Bi-directional Power Control Mechanism for a Microgrid Hybrid Energy System with Power Quality Enhancement Capabilities

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Abstract- The interconnection of different loads and renewable energy sources such as photovoltaic system, wind energy system and storage system to a distribution network leads to a new energy structure known as the Microgrid. This paper presents the analysis and operation of the microgrid hybrid energy system with power quality improvement features. In order to enhance the capacity to improve the power quality and stability of microgrid hybrid energy system, a hysteresis based bi-directional Power Transfer strategy with power harmonic filter is presented. This includes two modes i.e. inverter side power flow mode and DC/DC converter side power flow mode. The inverter side power flow mode is defined as the method of extracting power from the DC Microgrid and using it to boost the grid, and the DC/DC converter mode utilizes the grid power to provide power back to the DC microgrid for feeding local DC loads. The scheme goals to: minimize the disturbance in the output voltage of DC/DC converter, regulate the output voltage of the 3-phase inverter, compensate the wind power and solar irradiance changes, bi-directional power transfer, to reduce the carbon emission from the ENNOR thermal power plant-India and to enhance the power quality of the system. Therefore a dc to dc converter is employed with bi directional power flow capabilities to integrate the wind and solar sources to the microgrid. A wind/solar hybrid microgrid model is developed using the MATLAB Simulink/SimPower systems toolbox.

Keywords Microgrid, renewable energy sources, storage system, DC-DC converters, inverter, power harmonic filter, power quality, THD

1. Introduction

With the fast depleting fossil fuel reserves, energy security and environmental concerns there is an enormous requirement of alternate sources of energy to fulfill the present power demand. Out of the various available renewable energy resources, solar photovoltaic system and wind system are a clean, vast and reliable energy sources to meet up the present power scenario in the world, especially in India. Electric utilities of electric energy are becoming ever more disturbed about meeting the present power demand. More than fifty percent of overall power demand is completed by the fossil fuels. However, fossil fuels increase the global warming, air pollution, etc. Out of various factors causing hindrance to the large-scale usage of renewable energy sources, the power quality is the important concern of any system. Many schemes for integration of solar system and wind system have been developed which are based on various methodologies. Meanwhile the past decade, there has been a giant attention in different countries on the renewable energy sources for

energy generation [1]. To decrease in the losses on the power system as well as different thermal losses at the power station, the optimal sizing and distribution generation units location in the distribution network in environments of the load is useful, hence this would improve voltage and frequency profile [2], [3]. In certainty, since generation sources give the end consumers a better power quality, permit facility of greater reliability, good electric service as well as the reduction in the pollutant levels. Furthermore, the different generation resources fed by renewable energy resources are a great significance in the microgrid hybrid system, which includes distribution generators along with load side driver and a central controller. [4], [5]. A storage device, such as batteries and flywheels are being used to improve the stability as well as the efficiency of microgrid [6], [7].In Distributed generation (DG) level, the different renewable energy resources are being added. The distribution generator systems are necessary to confirm the reliable, safe and optimum process of the overall system. The utility is apprehensive due to an excellent penetration level of renewable energy source in distribution level as it creates a risk to network in stipulations of stability, dynamic performance, and power quality problems. With the development of the power electronics devices and different control strategy, the renewable energy systems could be actively controlled by using power electronics to enhance the system performance at the point of mutual coupling. But, the broad usage of power electronics based equipment's and controllers at the point of mutual coupling creates harmonic currents, then it would weaken the power quality [8], [9]. Frequently, current controlled and voltage controlled inverters are employed to interconnection the renewable energy sources in distributed level. Newly, some control methods for grid connected inverters combining power quality improvement have been proposed in [10]. To hold the harmonic current, the inverter can run as an active inductor at the certain level of frequency. An active shunt filter will act as active conductance to clear out the harmonics contains in distribution network [11].In [12], an approach for interfacing inverter based on p- q theory is discussed.With the enhancement of DC loads, renewable energy sources and microgrid becomes more popular and the main task of DC microgrid is proper control algorithms for a sovereign operation which could manage the operation of different energy storages, renewable sources, and loads. Thus this could enhance the system response speed and reliability [13]. In [14], the 30-kW hybrid system model case study is discussed and synchronous type wind generator is used with the variable speed control technique are used to extract the maximum wind power throughout the day. In [17-23], differenet techniques and anlalysis are done for renewable energy system.

In this paper, the proposed microgrid hybrid energy system configuration is described in Section II. Components Modeling of The Proposed Microgrid Hybrid Energy System is presented in Section III. In Section IV, Bi-directional Power Transfer strategy with power harmonic filter is presented. In Section III, dual boost converter power flow control scheme is presented. Results and discussion are described in Section IV. Finally, concluding statements are presented in Section V.

2. Proposed Microgrid Hybrid System

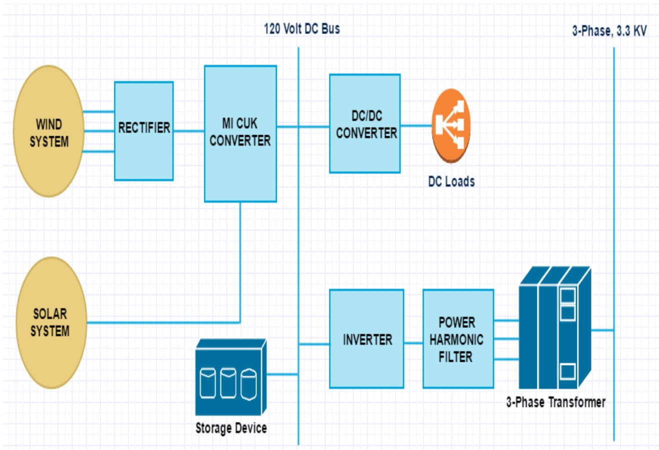


Fig. 1. Overall architecture of the proposed Microgrid hybrid energy system

A microgrid is an interconnection of loads and distributed energy resources within evidently clear boundaries that act as a sole handy entity on the main grid. Depending on the situations, it can be operated either with the main grid or in island mode. Micro-sources can comprise of diesel generators, fuel cells, microturbines, photovoltaic panels, wind turbines, battery, etc. Some requirements should be satisfied in interconnected mode and island mode, e.g., active power and reactive power flow control, voltage and frequency regulation capability, and black operation. IEEE Standard 1547 encloses guidelines for interconnection of DER systems [15]. Fig. 1 shows the structure of the proposed microgrid hybrid energy system with solar, wind and storage system. Harmonic power filter connecting inverter and AC microgrid can be used to offer the capability to enhance the power quality of the entire system. As soon as a fault or any disturbance on AC microgrid is detected. The power harmonic filter can provide harmonics compensation. Hence, the power harmonic filter becomes an essential component for the microgrid applications. On the other hand, power converters with multiple input structure are one of the most popular topologies in the hybrid energy system. Islanding mode can be either intentional or unintentional. Intentional islanding is used in scheduled maintenance and degraded power quality situation of the main grid.

Therefore, a DC to DC converter is utilized to the integration of wind and solar in microgrid in this paper. To get maximum power in PV system, the current control method is used. A dc microgrid power distribution network is selected because this system could attain higher energy efficiency in a simple way to than ac type power system. A voltage level of 120 V is chosen to dc bus voltage in this hybrid energy system because bidirectional power flow is simpler than any other voltage level and because it can be easily boosted up with a power converter and likely to control by different controllers. To support power variation and peak demand an energy storage device is required which is connected to the main dc Microgrid. This DC voltage is being utilized by different consumers like telecommunication system, electrical vehicles, etc. by converting this dc voltage in a suitable range by using dc/dc converter. The ac loads are severed by inverter and power harmonic filter. Power harmonic filter is a necessary component for ac system to reduce the harmonic and improved the power quality of the scheme. The output of filter feeds the three-phase 3.3 kV distribution grid with the help of three-phase 120 V/3.3 kV transformer that provides low harmonic contents. Hence the efficiency per module area is 16.12% consequently 32 modules are needed to generate 10kW power output. This system is economical as well as reliable since the solar output is used to feed the grid via an inverter. Whenever solar power is not available then the grid will supply electricity to the respected load. Table 1 shows the PV module Specification for equivalent circuit parameters and table 2 shows the size description of PV module.

3. Components Modeling of the Proposed Microgrid Hybrid System

3.1. Wind System Model

A wind turbine in the planned microgrid hybrid energy system is presented which drives a wind generator as shown in fig.2. The wind model must be able to simulate the activist variations of the different wind velocity. The wind velocity V_w can be defined as (P. M. Anderson and Anjan Bose 1983),

$$V_w = V_B + V_G + V_R \quad (1)$$

V_w = wind velocity,
V_B= Base wind velocity,
V_G = Gust wind component and
V_R = Ramp wind component.

$$\text{Wind Power } P_w = \frac{1}{2}\rho A V_w^3 \quad (2)$$

Where ρ is the air density and A is cross sectional area.

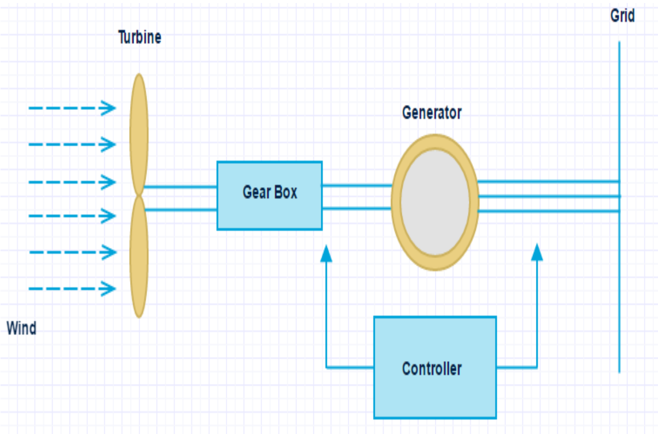


Fig. 2. Typical Wind System

The wind turbine power captured could be defined **as**,

$$P_m = P_w \times C_p \quad (3)$$

where C_p is the power coefficient.

$$C_p = \frac{1}{2}(\lambda - 1.022\theta^2 - 5.6)e^{-0.17\lambda} \quad (4)$$

Where θ is blade pitch angle, and the λ is the tip speed ratio of the turbine.

Table 1. Wind Turbine Model Specifications

Parameter	**Value**
Rated Power	12 kW
Rated Rotor Speed	56.42 rad/s
Rated Wind Speed	12.5 m/s
Blade Pitch Angle	0 degree

3.2. PV System Model

PV systems are composed of many PV modules which connected in series or parallel as shown in fig.3. During the day, solar irradiance and temperature changes always.

Short-circuit current (I_{sc}), open-circuit voltage (V_{oc}) and the maximum power point ($Impp$,V_{mpp}) are very important parameters in PV system. The power delivered by a Photovolataic cell achieves a maximum value at the points ($Impp$,V_{mpp}). This parameters information is enough to form a simple model of the module to test power converters.

Fill Factor (FF) provides a hint of the quality of a PV cell's semiconductor junction, it also measures the ability to accumulate the carriers generated by light.

$$FF = \frac{V_{mpp} I_{mpp}}{V_{oc} I_{oc}} \quad (3)$$

$$P_{max} = FF V_{oc} I_{oc} = V_{mpp} I_{mpp} \quad (4)$$

Photovoltaic cell characteristics can easily be observed that F F is always < 1 for successful operation

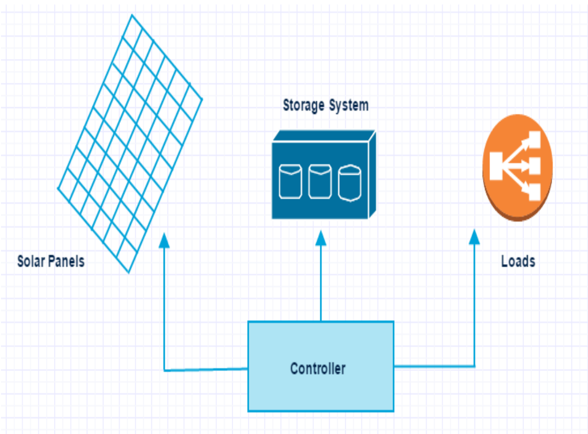


Fig. 3. Typical Solar System

The efficiency η is defined as

$$\eta = \frac{V_{mpp} I_{mpp}}{P_L} \quad (5)$$

Where P_L is the solar power received by the surface of the cell

$$\eta = FF \frac{V_{oc} I_{oc}}{P_L} = FF \frac{V_{oc} I_{oc}}{\int_0^{\infty} P(£)d£} \quad (6)$$

where P(£) is the solar power density at wavelength £.

$$\eta = \frac{\int_0^{£_g} P(£)d£}{\int_0^{\infty} P(£)d£} \cdot E_g \frac{\int_0^{£_g} N(£)d£}{\int_0^{\infty} P(£)d£} \cdot \frac{qV_{oc}}{E_g} \cdot FF \cdot (1-R) \cdot \frac{A_f}{A_m} \cdot \eta_e \quad (7)$$

where Af is the area of the front surface which is not covered by metal contacts, and Am is the overall area of the surface.Temperature Variation in the cell occurs due to changes in the ambient temperature as well as shifts in the insolation.

3.3. MI Cuk Converter

The general form of an MI Cuk converter comprises of many input sources and a single output as shown in Fig.4.. All the available input sources can supply power to the load either separately or together. When more than one input sources are delivered to the MI Cuk converter, all the input sources will give power to the load at the same time without disturbing each other's input sources operation. A two-input cuk converter has the many advantages. The multi-winding transformer is not needed in this case, and each dc sources could give energy to the load individually or simultaneously

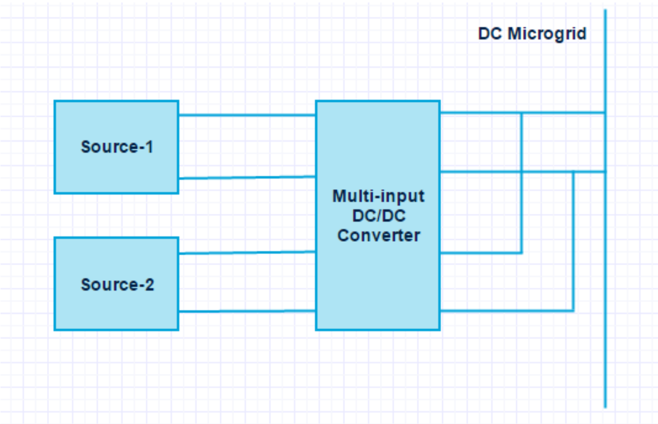


Fig. 4. Multi-Input Cuk Converter

3.4. Energy Storage System Model

The battery is energy storage devices for this system. A dc-dc power converter is needed for this system to improve the reliability of the system and lower the battery voltage to avoid higher voltage fluctuations. If renewable energy sources power generation is insufficient to satisfy the load demand, then this battery system gives power to the load similarly if power generation is higher than the load demand then battery system store energy. So the battery is needed to satisfy excess load demand when renewable energy sources are not able to give this much amount of power.

3.5. Power Harmonic Filter

Power harmonic filter is consist of RLC elements. This power harmonic filter can reduce the harmonic from the system and also improve the stability of the scheme. The control strategy includes the controller and driver circuit. The error signal is created by comparison of the output voltage and the reference voltage. The error is integrated through the controller and transfer to the driver circuit.

The current control method is used for active power filter which is consist of feedback control system. Band-pass filters and high pass filter are used for filter out the harmonics from the system.

4. Bidirectional Power Flow Control

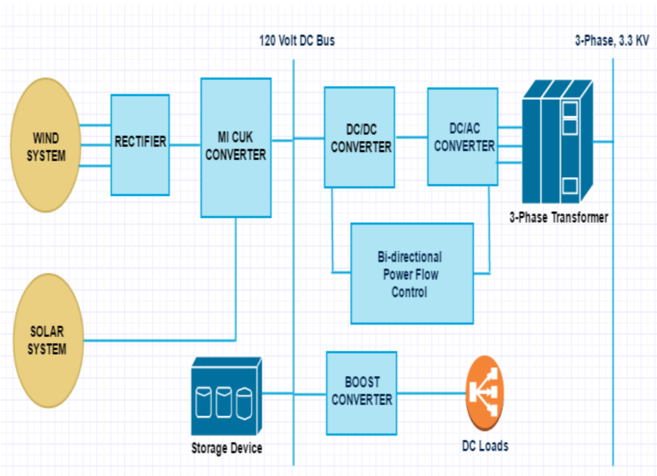


Fig. 5. Bidirectional power flow control

Bidirectional power flow control is needed in this system as shown in fig.5.This includes two modes i.e. inverter side power flow mode and DC/ DC converter side power flow mode. The inverter side power flow mode is defined as the method of extracting energy from the DC Microgrid and using it to enhancement the grid. This is accomplished by using DC/DC converter voltage to the necessary level after that changing it to ac with the proper frequency and voltage needed to inject current into the grid. As the voltage level is determined by the grid, the inverter would be of the current controlled type. Alternatively, the DC/DC converter mode has utilized the grid to give power back to DC microgrid for local DC loads; this is accomplished by rectifying the grid voltage and the change the DC level of this voltage according to DC microgrid demand. A hysteresis control method is used for this system because of its comfort of execution. This control system requires algorithms to work in conjunction to get the good power quality of the scheme.

$$V_{dc} = \left[\left(V_{dc-grid} - 2\right)^2 . \frac{T_{on}}{T}\right]^{1/2} \quad (8)$$

$$P_{dc} = \frac{{V_{dc}}^2}{load} \quad (9)$$

$$P_{dc-grid} = V_{dc-grid} . I_o \quad (10)$$

$$\text{DC/DC converter efficiency} = \frac{P_{dc}}{P_{dc-grid}} \quad (11)$$

Where V_{dc} is output voltage of DC/DC converter and $V_{dc-grid}$ is DC microgrid output voltage

RMS value of fundamental phase voltage of inverter

$$V_{p1} = \frac{2V_{dc}}{\sqrt{2}.\pi} . \cos\frac{\pi}{6} = 0.3898V_{dc} \quad (12)$$

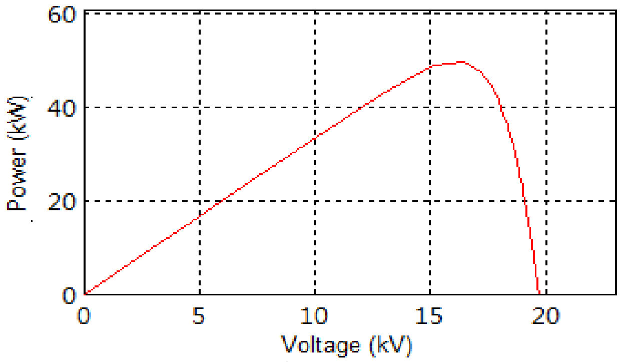
In the hysteresis control system, there is the comparison between output current and reference band. The reference voltage is sampled in every interval and the grid voltage is taken as a reference voltage. Hence, the grid side voltage and output current would be in the phase. Therefore power can flow in both the direction by using this scheme so this is an easy method to control the power of hybrid energy system.

5. Simulation Studies

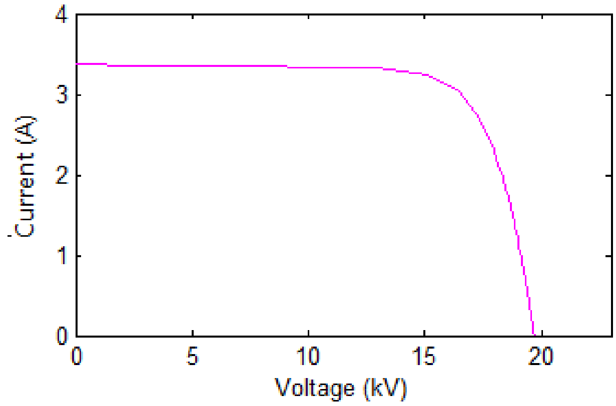
The simulation model of the hybrid energy system is developed in MATLAB Simulink/Sim power systems. To evaluate the performance of system ac load and grid inserted power varies, the power harmonic filter is designed in MATLAB Simulink/Simpowersystems to reduce the harmonics in the system. Wind system gives 12 kW, and the solar system gives 50 kW output to feed the microgrid.

5.1. Control Performance of the PV system with MPPT

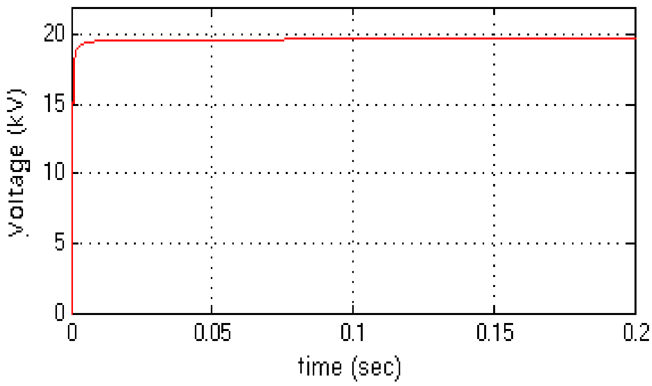
The surface temperature of PV panel is considered to be fixed throughout the entire operation of the simulation period. PV modules functioning are being tracked at different points of power toward the Maximum power achievement. Hence, PV system controller tracks the Maximum power point of solar system irrespective of the change in the wind speed. Explicitly, this PV is independently controlled by MPP algorithm with **affecting** another source. Fig. 6. shows the I-V characteristics, P-V characteristics of **the photovoltaic** module and the output voltage of PV solar system.



(a)



(b)



(c)

Fig .6. PV system control performance (a) P-V characteristics of PV module with MPP, a (b) I-V characteristics pf PV module with MPP and (c) Output **voltage** of PV system.

5.2. Control Performance of the wind energy system with MPPT

A wind model is used to simulate the different effect of changing wind components. When the rotor speed of wind turbine **goes** faster, then wind turbine output power also increases. Similarly when the wind turbine rotor speed slows down, then wind turbine output power decreases. Wind energy changes continually because of wind speed changes during the day. The exact amount of power output is tracked by the MPPT controller of the wind energy based system. Fig.7 and fig.8. shows the control performance of wind energy system.

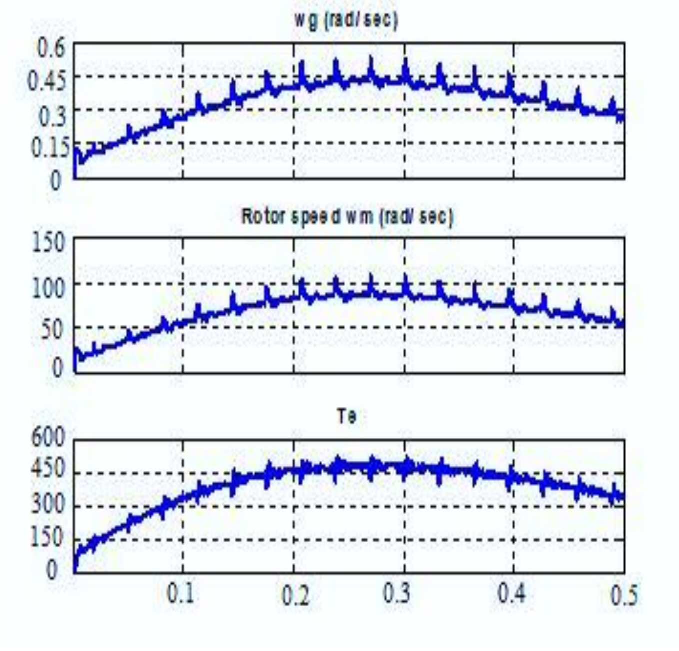


Fig. 7. Wind turbine control performance. Generator speed (per unit), Turbine rotor speed, and Electromagnetic Torque

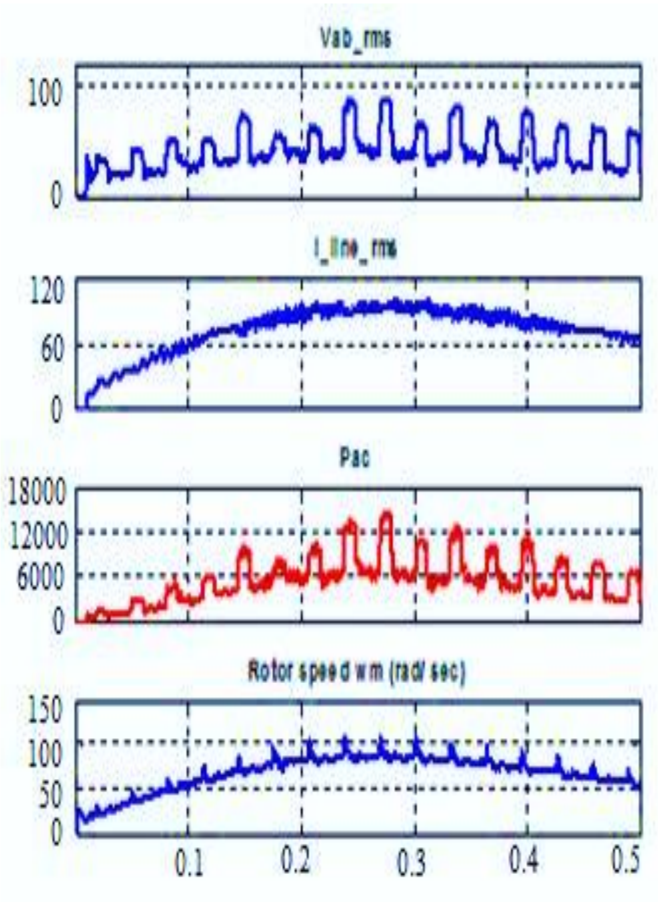


Fig. 8. Wind energy system performance

5.3. Inverter Performance with Power Harmonic Filter

Power Harmonic filter reduces the harmonic in the system. fig. 9. shows the voltages at the output of the inverter. Power harmonic filter is switched on then harmonic reduces. Without *power harmonic* filter inverter output voltage has harmonics. Current may get distorted because of harmonics, so power quality of system becomes poor. With the *power harmonic* filter, the THD level of the system is decreased to a low level which enhances the power quality of the scheme.

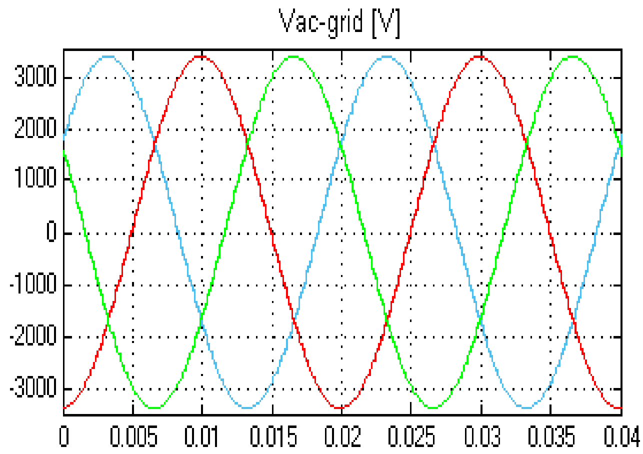


Fig. 9. Inverter output Voltage with power harmonic filter

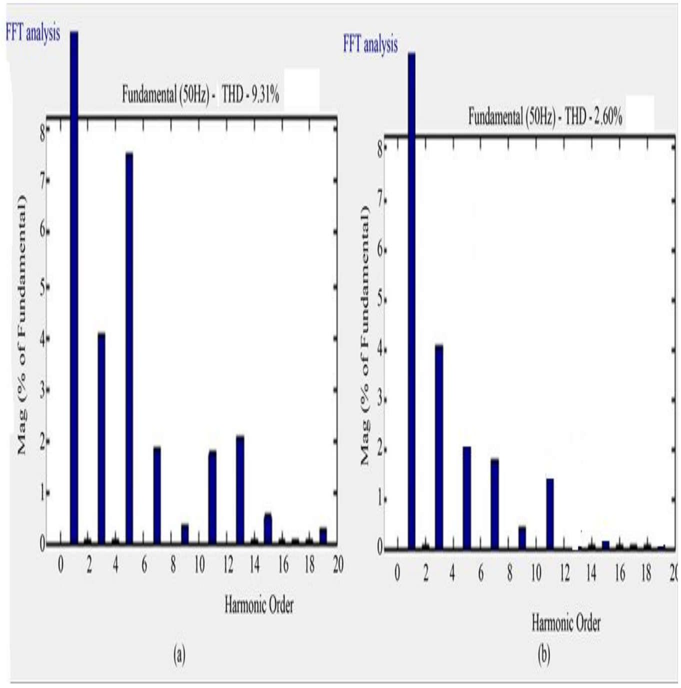


Fig. 10. Harmonic analysis sperctrum before and after the filter

Fig 10. Shows the harmonic analysis spectrum before and after the filter. It shows that , THD is 9.31 % when power harmonic filter is not used. It reduces to 2.60 % when harmonic filter is added to the system. Hence, Power harmonic filter reduces the harmonic distortion and improves the power quality of the hybrid energy system.

5.4. Carbon Emission Reduction with Hybrid Energy System

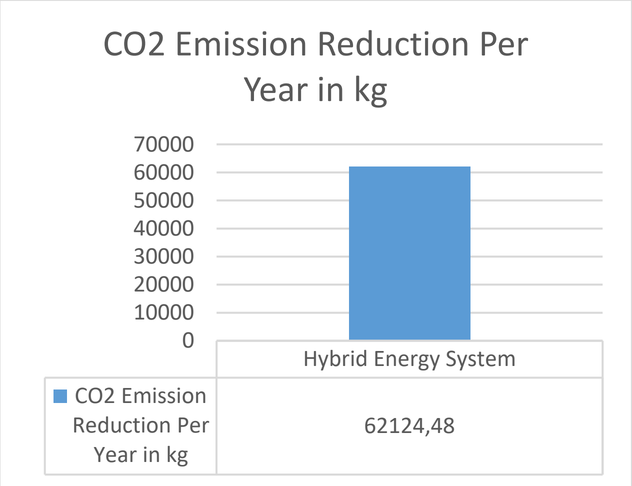


Fig. 11. Carbon emission reduction per year

If the hybrid energy system is not used then carbon emission increases in all the areas near thermal power plant each year. This is very harmful to the environment, therefore hybrid energy systems are used to reduce the carbon emission. In 1unit electricity emission per kWh generated is equal to the value of 0.814 kg as mention in global warming mitigation technology promotion project under the Ministry of Economy, Trade and Industry Contractors.

For the proposed Microgrid hybrid energy system, the solar system generates 200 units per day and wind system generates 12 units per day. Therefore, the total numbers of units generated per year are 76320.

CO_2 Emission from this 76320 units = 76320×0.814 kg
= 62124.48 kg

ENNORE thermal power station generated 1396000000 units per year.

CO_2 Emission from this 1396000000 units
=1396000000×0.814 kg
= 1136344000 kg

This analysis indicates that 62124.48 kg CO_2 emission is reduced from ENNORE thermal power station, India by using this hybrid energy system as shown in fig. 11.

6. Conclusion

The increased permeation of renewable energy sources and storage system into the microgrid has introduced the concept of new technology for the power system. This paper presented the modeling and efficient strategy for reduced harmonic distortion of a sustainable microgrid hybrid energy system. A hybrid microgrid energy system is developed with MATLAB Simulink/Simpowersystems. A dc to dc converter is used to integrate the wind and solar sources to the DC microgrid. The power harmonic filter is developed with grid connected inverter system and the DC voltage generated by hybrid energy system is regulated by using DC/DC Converter. The power harmonic filter reduces system total harmonic distortion up to 0.25 % and hence power quality improvement is observed in the microgrid hybrid energy system. Also, this system is equipped with a **bi-directional** power flow controller and is connected to the microgrid. This different power flow controller can improve the microgrid performance and power flow within the system.Furthermore, DC/DC converter is also used to compensate the wind power, solar irradiance changes and to minimize the disturbance in the input voltage of 3-phase inverter circuit. This analysis also shows that 62124.48 kg CO_2 emission is reduced from ENNORE thermal power station by using this hybrid energy system. Therefore this control technique is very effective for integration of renewable energy sources to microgrid as well as the main grid.

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