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Smart Hybrid Power Generation Technology with Different Renewable Energy Sources

Manish Kumar Soni, Dr. Shanti Rathore

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Abstract: The paper examines smart technology combine with solar PV system, wind power generation system and piezo electric power generation system as renewable energy sources. Power generation through individual renewable energy system have variety of issue like intermittent in nature and also depends on geographical condition. This research paper introduces a smart technology to mitigate intermittent or fluctuated power supply through individual power generation unit to combined in a hybrid form. The solar PV system and wind power generation is most prominent used renewal energy sources but in combination with piezo electric system it becomes more efficient as compared to individual unit. The research paper deals with implementation of individual power generation as well as hybrid system with the help of MATLAB/Simulink.

Keywords: *Solar PV, wind power generation, piezoelectric, hybrid system, smart technology,*

1. Introduction

1.1 Background to research problem

For the progress of a nation energy seems to be crucial, therefore it is necessary to utilize energy efficiently. The economy of a country depends on a energy alone, so it is also necessary to preserve the conventional available energy sources. Almost all the appliances in our day-to-day life require electricity. Electrical energy can be generated in two ways – conventional and non-conventional. With the increasing population and technological advancement, the requirement of electrical energy increases exponentially. To meet the rapidly increasing electrical demand, we must increase the sources of electrical energy generating sources. The biggest issue with the use of conventional technology is the pollution of the atmosphere due to production of various pollutants like ash in thermal power plants, harmful radioactive material in nuclear power plants, gases in diesel power plants etc. The best way is to switch over non-conventional sources of electrical energy. Maintenance of these pollutants is also very difficult and expensive [1]. Renewable energy sources are those sources where energy can be obtained without depletion of earth's natural resources. Nonrenewable energy sources like coal, gas, diesel emits huge amounts of greenhouse gases and other by product as compared to renewable energy sources like solar, wind, hydro, geothermal, biofuels etc. which are cleaner and greener. Renewable energy sources have several advantages as compared to non-renewable energy sources. There is no production of pollutants and greenhouse gases etc. Also, the operating cost of renewable energy generation systems is low as compared to conventional sources. With this advantage it also has a lack in different fields. Renewable energy units are not reliable, and efficiency is also not high as compared to conventional generating units. Renewable energy units cannot continuously supply. It fluctuates in nature [2].

The development of technology in the field of renewable energy helps to preserve non-renewable energy sources but there is lack of reliability and efficiency in renewable energy sources. Sources of fossil fuels in the world decrease rapidly. Also, the use of fossil fuels produces greenhouse gases and other pollutants which affect the environment. In such cases there is a need to encourage industrialists and other growing nations to switch towards the use of renewable energy sources. Renewable energy sources are eco-friendly in nature and there are almost zero or nil emission to the environment. This will help in the economic

Research Scholar, Dr. C. V. Raman University Bilaspur, CG, India
soni.manish2588@gmail.com
Professor, Dr. C. V. Raman University Bilaspur, CG, India
rathoreshanti@gmail.com

development and growth of a country. The best opinion to use hybrid power generation technology is the combination of renewable energy generating sources solar, wind, fuel cell, piezoelectric etc. The efficiency of the generating units can be improved by incorporating different technologies with this.

1.2 Socio-Economic significance of research problem

For the economic development of a country energy should be utilized in an efficient way and carefully. Energy sources are the fundamental element for the economy of a country or economic development of a country. Excessive use of conventional sources or non-conventional sources of energy affects the economic status of a nation, no matter if the nation is developing or developed because sources of energy are available in limited [3].

Using conventional sources of electrical energy which are responsible for emission of greenhouse gases, especially CO2 gases, economic development of a country is faster but there is a problem of carbon emission and climate changes. CO2 is the byproduct of utilization of conventional energy sources which are mainly fossil fuels. [3]

Deployment of renewable energy sources throughout the country is required to mitigate the problem of global warming and climate change. Renewable energy sources eliminate harmful gases like carbon dioxide, carbon monoxide etc. [4]. For sustainable development long term potential effort is necessary to solve the problem of environmental issues. In today most cost effective and efficient solution is renewable energy. There is a clear connection between renewable energy and sustainable development. Renewable energy sources provide number of direct and indirect benefits [5].

1.3 Statement of Problem

Conventional energy sources result in depletion of naturally available resources as well as environmental issues. The excess consumption of conventional energy sources like coal, oil and gas cause depletion of natural sources available in limited quantity. Also, uses of conventional energy sources also cause greenhouse effect which affects environment to high extent. The alternate option is to use renewable energy sources which are available in abundant and free of cost. The renewable energy sources are environmentally friendly, non-polluting and clean. Examples of renewable energy sources are solar, wind, piezoelectric, hydro etc. but these renewable energy sources are susceptible to climate and environment changes which causes efficiency of these sources to decrease [6].

To increase the efficiency of renewable energy sources it is better to combine two or more renewable energy sources in hybrid form. The hybrid form of renewable energy sources is able to overcome the disadvantages of single renewable energy sources also satisfy the load demand. The cost of the hybrid renewable energy generation technique is less and is more effective, dependable and ecofriendly. The hybrid techniques resolve the problem of global warming, degradation of fossil fuels and pollution of environment etc. Also, the fluctuated power supply can be maintained uniformly by incorporating a tracking system and uses of power electronics devices [6].

1.4 Objectives of the study

The main objective of the thesis is to

i) Improve the dynamic performance of the WECS, PV system, and piezo electronics hybrid grid-connected power system.

ii) Enhancing the system's FRT (Fault Ride Through) capability while maintaining the RES grid-connected during undesirable abnormal operating conditions without disconnection.

2. Different Renewable Energy Sources

2.1 Solar power generation

Sun emits energy in the form of heat and radiation. By accessing enormous amounts of sun light it can be used in different forms.

In solar PV system, sunlight is directly converted into electricity with the help of PV cells or thermal system. Solar photo voltaic cells are made of silicon or other semiconductor material which directly converts the solar energy of sunlight into electrical energy. In photovoltaic system when sunlight irradiates in p-n junction of semiconductor then a electromotive force or voltage is generated between two electrodes of p-n junction which in known as photovoltaic voltage [7].

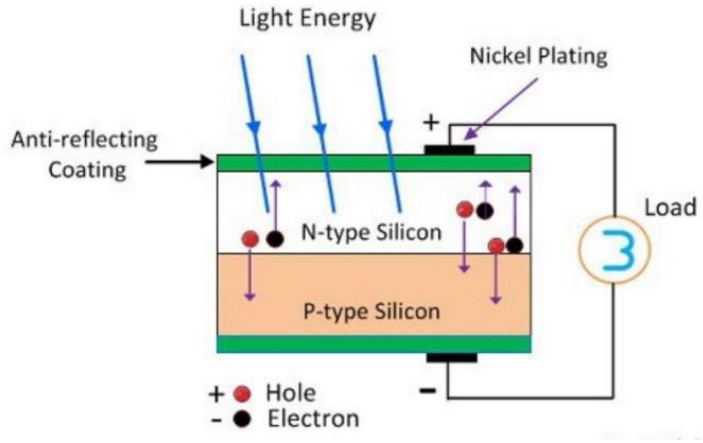


Fig. Wafer based solar technology [8]

The photovoltaic system consists of the following components [9]:

Solar Panel: Solar panel is made up by combining individual solar cells and several solar modules are combined in series and parallel to form solar array. So that maximum power output can be obtained.

Charge Controller: It is used to control the output power of solar panels so that overcharging of battery can be avoided in case of high-power generation. It can be controlled by pulse width modulation technique or by controlling maximum power point tracking method.

Batteries: Battery are used to store the generated electrical energy in case of non-use.

Power Inverter: The solar panel generates electricity in DC form which is further converted into AC with the help of inverter for utilization.

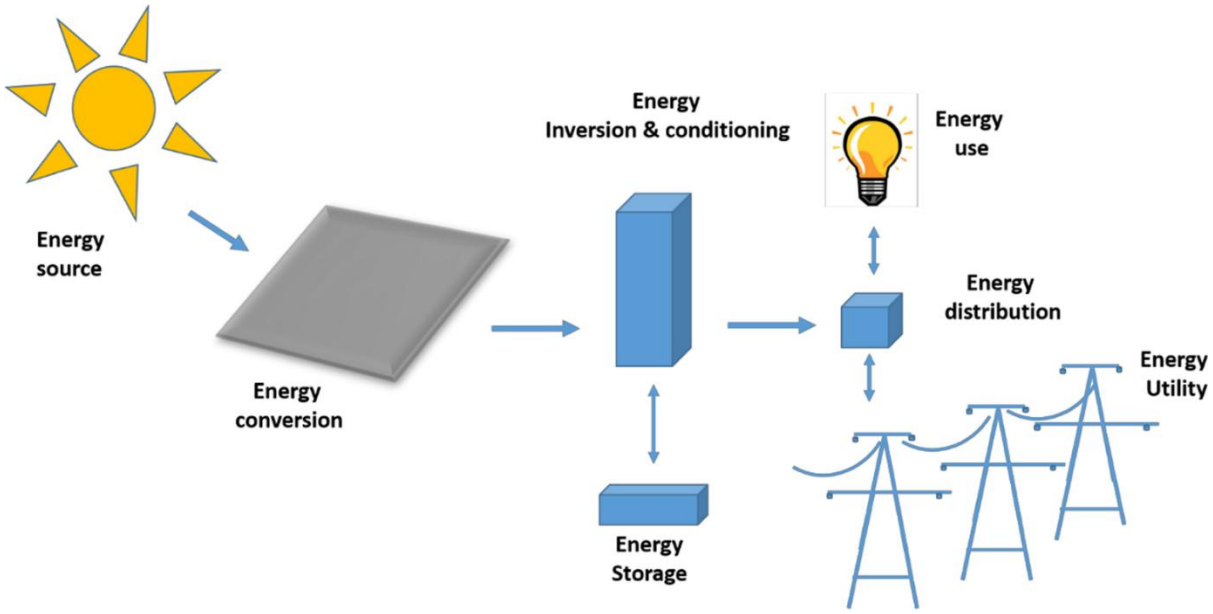


Fig. Solar photovolatic system [10]

2.2 Wind power generation:

Wind power generation is the process of conversion of kinetic energy of wind inro electricity. Wind turbine generator extracts the kinetic energy of wind with the help of blades connected on the same shaft though which electrical generator connected.

There is always a upper limit of power production in wind plants, above which no power can be generated and depends on kinetic energy of wind [11].

The power conversion in horizontal wind turbine is proportional to swept area of rotor. So, in order to

capture more kinetic energy rotor blades should be as long as possible. For further increase in power, rotor of wind turbine installed in increased height in tower because wind speed is relatively high as compared to ground level [11].

The wind power generating technologies have following main components [12]:

i. Rotor: Rotor is the key components of wind turbine which is connected with blades and captures the power of blades and converts kinetic energy of wind into mechanical energy. Rotors generally have two or three blades and may be horizontal axis type or vertical axis type.

ii. Transmission System: The transmission system comprises of rotor shaft, mechanical brakes and gear system. The fear system is used for increasing or decreasing the speed of rotor shaft as per requirement for driving electric generator.

iii. Generator: Generator is the components which converts mechanical energy of shaft into electrical energy. There are two main types of generator used in wind system i.e. synchronous and asynchronous.

iv. Power electronic interface: The generated electrical is fed into the grid with the help of power electronic interface. The power electronic interface works between generator and grid which controls electrical element of electrical power to feed into the grid.

v. Control system: Control system assures satisfactory operation of wind turbine under all operating condition. It controls the operation of turbine as per requirement of electrical power and available wind speed.

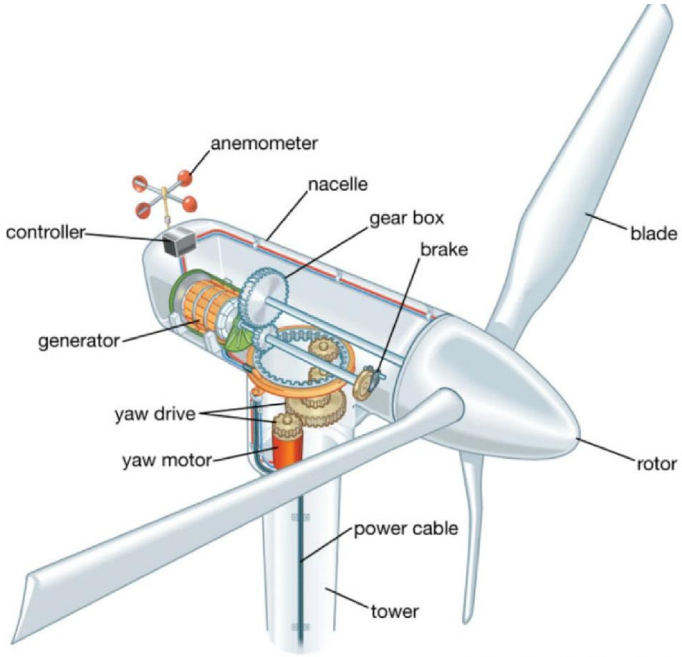


Fig: Constructional diagram of wind mill [13]

2.3 Piezo electric power generation:

Piezo electric power generation technique is a new approach for generation of electrical energy with the help of piezo sensor. In piezo electric effect a crystalline piezo material converts mechanical stress into electrical power directly [14].

Piezo electric effect is the ability of a material to generate electricity when subjected to a mechanical vibration or stress. It is a form of transducer that inter-change mechanical stress and electrical energy. The generated electrical energy is used to supply electrical load or stored in battery. This process is reversible in nature i.e. when an electrical voltage is applied to piezo material then its dimension get changed in proportional to applied electrical voltage [14].

The mechanical stress applied in piezo material is in the form of stretching, bending or squeezing in nature. Due to this mechanical stress positive and negative charge of crystal lattice got displaced and the net charges of the lattice get imbalance. The positive charges of lattice concentrate on one surface and negative charges accumulated on other surface. This charge separation causes generation of electric voltage across the surface of crystal. The generated electrical voltage is proportional to mechanical stress or pressure applied on the surface of crystal and it can be accessed with the help of electrodes on the surface of piezo crystal [14].

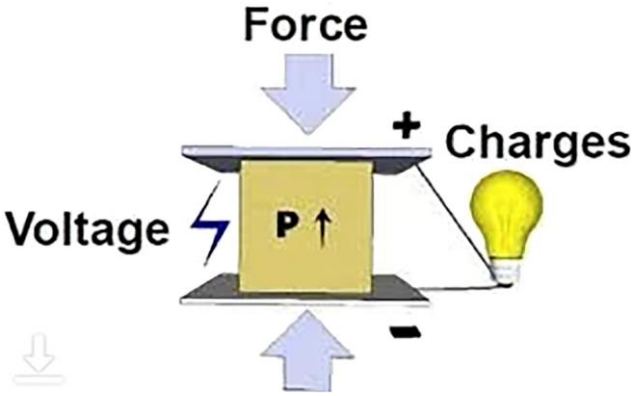


Fig. Piezoelectric power direction with force [15]

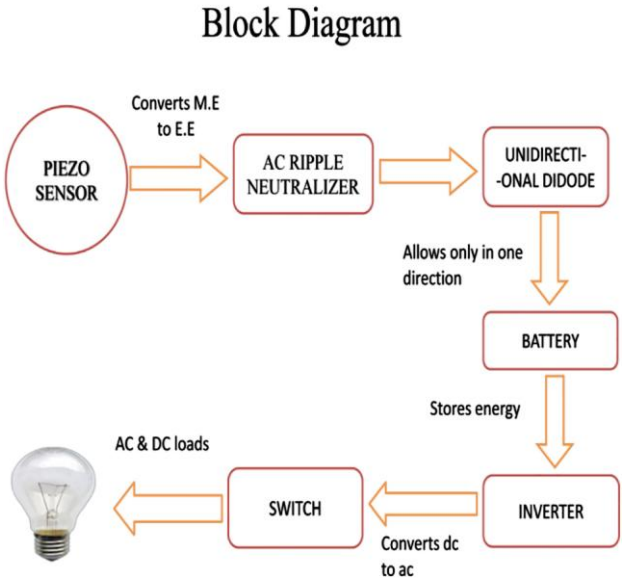


Fig. Block diagram of Piezoelectric power generation [15]

2.4 Hybrid Renewal Energy System

Hybridization is commonly known as the coupling of multiple energy sources at various stages during the life cycle of an energy system. Renewable energy resources provide numerous benefits, notably in terms of the environment and future growth potential. Furthermore, they represent significant hurdles, based on service continuity as well as cost.

To solve this type of problem, two or more resources (Solar and Wind) are combined to produce a multisource system that provides a reliable and cost-effective solution to electricity. The optimal selection of such systems' components is the main focus of their design. The primary goal is to reduce the cost of generating power as well as utilizing the National Grid and/or conventional energy sources while maintaining excellent service dependability.

The hybrid renewal energy systems consist of two or more than two renewal energy sources to generate electricity. Hybrid renewal energy sources have great advantages as compared to individual energy sources. By integrating individual sources electrical supply become more reliable and reduces the power outage in abnormal

condition and maintain continue power supply. This increases the overall system efficiency.

3. Objective of study

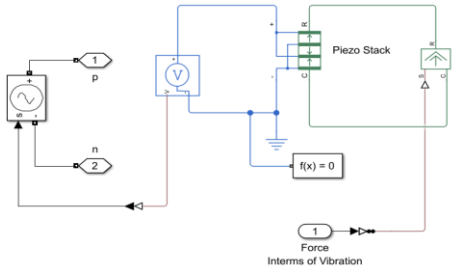
As per the previous existing in research gap there are followings objectives which we will
cover in this work and they are followings:
(i) Improving the dynamic performance of the WECS, PV system, and piezo electronics hybrid grid-connected power system.
(ii) Enhancing the system's FRT (Fault Ride Through) capability while maintaining the RES grid-connected during undesirable abnormal operating conditions without disconnection.

4. Methodology

The methodology starts with real-time data acquisition from the PV, Wind Energy Conversion System (WECS), and Piezoelectronics, monitoring voltage, frequency, and power fluctuations. A Fuzzy Logic Controller (FLC) processes these inputs to optimize power distribution and dynamically regulate voltage and frequency. Under normal conditions, the system maintains optimal energy management by balancing power generation and load demand. However, during fault conditions (voltage sags, frequency deviations, or grid disturbances), the fuzzy-based FRT mechanism activates, adjusting power-sharing strategies and injecting reactive power to support the grid. The control strategy ensures Low Voltage Ride-Through (LVRT) and High Voltage Ride-Through (HVRT) compliance, preventing system disconnection. The final stage involves grid synchronization and stability restoration, ensuring a smooth transition back to normal operation. This intelligent control mechanism enhances dynamic performance, response time, and fault tolerance, making it highly effective for hybrid grid-connected renewable energy systems.

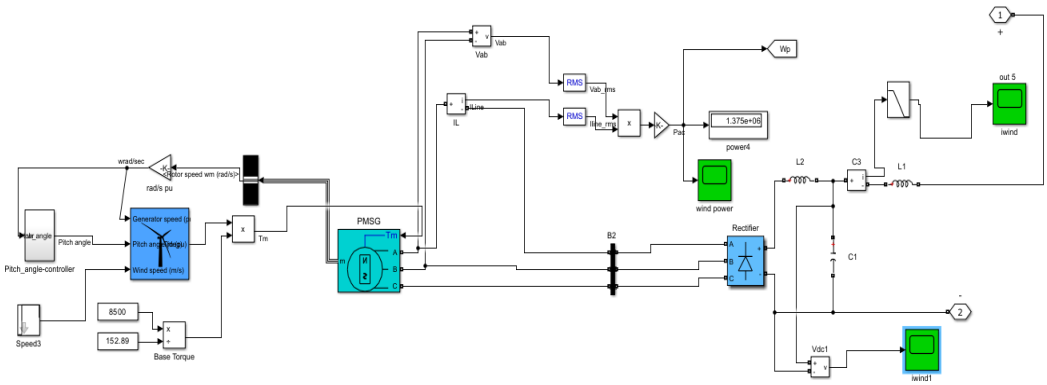
4.1 Modeling of piezoelectric system

The Piezoelectric Stack System used for energy harvesting and vibration force generation. The system converts electrical energy into mechanical force via a piezoelectric stack, which can be used in applications such as vibration control, damping, and energy harvesting in hybrid renewable energy systems



4.1.1 Wind energy conversion system (WECS)

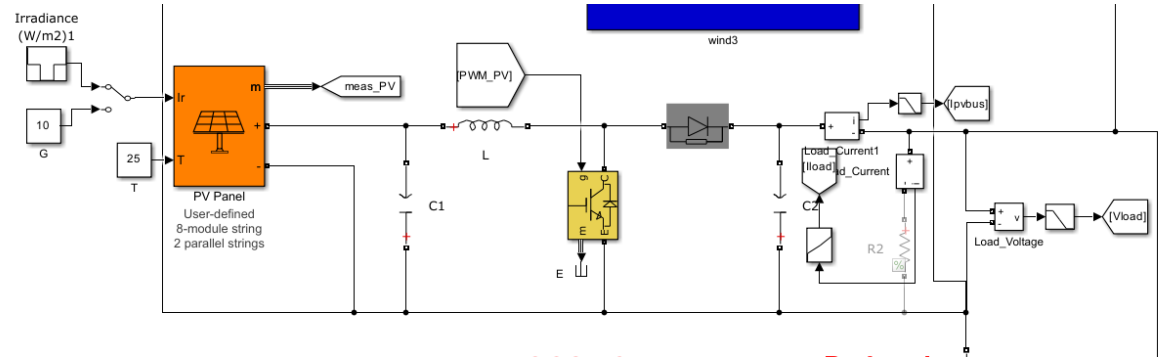
A wind energy conversion system (WECS) based on a Permanent Magnet Synchronous Generator (PMSG) is modeled with the help of MATLAB simulink, which is integrated with a rectifier and power conditioning system for grid or load connection.



Wind energy is converted into electrical power using a PMSG-based wind system. The rectifier converts AC power output from generator to DC, ensuring stable power output. The pitch angle controller optimizes power extraction from wind and DC-link and filters used to stabilize voltage before feeding into the grid or load.

4.1.2 Solar PV System

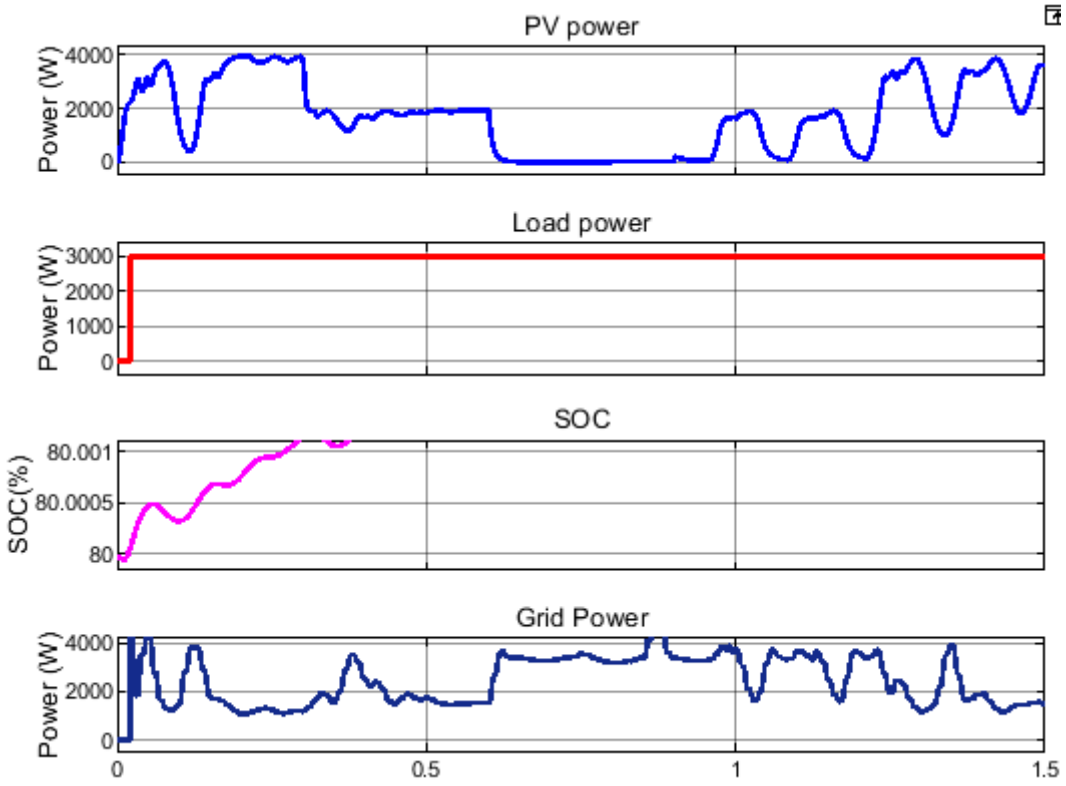
A Photovoltaic (PV) power generation and energy conversion system**,** integrating a PV panel, power electronics components, and load measurement units to efficiently manage and supply power.



Solar PV panels convert solar irradiance into electrical energy, with real-time power measurement. DC to DC convertor regulates PV output power and ensure efficient power delivery to the load. Load measurement units help in dynamic power flow control and optimization of electrical power output. PWM control fine-tunes the power conversion process for stable operation.

4.1.3 Hybrid PV, Wind and Piezoelectric system

In hybrid system all three systems solar PV system, wind system and piezoelectric system combined together to form a hybrid power generating system. The wave form shows the generating power, load power, state of charge and grid power.



5. Conclusion

The novel fuzzy-based control methodology for a hybrid grid-connected renewable energy system (RES), integrating Wind Energy Conversion Systems (WECS), Photovoltaic (PV) systems, and piezoelectric transducers enhances dynamic performance, improves transient stability, and strengthens Fault Ride-Through (FRT) capability by efficiently managing power flow and reactive power injection. The proposed control method outperforms traditional techniques in voltage regulation, reactive power compensation, and system reliability.

6. Future Scope

The proposed fuzzy-based control system and piezoelectric energy harvesting approach, further research is required to explore real-world applications and scalability. Experimental validation using HIL testing and real-time deployment to assess practical performance under real grid conditions.

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