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Anfis Based Energy Management System for Microgrids

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Abstract: - Microgrids are typical low or medium voltage distribution networks that operate on an adaptive system. Which, employing intelligent energy management techniques, govern the power exchange between the main grid, locally distributed generators (DGs), and associated loads. This paper describes and evaluates the intelligent ANFIS based energy management approach for grid integrated microgrid networks. The ANFIS based intelligent controller estimates the power that must be generated by (or) stored in batteries, taking into consideration of power demanded by loads and available battery power by accounting the battery state of charge. To evaluate the power allocation an artificial intelligent based technique i.e., Sugeno-based fuzzy EMS is implemented. The stated fuzzy logic control enhances power distribution within the micro-grid components while minimizing the requirement for power transfer to/from the main grid.

Keywords: Microgrid, MPPT, PV System, Wind energy System, Energy storage system, ANFIS, Grid Integration, Battery Management system.

I. INTRODUCTION

Micro grids (MG) are suggested as a way to control local area energy balance and reliability while also meeting the ever-increasing demand for energy. Microgrids are traditional low or medium voltage distribution networks. The principal objective of a microgrid's is to satisfy load demand by giving preference to energy generated from renewable sources over energy provided from auxiliary sources, including energy storage ones. When compared to typical electric utility networks, the microgrid (MG) uses renewable energy sources (RESs), it is not only more economical, flexible and stable, but it also has a positive environmental impact. In order to provide high-quality, secure, sustainable, and ecologically friendly energy, an energy management system is required for a microgrid system to govern the flow of power and energy between sources and loads. An intelligent microgrid energy management system (EMS) typically has to oversee and integrate a variety of distributed generation (DG), energy storage systems (ESSs), and loads. The standards for microgrids, which include topology, configuration, and regulations to manage the microgrid and its integration with renewable energy sources, were covered by writers [1]. The microgrid's are operatable in two functional modes based on the economic considerations, as grid connected operating mode through coupling point or in islanded moder are elaborated in [2]. Being renewable energy sources as part of micro grids in [3], it become more affordable, flexible, and dependable than typical utility networks, but it also has a positive impact on the environment. Also, MG's are categorized as low, medium networks voltage and hybrid configurations [4] primarily to offer reliable power supply to remote areas.

The authors in [5] discussed the necessity of power converters in connecting the intermittent renewable power sources. which yield an output with good power quality and offer a power supply that is both dependable and efficient. Local generation (isolated) lowers associated costs and transmission losses in comparison to the conventional power grid. The renewable power units are usually utilized to sustain the peak load for the demand, and the generation could range from 1 kw to a few hundred MW [6]. Renewable and non-renewable sources, such as wind turbines, photovoltaic panels, small hydropower facilities, and diesel generators, are examples of distributed generation sources. Since dispatchable energy sources, like wind and photovoltaics, are typically dependent on climatic and meteorolocal circumstances, integrating them raises the issue of intermittent power generation. A steady supply of power authors on [7] discussed a hybrid energy system made up of storage components and renewable energy sources is employed. Intelligent power grid technology is necessary to ensure that consumers

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have access to affordable, sustainable power on a consistent basis. To provide a dependable system, a sophisticated network of devices must come together to make a smart distribution system functional. In [8] authors presented the key elements to transform the traditional network into a smart, interdependent system. To make the effective communication between the operator and consumer IOT and smart meter system is implemented. This technology provides the efficient monitoring, measuring and control system for fast reliable communication.

To address various control methods of MGs, Lopez-Garcia etc. [9] present review to understand the present status of neural network (NN) research as a means of overcoming issues associated for safe and efficient operation of smart grids. Some NN-based controllers have been described as having power tracking, V&f control, and load sharing with primary control. Others are concerned with secondary and tertiary control levels, such as nominal voltage and frequency. Also improving the power dispatch of the MG's while taking into account several producing units, providing protection, and handling communication among various renewable power units. In [10] different control strategies and operational methods over traditional power system depending on the type and depth of penetration of distributed resource units have discussed. Also, authors discussed operational strategies of a microgrid in consideration of load characteristics, power quality constraints, and market participation strategies. The authors on [11] focused on energy management strategies for grid integrated of active PV system in microgrid to run at a constant and stable power output. Additionally, battery and ultra capacitors are included for local power management based on the power demand. In [12] authors given rigorous review which gives comprehensive study of control technologies for microgrid operation. Further it focuses on the benefits and drawbacks of conventional advanced control systems for sustainable operation and management. Thus, this review will strengthen efforts to design efficient and long-lasting microgrids for future smart grids. In [13] Furthermore, the stored energy is managed by using artificial neural network controllers (ANNCs) to optimize battery charging and discharging. The primary goal of the system is to maintain power balance in the microgrid while also providing adaptable and flexible control for a variety of scenarios involving various fluctuations. The Java Agent Development Framework (JADE) was used to build the MAS system, and Multi-Agent Control using Simulink was utilized to ensure communication between Simulink and JADE.

In [14] the authors addressed hybrid energy system considering renewable system connected to energy storage systems. Also control approaches are elaborated for energy management with respect to buildings. More than control strategies performance of the EMS is studied in [15], here authors implemented optimal scheduling of the generating units and energy storage system by implementing optimization algorithms. The standalone system is prioritized with the chief advantage of remote applications and battery storage system is key component of interest, hence authors in [16] implemented fuzzy interference system to reach the energy management goals. But when the system is equipped with hybrid energy, a multi-objective system is required for the implementation of battery energy system. Hence authors in [17-18] implemented the IOT based technology for real time data based on the operational level equipment and integrated with fuzzy based system for comprehensive energy effective system. Similarly, in [21] fuzzy based system is implemented for isolated with the effective forecasting data considering both of generation and demand. The authors in [19-2] gave implemented controller-based energy management system with the help of state space method for microgrid system performance and authors in [22-25] implemented soft computing technology for the optimization and management of energy in grid connect and standalone system. Also, a detailed review is given in [25] for the centralized, decentralized and distributed control strategies. The present analysis is carried for power and energy management control for the hybrid system.

The key contribution of this study is that it demonstrates how to easily implement energy flow management while considering optimal power flow between a PV system, a battery storage system, and the grid. A balance is maintained between the minimum required power flow in the tie line and the minimum required battery storage capacity. Furthermore, fuzzy logic gives very stable and smooth performance

II. MICROGRID MODELLING

The autonomous microgrid under investigation consists of a PV source, wind generating unit and battery energy storage as a backup supply and loads. A common point connection (CPC) connects microgrids to the main grid as represented in “Fig. 1”.

A. Photovoltaic system:

The solar system consisted of a photovoltaic panel, a boost converter, and an MPP tracking controller. A solar PV cell is a kind of electronic component that produces energy when exposed to sunshine. The cell can be used alone or in conjunction with other solar cells in a photovoltaic panel. There are numerous PV cell models available, and each has a different degree of accuracy and complexity. The analogous electrical circuit shown in "Fig .2" can be used to mimic photovoltaic cells

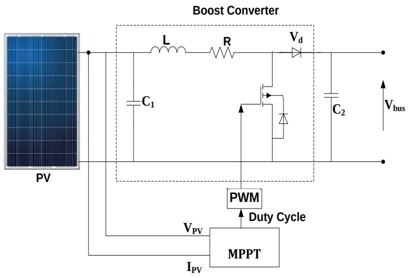


Fig. 1. Components of PV system in microgrid

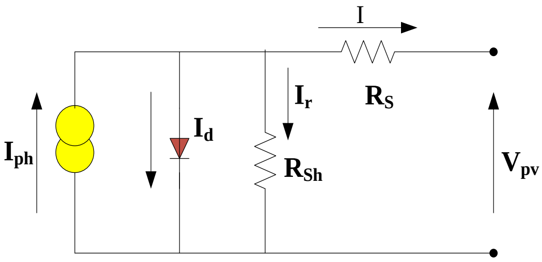


Fig. 2. Equivalent PV cell circuit representation

To model the equivalent circuit of the PV cell below equations in (1) & (2) are considered

$$I = I_P - I_O(e^{\left(\frac{V_d}{\eta V_T} - 1\right)} - \left(\frac{V + IR_s}{R_{SH}}\right)$$

$$where\ I_d = I_o\left(e^{\frac{V_d}{\eta V_T} - 1}\right)\ \&\ V_T = Thermal\ Volt = \frac{N_s \eta KT}{q} \quad (2)$$

For the implementation of PV mode, we have used reference module in MATLAB/Simulink (SunPower SPR-415E-WHT-D 7-module strings are used. The PV module properties are given in Table.1.

Table. 1 Parameters of PV model

Parameters	Values
Maximum Power	400 W
Peak voltage	72.9V
Peak Current	5.69A
Open circuit voltage	85.3V
Short circuit current	6.09A
Cells per module	128
Shunt Resistance	419.78
Series resistance	0.5371

The most power generated by PV generators is collected and transferred to the load using a static converter, also known as a DC-to-DC power converter. Maximum operating power point or MPPT, controllers operate the boost converter to provide optimal power efficiency consistently. This study makes use of the conventional perturb and observe approach. The control programme utilizes an analytic procedure to estimate the maximum power output from PV system through an iterative approach, as illustrated in "Fig. 3".

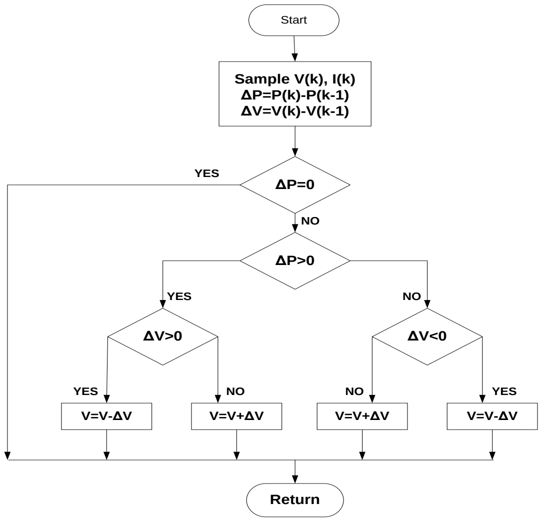
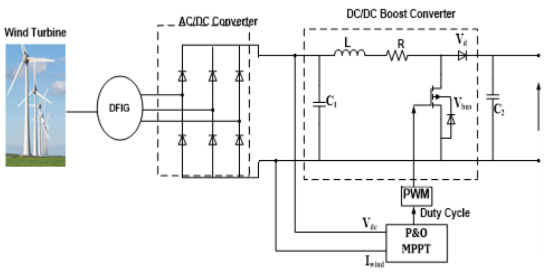


Fig.3. Flowchart of MPPT technique

B. *Wind Energy Systems:*

Electrical energy from wind energy generating unit is the most accessible and promising. Turbines provide mechanical energy by spinning due to wind's kinetic energy. Electrical energy is produced from mechanical energy by generators. Consequently, the generation of wind energy has a linear relationship with wind speed. The maximum operating power point for each wind speed is what the MPPT control unit uses to operate. The ideal power of a wind turbine is distinctly bell-shaped and nonlinear. Similar to searching for the optimal rotational speed, the system seeks the maximum operating power for each wind speed. The power is plotted in relation to the turbine's rotational speed. Every wind speed has a single preset value that allows to extract most possible maximum power. The wind generator is made up of a DFIG, a power converter that is MPPT-Controlled, and a wind turbine, as depicted in "Fig. 4".



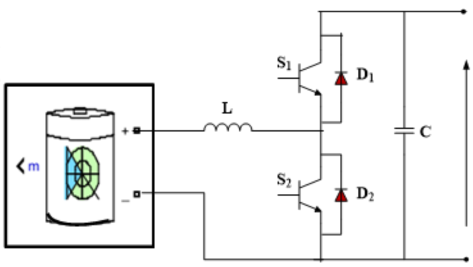


Fig. 4. Wind energy system (WES)

Fig. 5. Energy storage system with bidirection inverter

C. *Energy Storage Systems (ESS):*

The energy storage system (ESS) is utilized as a backup to maintain energy balance in deficient of renewable to meet load demand. To protect the microgrid, use a Li-ion battery, a bidirectional DC-DC converter, and a controller that handles battery charging and discharging as seen in "Fig. 5". It is challenging to forecast lithium-ion batteries because of their nonlinear voltage response. The Simulink Sim Power systems package's dynamic battery model is employed in this study.

Transporting electricity between the battery and the microgrid is made possible by bidirectional DC/DC converters. The study utilized a bidirectional configuration of a IGBT based half-bridge topology operating in continuous conduction mode, as shown in "Fig. 6". These connections are increasingly being used to operate battery charging and draining because of the ability to reverse the direction of current flow while maintaining an unchanged voltage flow at either end. The converter is operated either in buck mode or boost mode depending on whether excess energy is stored at the DC bus. Because D_1 and S_2 are operated in boost mode, where current flows to the DC bus. Also, S_1 and D_2 are operated in the buck mode, where power is provided to the battery.

III. ENERGY MANAGEMENT SYSTEM (EMS)

An energy management system is a collection of computer-aided tools used by an electric utility grid operator to control, monitor and optimize the grid's operation. Because the battery's limited storage capacity prevents any excess energy from being saved, additional energy can be supplied to the grid. To supply load and grid, it is composed of a bi-directional battery that permits bi-directional current low and can be charged and discharged, gives electricity to the load. when the renewable sources are unable to generate a significant amount of power, "Fig. 6" depicts energy management system connected to the DC bus via multiple converters. The PV and Wind operates via an MPPT block to extract the most power. The battery storage system, which consists of a Li-Ion battery that permits bi-directional current flow and can be charged and discharges, gives electricity to the load when the PV system is unable to generate a significant amount of power. The battery system is connected to the microgrid and is run by FL, while the main grid is connected to the DC bus via an AC/DC converter and will only be used in an emergency (in the insufficient renewable energy). The battery storage system is managed using a fuzzy system for energy conservation. The inverter transforms the electricity from the DC bus bar into grid quality AC power.

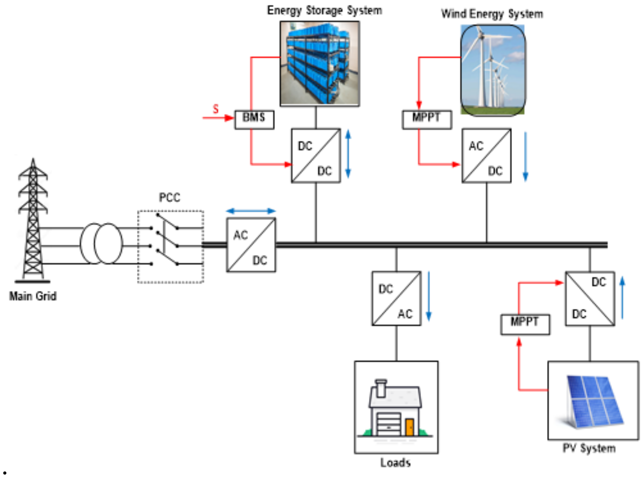


Fig. 6. Proposed System for Energy management

The key contribution of this study is that it demonstrates how ease & effective to implement energy management while considering optimal power flow between the renewable power sources, a battery energy storage system, and the grid. A balance is kept between the minimum required power flow in the connection grid line by maintain possible storage capacity.

The primary goals of the suggested energy management are to:

1) Examines the storage system into grid connected microgrids
2) Power flow control while taking storage system capacity into account
3) To prevent overcharging or battery draining, by maintaining the DC bus voltage constant.

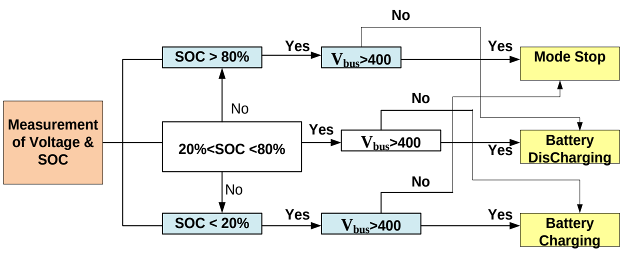


Fig. 7. Flow of Energy management strategy

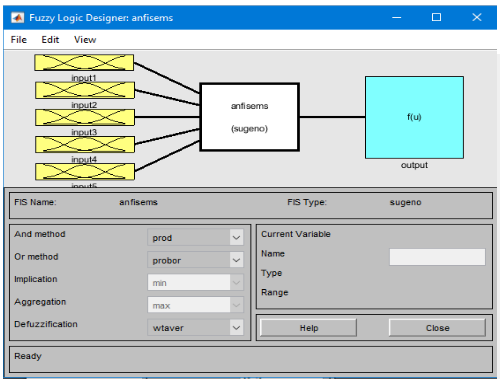
The energy management operational modes for the microgrid based system are shown in “Fig.7”. The operating modes are defined based on the several power producing modes, the load consumption, and the battery’s level of charge (charging/discharging). consequently, three operating scenarios may be identified for the system’s power flow based on SOC condition of the battery. Physical conditions must be adopted in order to extend the battery lifecycle. The battery’s state of charge needs to fall between a lower and upper bound (20% < SOC< 80%). In order to meet the demanded load i.e., P_{Load} and maintain battery optimum capacity, the power source P_{res} runs in the MPPT mode. In charging mode ($P_{res} > P_{Load}$) the battery absorbs surplus power in the DC bus to control the microgrid’s voltage when power generated from renewable power sources exceeds load demand. The battery can assist to match the load requirement in the event power supply module is not unable to meet it ($P_{res} < P_{Load}$).

The energy management system’s (EMS) primary function in this control approach is to guarantee an ideal power flow, increased efficiency and increased system reliability. The error between the generated renewable power and load demand power as well as the state of charge and time is the input of the fuzzy logic controller (SOC) between this instance, the mistake stands for a mismatch between supply and demand. The battery’s level of energy for charge is determined by its state of charge. The fuzzy logic controller receives these inputs, and its output is the battery reference power.

IV. PROPOSED CONTROL

The key contribution of this study is that it demonstrates simple & effective method to implement energy management system, while considering optimal power flow between the renewable power sources, a battery energy storage system, and the grid. The energy storage system is interfaced to the microgrid and is run by FL, while the mains grid is interconnected to the DC bus via an AC-to-DC converter will only be used to supplement the load demand. Furthermore, the energy storage system is managed using a fuzzy logic method for energy conservation.

The fuzzy logic controller performs superior in complex type of problems that are managed by an expert operator who is unaware of the inherent behavior. The basic concept behind a fuzzy logic controller is to use a human expert’s experience and knowledge to create a control system to regulate an application process. The fuzzy control rules decide the input relationship using linguistic variables rather than a complicated dynamic model in “Fig .8”. An IF-THEN rule is used to construct a controller, linguistic variables, fuzzy control rules.



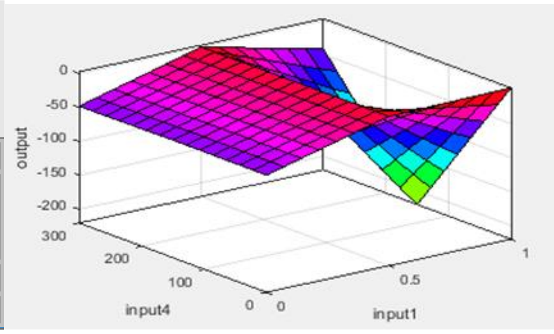


Fig. 8. fuzzy interference rule based sugeno system

Fig. 9. surface plot for status of battery with inputs

A fuzzy logic controller was developed employing the MATLAB/Simulink fuzzy logic toolbox to integrate it to the microgrid. One important feature of fuzzy rule reasoning is its partial matching capacity as shown in the surface plot in “Fig. 9”, which enables inference from fuzzy rules even the requirements are partially satisfied. The three important component of fuzzy logic controller (FLC) are fuzzification, inference system and defuzzification. The technique of transforming a sharp (crisp) input into a linguistic carriable is known as fuzzification.

V. SIMULATION RESULTS

The performance of the configured energy management system as illustrated in "Fig .9" was implemented under various dynamic and nonlinear load conditions. The simulations are carried in the MATLAB environment with the help of the Sim-Power-Systems functional toolboxes. The Table. 2. Lists the considered parameters for the design of microgrid.

Table. 2 Design parameters of the microgrid system

S. No	*Microgrid Connected unit*	*Ratings*
1	Solar PV	SPR-415E-WHT-D-300kW 7 modules in parallel strings ($35*P_{mod}$)
2	Wind energy System	DFIG-50KW Nominal voltage V_{LL}- 400V Mechanical speed 2850 rpm
3	Energy Storage system	Nominal voltage: 480V Battery capacity 300Ah
4	Grid connections	0.5MW-33kV main grid Line- line voltage: 400V Grid frequency- 50 Hz Grid connected transformer 33kV/0.4kV
5	DC link voltages	400V
6	Loads	Dynamic Loads of 1kw each, V_{rms}=400V Variabl load- intial -300kw Final value -350kw
7	Distribution transformer	100kVA

***a*) Performance of PV system:**

The microgrid compose of PV array of SunPower SPR-415E-WHT-D with 7 modules in parallel strings too provide a full power of 300KW. In accordance with the standard irradiance is set at 1000W/m2 and room temperature is fixed at 25 degrees Celsius the respective voltage and current plots are depicted in "Fig. 10" & "Fig. 11".

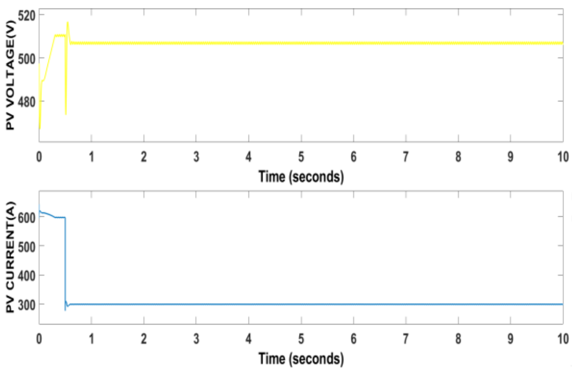


Fig.10. *PV voltage and current plots*

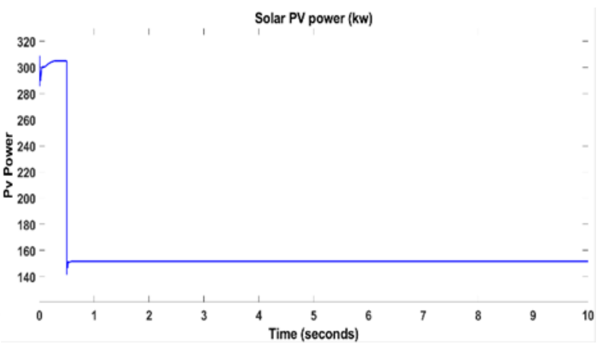


Fig. 11. generated PV power *at standard test conditions*

***b*). Wind energy system in Microgrid:**

At a wind speed of 10m/s, the wind turbine generator produces a total output of 50 kW. The Change in generation along with load demand were simulated to evaluate the performance of the Fuzzy EMS. The voltage and current waveforms shown in “Fig. 12” and “Fig. 13” displays the observations of wind power.

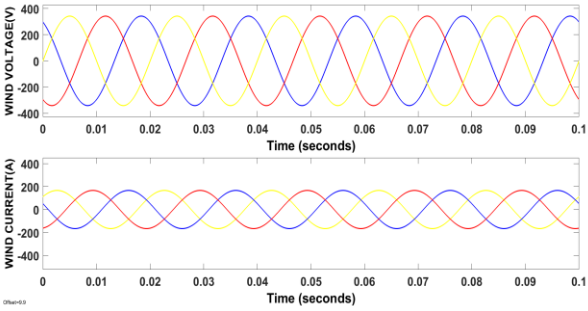


Fig. 12 Wind voltage & current characteristics

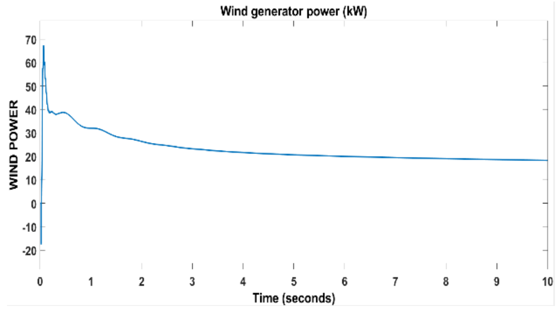


Fig .13. generated Wind power characteristics

***c*) Performance of Grid Integration:**

The grid has the rating of 33 kV, 0.5 Mw. The transformer has a rating of 40 MVA, 33/0.4 kV. The performance of the grid connected system voltage, current and power graphs are shown in “Fig. 14” and “Fig. 15”.

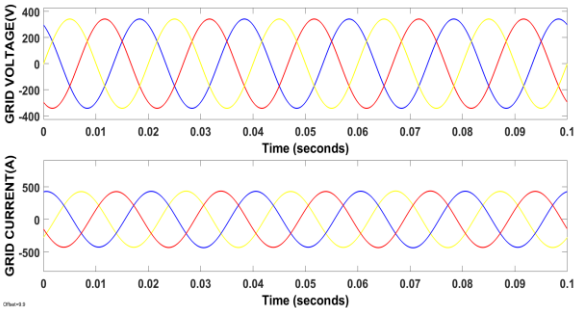


Fig .14. Grid interfaced voltage and current plots

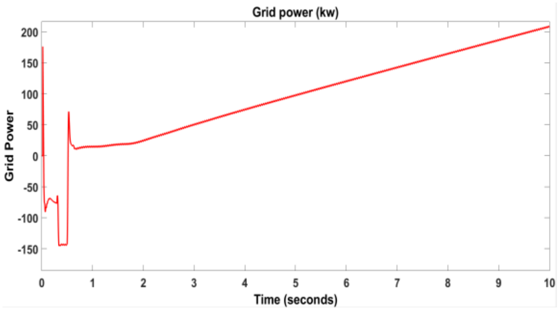


Fig .15. Distributed grid power flow

d) Performance of battery under dynamic conditions:

The proposed system injects maximum possible power into the grid instead of charging the battery. In this study, another instantaneous feedback control is added to prevent the sudden discharge or overcharging of the battery. The reference value for SOC is 50% to safeguard the energy management systems, the allowable range of charge & discharge is (20-80). When the load exceeds the generation, the micro-grid has a power deficit. At this moment, the Energy storage system discharges at varying rates dictated by the EMS algorithm as shown in “Fig. 16”.

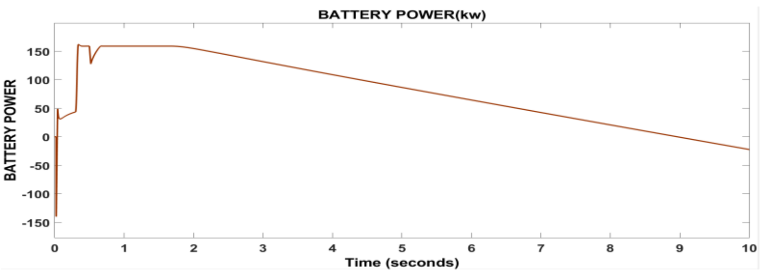


Fig. 16 battery power in the energy balance

***e)* Performance of Energy management system by ANFIS:**

The proposed control provides energy management system and also grid voltage support. The fuzzy system is considered to match the renewable unit and load consumed. The rules of the FLC are developed to control the injected/stored power of ESS (Pref) by taking the SOC of the battery. The reference power is taken from the nonlinear relation of the load change and SOC. This non-linearity is introduced with the help of membership functions of FLC by considering SOC, renewable power & load power as inputs. To evaluate the effectiveness of the Fuzzy EMS, variations in generation and load demand were simulated. The voltage and current profiles with the effect of load are plotted in "Fig. 17".

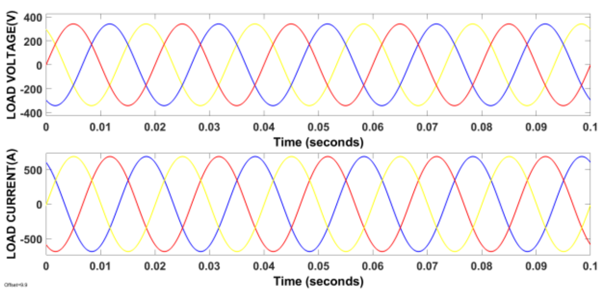


Fig. 17 Voltage & current profile under the load effect

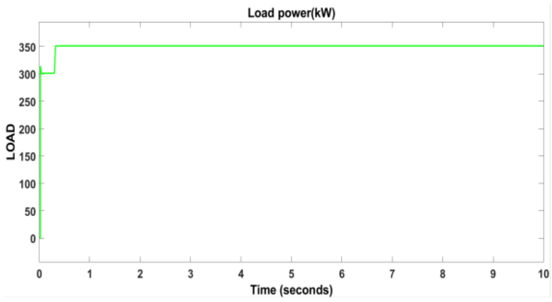


Fig. 18 Load power with storage system

The converter that connects the battery to the DC bus uses voltage control to adjust the voltage on DC bus. This reduces charging and discharging cycles, resulting in longer battery life. At this moment, the grid power is reduced to zero, and the power demand is satisfied by the energy storage system by discharging the ESS at varying ratios dictated by the EMS algorithm. The load power as shown in "Fig. 18" is maintained constant irrespective of the generated power form renewable source by the effective battery energy management.

CONCLUSION

The studied microgrid, which consists of a PV generation, wind turbine power producing unit, energy storage system, variable load, and unbalanced load, is modeled, controlled, and simulated in Matlab/Simulink environment. The present study examines the integration of energy storage systems (ESS) into grid-connected microgrids for voltage support and energy management, taking into account the ESS capacity and load power.

The reported results shows that the ESS performs well in load matching under all conditions. The simulation intends to demonstrate the successful performance of the energy storage system while contributing to power management and simultaneously compensating for unbalanced power and providing voltage support using the proposed control system.

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