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"Improvement of power quality in grid-connected hybrid system with power monitoring and control based on internet of things approach"

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Purpose: This article proposes a new control monitoring grid connected hybrid system. The proposed system, improvement of power quality is achieved with internet of things power monitoring approach in solar photovoltaic grid system network. The novelty of the proposed work consists in presenting solar power monitoring and power control based internet of things algorithm, to generate DC voltage and maintain the constant voltage for grid connected hybrid system. Methods. The proposed algorithm which provides sophisticated and cost-effective solution for measuring the fault and as maximum power point tracking assures controlled output and supports the extraction of complete power from the photovoltaic panel. The objective of the work is to monitor and control the grid statistics for reliable and efficient delivery of power to a hybrid power generation system. Internet of things is regarded as a network comprising of electronic embedded devices, physical objects, network connections, and sensors enabling the sensing, analysis, and exchange of data. The proposed control technique strategy is validated using MATLAB/Simulink software and real time implementation to analysis the working performances. Results. The results obtained show that the power quality issue, the proposed system to overcome through monitoring of fault solar panel and improving of power quality. The obtained output from the hybrid system is fed to the grid through a 3ϕ voltage source inverter is more reliable and maintained power quality. The power obtained from the entire hybrid setup is measured by the sensor present in the internet of things-based module. In addition to that, the photovoltaic voltage is improved by a boost converter and optimum reliability is obtained with the adoption of the perturb & observe approach. The challenges in the integration of internet of things – smart grid must be overcome for the network to function efficiently. Originality. Compensation of power quality issues, grid stability and harmonic reduction in distribution network by using photovoltaic based internet of things approach is utilized along with sensor controller. Practical value. The work concerns a network comprising of electronic embedded devices, physical objects, network connections, and sensors enabling the sensing, analysis, and exchange of data. In this paper, internet of things sensors are installed in various stages of the smart grid in a hybrid photovoltaic wind system. It tracks and manages network statistics for safe and efficient power delivery. The study is validated by the simulation results based on MATLAB/Simulink software and real time implementation. References 28, tables 1, figures 22. Key words: renewable energy source, photovoltaic system, power quality, internet of things, hybrid grid connected system.

Introduction

The concept of renewable energy source (RES) faces increasing concentration by general public and experts in the last years. These sources address the issues caused by global warming and depletion of fossil fuels. Depending on fossil fuels results in environmental pollution, green house problems and carbon dioxide emissions. This paved the way for an increase in clean environment awareness. Due to the environmental friendly nature, RES is crucially significant and is regarded as clean energy sources. RES possess the ability of providing energy services generating almost zero or zero air pollutant emissions. These emissions also have the ability to fulfill the requirements of domestic energy. RES provide pollution free environment, environmental protection, economic benefits and energy security. Therefore, it is important for the future and present generation to rely on RES for meeting energy needs [1].

Considering the renewable energy sources, the solar energy is more fascinating due to its advancements [2-4]. The photovoltaic (PV) systems utilize cells comprising of semi-conductor material for extracting the solar energy and its conversion to electricity. The PV systems are utilized as standalone systems or may be connected to grid [5]. Operating conditions like geometric location of the sun, irradiance level and the ambient temperature of the sun highly influence the performance of the PV system [6]. This uncertain nature of solar energy results in technical problems corresponding to the control of power system [7, 8].

Due to partial shading, loss of considerable amount of energy occurs in PV systems forcing the voltage to zero. This demands a maximum power point tracking (MPPT) approach to capture the maximized power from the PV system and differentiate the global peak from the local peak [9-13]. The MPPT algorithms regulate the pulse width modulation (PWM) generator's duty cycle with the help of the current and voltage obtained from the PV system. The generated pulses are fed to the converter switches for the regulation of its current and voltage [14]. A simple boost DC-DC converter [15] can be used for the boosting of input voltage obtained from PV system. When compared to the improvement of converter efficiency and conversion ratio of PV cells, the improvement of the MPPT efficiency is easier. This paves the way for the adoption of MPPT algorithms and Hill Climbing (HC) [16] approach is the most common among them. It uses the PV characteristics for finding the MPP but gets influenced by varying atmospheric conditions [17]. Incremental Conductance (INC) [18] is regarded as a version of HC and tracks the MPP even in times of rapid variations in solar radiation. Anyway, INC requires extra voltage and current sensors which in turn increases the system complexity. Henceforth, this work adopts Perturb & Observe (P&O) algorithm for the tracking of maximized power by oscillating around the peak point on attaining steady state condition.

Subsequently, the wind energy source exhibits a remarkable progress everywhere as a clean and inexhaustible energy source due to the growing power demand [19-22]. An unsteady pattern occurs in the production of wind power due to its intermittent nature. Added to this, fast ramps occur in the patterns of wind output power. Serious challenges exist in the grid stability when such intermittent sources are integrated with grid [23].

Considering the above mentioned issues of renewable energy sources, the monitoring of power obtained from these sources becomes mandatory. This introduces the concept of smart grids. Smart grids improve the performance quality, reliability, efficiency, sustainability and balance the power production with the integration of renewable energy sources [24, 25]. It also enables the consumers in employing alternate energy sources for efficient power source utilization and cost reduction [26]. By using Internet of Things (IOT), the components of SG are enhanced with the connection of internet [27]. The smart grids based on IOT comprises of smart sensors, actuators and objects for providing reliable energy transmission [28]. Hence, smart grid based on IoT is opted by the renewable energy sources for the efficient monitoring of power.

On the whole, this paper concentrates on an IoT based smart grid system utilizing hybrid PV-wind energy renewable source. A boost converter is deployed for enhancing the resultant voltage of the PV system. The obtained power from the hybrid renewable energy source is continuously monitored by the IoT device and is applied to the grid via a three phase voltage source inverter (3φ VSI).

Proposed control system.

Generally, the smart grid is termed as an electric grid of next generation that combines control system along with information and communication technologies with the power grid. The system has to be in dynamic and must be mandatorily in bidirectional communication as depicted in Fig. 1. The major purpose of the system is to quickly find the solutions to the problems with continuous monitoring and automation. Thus it reduces the man power targeting the reliability, safety and quality in electric power to all the consumers.

Fig. 1. Smart grid layout depicting the bidirectional communication

In order to establish a smart grid, following technologies must be grouped together as shown in Fig. 2:

· smart appliances;
· smart algorithms in power generation;
· smart power meters;
· super conducting cables;
· smart substations;
· integrated communications.

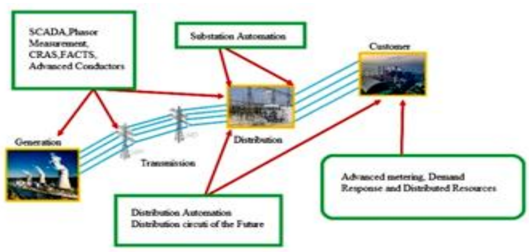

Fig. 2.Vital components of smart grid

By implementing all the advanced technologies one can achieve the smart grid technology with the integration of advanced software and can be managed easily from a remote location. When compared to the conventional grid structure the smart grid structure is easy to maintain and robust in performance making it more reliable and feasible to add more and more technologies and integrating any compatible hardware making it atomized as an ever ending evolution process (Fig. 3).

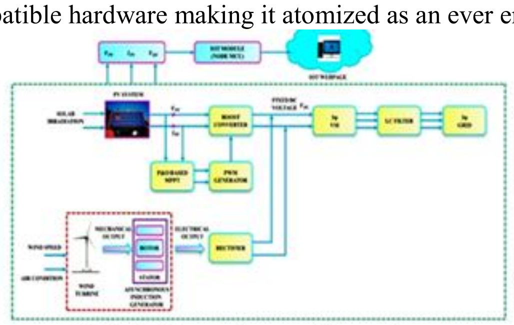

Fig. 3. Proposed generation system

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PV system

The basic PV cell circuit is given in Fig. 4. It comprises of a series resistance Rs, parallel resistance Rsh and diode VD.

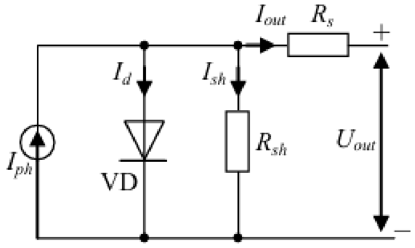

Fig. 4. PV system

The equations relating the PV cell and the output current are given by

$$I_{out} = I_{ph} - I_d; \quad (1)$$

$$I_d = I_0 \cdot \left[\exp\left(\frac{q \cdot (U + I \cdot R_s)}{n \cdot K \cdot T} \right) - 1 \right]; \quad (2)$$

$$I_{out} = I_{ph} - I_0 \cdot \left[\exp\left(\frac{q \cdot (U + I \cdot R_s)}{n \cdot K \cdot T} \right) - 1 \right], \quad (3)$$

where Iout is the output current; Iph is the photovoltaic current; Id is the diode current; I0 is the reverse saturation current; K is the Boltzmann constant; q is the charge of an electron; U is the work voltage of a PV cell; n is the p-n junction curve constant; T is the temperature. The obtained power from the PV system is enhanced by a DC-DC boost converter modelled as follows.

DC-DC boost converter

It is a step-up converter which boosts the input low level voltage to an output high level voltage. The basic circuit of boost converter is indicated in Fig. 5.

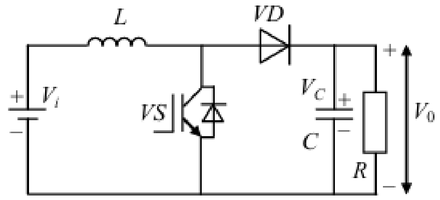

Fig. 5. Boost converter

The energy is stored in inductor L due to the current flow during the ON condition of the switch VS. During the OFF condition of the switch, a voltage is induced across the inductor due to the energy stored. The voltage across the inductor and the input voltage charge the capacitor C to an improved voltage. The estimated inductor ripple current at maximum input voltage determines the value of the inductor. Subsequently, the variation in the output ripple or voltage estimates the capacitor value. The pulses for the converter switch are obtained from the PWM generator. The MPPT algorithm in turn supplies the maximum power point voltage to the PWM generator and the corresponding operation is explained below.

P&O based MPPT

The MPPT algorithm is utilized for improving the efficiency of the solar panel. The main aim is to maintain the system operating point nearer to MPP. Here, P&O is adopted due to its simple structure, less parameters, ease of implementation and low cost. Fig. 6 represents the P&O flowchart.

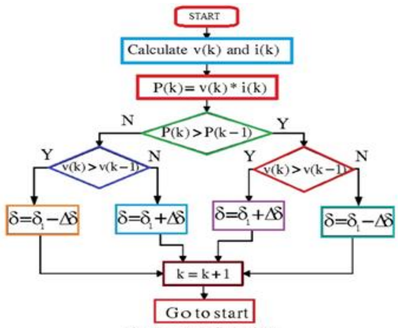

Fig. 6. P&O flowchart

At first, the current along with voltage from the PV system are estimated. The actual power is obtained from the product of voltage and current and the condition $\Delta P = 0$ is checked. The operating point occurs at MPP if this condition is satisfied else the condition $\Delta P > 0$ is checked. Another condition $\Delta V > 0$ is checked if the former gets satisfied and the operating point lies in the left portion of MPP. The operating point lies in the right portion of MPP if $\Delta V > 0$ is not satisfied. Till the reach of MPP, the process gets repeated. The obtained VMPP is fed to the PWM generator which in turn generates the pulses for the boost converter.

A wind energy conversion system (WECS)

The basic principle of the wind turbine is to perform the conversion of the linear wind motion to rotational energy. This drives the electrical generator which further converts the wind kinetic energy to electric power. The captured wind power is:

$$P_V = \frac{1}{2} \cdot \rho_a \cdot A_v \cdot u^3,$$

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where ρa is the density of wind; u is the speed of the wind; Av is the area swept by the turbine.
Due to the wind speed, the rotational wind turbine speed varies. The obtained variable AC output is applied to the rectifier for the generation of DC voltage and is transferred to the DC link.

Grid connected 3φ VSI

A grid connected 3φ VSI is given in Fig. 7. The constant DC link voltage VDC is applied as the input to the inverter and the conversion to AC output is carried out by dq theory

$$u_d = v_d^* - \omega \cdot i_q \cdot L_f + v_d \, ;$$

$$u_q = v_q^* - \omega \cdot i_d \cdot L_f + v_q \, ;$$

where $\omega = 2 \cdot \pi \cdot f$ and

$$v_d^* = \left(k_p + \frac{k_i}{s}\right) + \left(i_{dref} - i_d\right);$$

$$v_q^* = \left(k_p + \frac{k_i}{s}\right) + \left(i_{qref} - i_q\right),$$

where idref, iqref represent the d-axis and q-axis currents respectively.

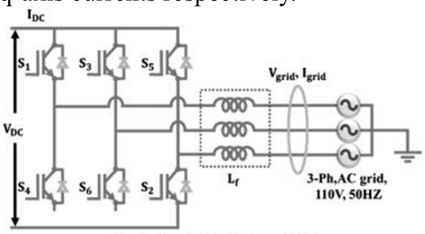

Fig. 7. Grid connected 3ϕ VSI

The AC parameters are obtained from:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} \sin\omega t & \cos\omega t & 1 \\ \sin(\omega t - 120) & \cos(\omega t - 120) & 1 \\ \sin(\omega t + 120) & \cos(\omega t + 120) & 1 \end{bmatrix} \begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix}, \quad (13)$$

where ua, ub, uc are the controlling input signals which are sinusoidal in nature. Comparison of these signals is carried out with the carrier signal in the sinusoidal pulse width modulation (SPWM) block. The gate pulses are generated from this block and these pulses are responsible for the inverter operation. The entire grid connected PV wind system is monitored by the IoT and the controller used is demonstrated as follows.

IoT based power monitoring.

In this work, the power obtained from the hybrid PV wind system is monitored by the IoT based Node MCU controller. The overall system for power monitoring using IoT is shown in Fig. 8. The IoT module used is Node MCU ESP8266 and the sensor used is INA219 sensor.

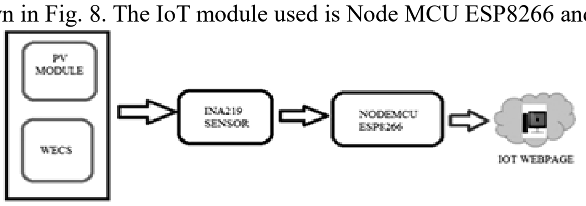

Fig. 8. Power monitoring system using IoT

The sensor is attached to the Node MCU ESP8266 module for the tracking of voltage and current form the hybrid system. The power is determined with the obtained value of current and voltage. Node MCU controller collects the data from the sensor and processes it. The processed data is further send to the web page. The corresponding flowchart is given Fig.

Fig. 9. Flowchart

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INA219 sensor. It has the ability to measure the current and voltage from the hybrid system. The input supply ranges from 3 V to 5.5 V. The 5 V output pin of the Node MCU supplies the 5 V to the sensor. The pins D1 and D2 of the controller are connected to the INA219 sensor. The current and voltage of the hybrid system are estimated by Vin+ and Vin– which indicate the measuring pins.Node MCU ESP8266 module. The pin diagram of the Node MCU ESP8266 module is given in Fig. 10. The controller communicates with the INA219 sensor, drives the LCD display and connects to the internet through a Wi-Fi module. It comprises of a built-in capability to access the internet and also supports numerous peripheral communication protocols. The Node MCU is connected to the internet and sends the measured data to the web page for future analysis. Thus the described IoT based monitoring system performs the efficient monitoring of power in grid connected hybrid PV-wind system.

Results and discussion. The monitoring of power in a grid connected hybrid PV wind system with the adoption of IoT based module is demonstrated in this

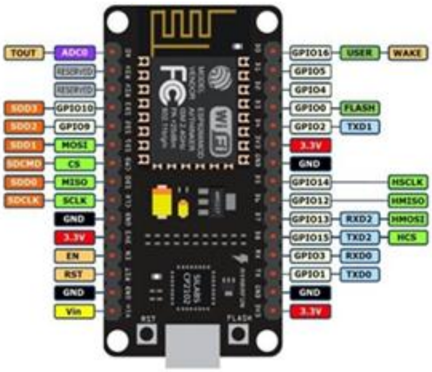

Fig. 10. Node MCU ESP8266 pin diagram

The simulation diagram of the solar PV model and wind turbine model are illustrated in Fig. 11, 12 respectively. The proposed generation model is shown in Fig. 13. In this the solar PV module take the solar radiation, temperature are measured by IoT web portal. In addition to that, wind speed and active power, reactive power, voltage and current are measured.

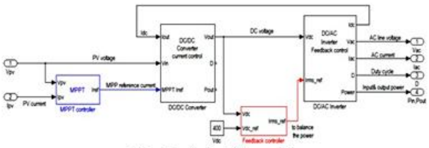

Fig. 11. Solar PV model

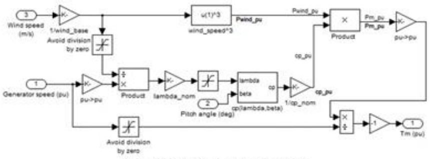

Fig. 12. Wind turbine model

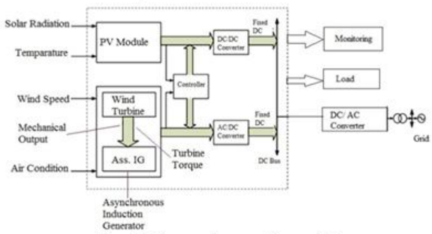

Fig. 13. Proposed generation model

The hybrid smart grid load are connected to an IoT based system, its performance are evaluated. It is shown the loads real time results. Initially, load data is connected through the IoT based Wi-Fi module and communicated to load data. The system allows for various loads monitoring in terms of active power, reactive power, voltage and current respectively.

At any instant of load, the user can see the local details of active power, reactive power, voltage, current and total harmonic distortion (THD) of voltage and currents are shown in Fig. 14–19 respectively.

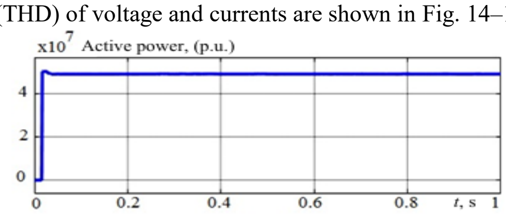

Fig. 14. Active power

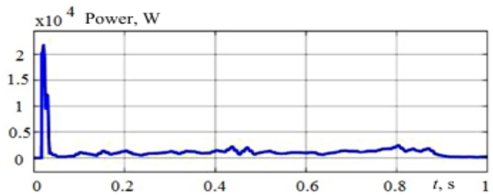

Fig. 15. Reactive power

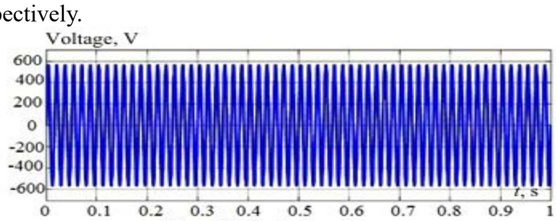

Fig. 16. Output voltage

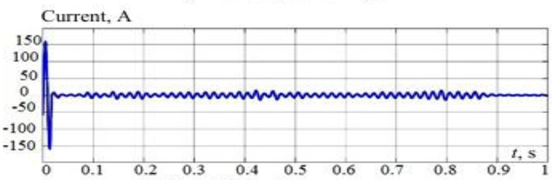

Fig. 17. Output current

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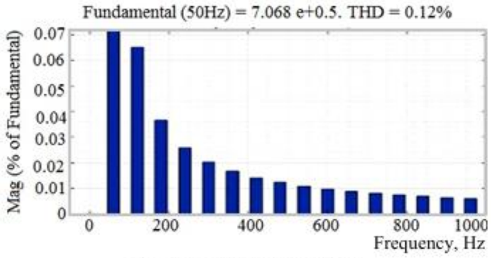

Fig. 18. Voltage harmonic

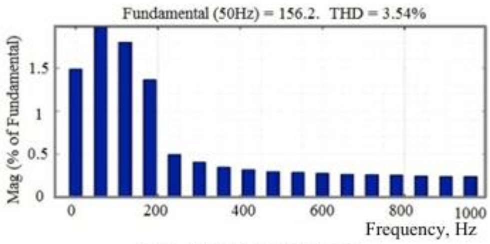

Fig. 19. Current harmonic

The IoT based PV power under shading effect is depicted in Fig. 20. And also the irradiance of the PV system is shown in Fig. 21.

The hybrid smart grid based IoT system, voltage harmonic on the grid side is shown in Fig. 20. In this the fundamental frequency takes in to 50 Hz. The system reduced the THD of 0.12 %. The current harmonics are depicted in Fig. 21. It shows the fundamental frequency of 156.2 Hz and THD reduced 3.54 %.

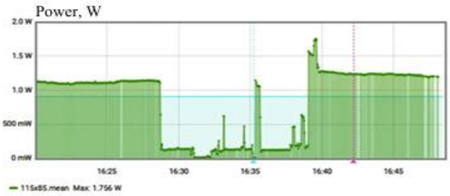

Fig. 20. Monitored PV power under shading effect

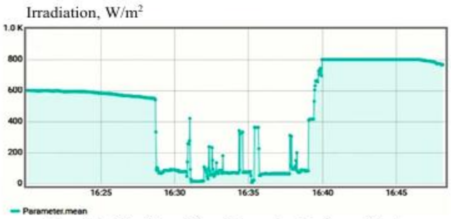

Fig. 21. Monitored irradiance in shading effect

The hybrid power generation for smart grid integration facilitates and enhances communication between grid and consumer. The power consumption and power quality is the main aim of smart grid integration. In this method effective monitoring and maintain power quality achieved by proposed IoT based hybrid smart grid.

The comparison of the PV solar panel power quality is depicted in Table 1. It shows the THD values of current and voltage harmonic with and without IOT approach.

Comparison THD – PV module with and without IoT

Conditions	THD, %
Without IoT monitoring and control approach current harmonic THD	20.25
With IoT Monitoring and control approach current harmonic THD	3.54
Without IoT monitoring and control approach voltage harmonic THD	4.59
With IoT monitoring and control approach voltage harmonic THD	0.12

The obtained IoT results are mentioned in Fig. 22. The display indicates the measured values of current and voltage of the hybrid PV-wind system. The ESP8266 communication is performed with the utilization of serial monitoring of the Node MCU.

Conclusions

In this work, an efficient power monitori ng approach is introduced for a hybrid photovoltaic wind system. This approach adopts internet of things based module with node microcontroller unit which processes the measured data obtained from sensor. The tracking of maximum power from the photovoltaic system is carried out by perturb & observe algorithm which in turn generates the maximum voltage for the operation of the boost converter. Subsequently, the obtained voltage from the photovoltaic system and wind energy conversion system is maintained constant at the direct current link. This fixed direct current voltage is converted to AC form by a 3ϕ voltage source inverter and further supplied to grid. The power of the entire setup is monitored by the internet of things based module which facilitates the smart consumption of power.

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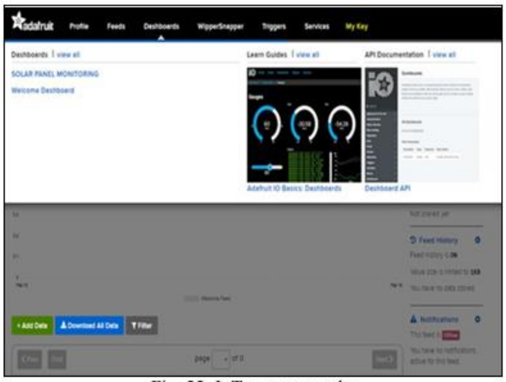

Fig. 22. IoT system results

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