, inverter current iiabc with the assistance 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 actuate 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 Vsm [14], as in

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

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

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

The in-phase generated reference currents are determined utilizing the in-phase unit voltage layout 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 actualizes the significant 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. In such circumstances the voltage sensors sense the situation and will transfer the switches for the generation of reference voltage from 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. Hanfis Based Current Controller

Neuro-fuzzy hybridization results in a hybrid intelligent system that synergizes these two techniques by combining the human-like reasoning style of fuzzy systems with the learning and connectionist structure of neural networks. Neuro-fuzzy hybridization is widely termed as fuzzy neural network (FNN) or neuro-fuzzy system (NFS) in the literature. Neuro-fuzzy system (the more well known term is utilized henceforth) consolidates the human-like thinking style of fuzzy systems using fuzzy sets and a linguistic model consisting of a set of IF-THEN fuzzy rules. The main strength of neuro-fuzzy systems is that they are universal approximators with the ability to solicit interpretable IF-THEN rules.

The strength of neuro-fuzzy systems includes two conflicting necessities in fuzzy modeling: interpretability versus precision. In practice, one of the two properties prevails. The neuro-fuzzy in fuzzy modeling research field is divided into two areas: linguistic fuzzy modeling that is focused on interpretability, mainly the Mamdani model

TABLE I. Fuzzy Rule Table

ΔP/ PVdc	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	NL
NM	NL	NL	NL	NM	NS	EZ	NM
NS	NL	NL	NM	NM	EZ	PS	NS
EZ	NL	NM	NS	EZ	PS	PM	EZ
PS	NM	NS	EZ	PS	PM	PL	PS
PM	NS	EZ	PS	PM	PL	PL	PM
PL	EZ	PS	PM	PL	PL	PL	PL

C. DAPF 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 DAPF. The DAPF responds to the step change command for increase in additional load. When DAPF 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 DAPF compensator. Thus, DAPF can regulate the available real power from source.

IV. SIMULATION RESULTS

The proposed model is simulated in MATLAB/SIMULINK environment. The simulation parameter values for the given system are given in Table II.

TABLE II System Parameters

S.No.	Parameters	Ratings
1	Grid Voltage	3-phase,415v,50Hz
2	Asynchronous Generator	3.35KW,415v,50Hz,p=4,
3	Source Load Line Inductance	2mH,0.05mH
4	DC Link Parameters	DC Link=800V,C=100µf
5	Rectifier 3 arm Bridge type	Snubber R=100Ω, Ron=0.01Ω, C=100µf

A. Steady State Analysis of the System:

The harmonics in the grid current are injected by the non linear loads. To suppress these harmonic components in the current equivalent opposite current is free from harmonics. Fig.3 shows the various currents developed at PCC.

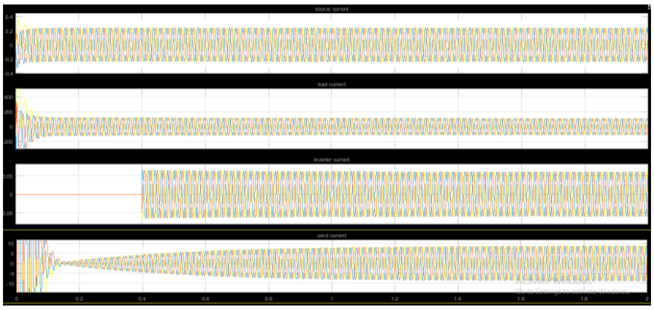


Figure 3. System Currents with HANFIS based current controller a) Grid Current, b)Load Current, c)Inverter Current,d) Wind Current

B. DC Link:

The voltage across the capacitor is maintained at constantly at 800V by the storage unit. The DC link voltage current and are as shown in Fig.4.

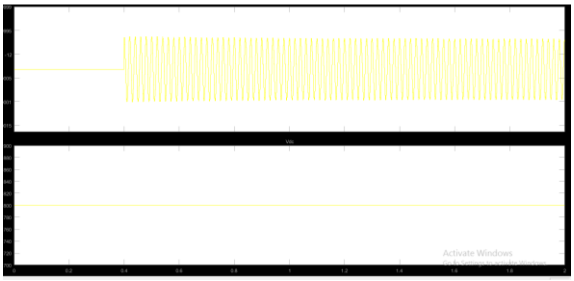


Fig.4. DC link Voltage

C. UPF:

The APF is connected at T=0.15. Before this time both voltage and current are not in phase. When APF is connected, the voltage and currents are in phase,which leads to unity poweer factor at point of common coupling and desired power quality norms are maintained.The in phase grid voltage and figure are as shown in Fig.5.

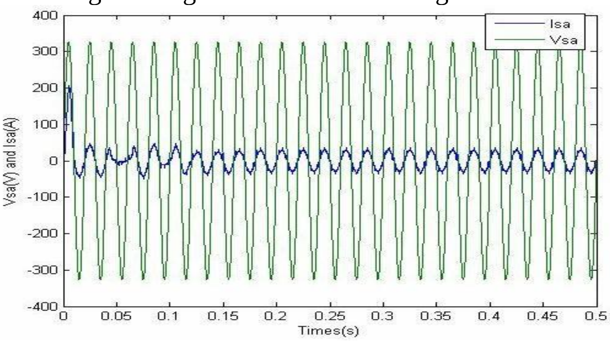
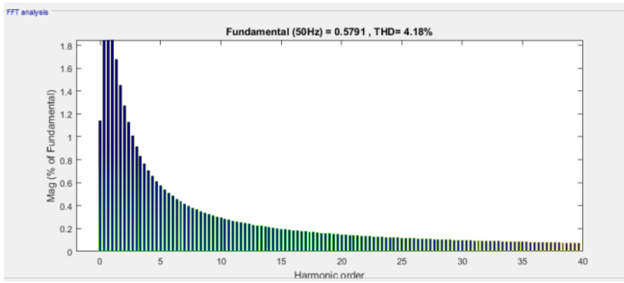


Fig.5. Voltage and current waveforms with and without APF

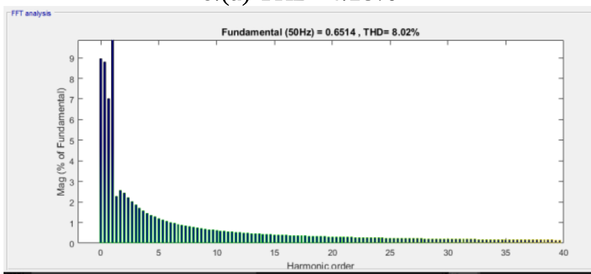
D. Power Quality at PCC

The power Quality is analyzed in three different cases without APF, with Hybrid ZN-PID Fuzzy controlled APF and with HANFIS controlled APF.

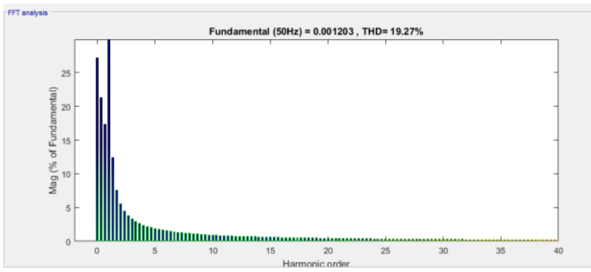
Case 1: The %THD of the currents without APF are as shown in Fig.6.



6.(a) THD=4.18%



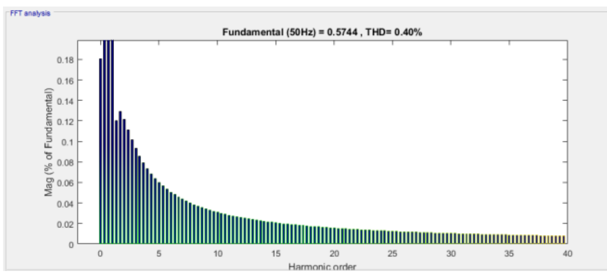
6.(b) THD=8.02%



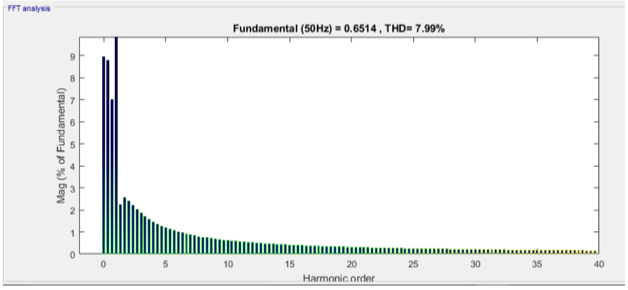
6.(c) THD=19.27%

Fig.6 %THD of a)Source current, b) Load current, c) Wind current without APF

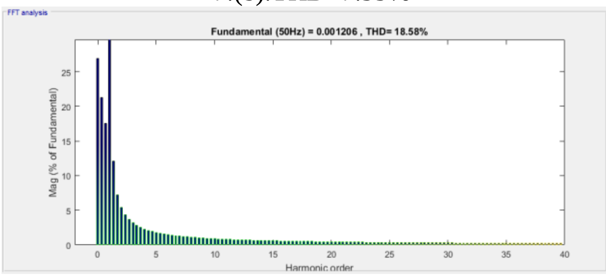
Case 2: APF is connected to the line at 015 the % THD of the currents with Hybrid ZN-PID Fuzzy controlled APF are as shown in Fig.7



7.(a). THD=0.40%



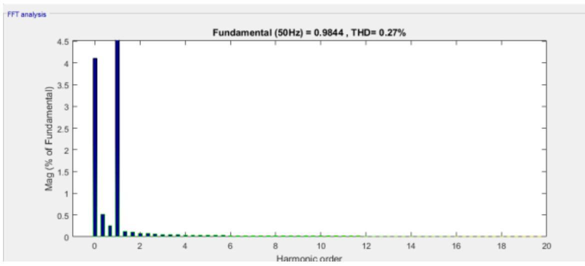
7.(b).THD=7.99%



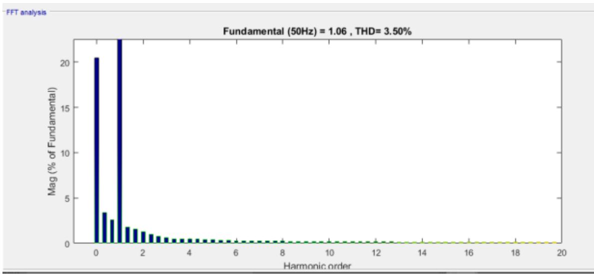
7.(c). THD=18.58%

Fig.7 % THD of a) Source current, b) Load current, c) Wind current with Hybrid ZN-PID Fuzzy controlled APF

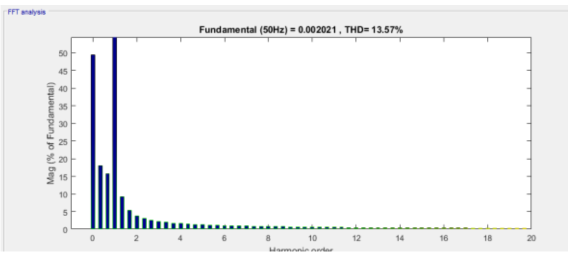
Case 3 : The % THD of the currents wiith HANFIS controlled APF are as shown in Fig.8



8.(a) THD=0.27%



8.(b) THD=3.50



8.(c) THD=13.57%

Fig.8. %THD of a) Source current, b) Load current, c) Wind Current with HANFIS controlled APF

TABLE III Comparision of %THD for various Currents

Parameters	Without APF	With Hybrid Fuzzy-ZN PID controlled APF	With HANFIS Controlled APF
Power Factor	0.86	1	1
%THD			
Source Current	4.18	0.40	0.27
Load Current	8.02	7.99	3.50
Wind Current	19.27	18.58	13.57

From the Table-III it is clear that the HANFIS based controller effectively reduces the harmonics at Point of common coupling from 4.18% to 0.27% THD

V.CONCLUSION

The paper proposed 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 utilized to generate the switching signal for inverter such 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 managed over the dc bus having energy storage and is made accessible under the steady state condition. This additionally permits the real power flow during the instantaneous demand of the load. The recommended control system is suited for rapid infusion or ingestion of reactive/real power flow in the power system. The battery energy storage provides quick response and enhances the performance under the fluctuation of wind turbine output and improves the voltage stability of the system. This scheme is giving 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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