Micro grid Power System Modeling and Simulation Including a Hybrid Energy Storage System

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ABSTRACT

As renewable energy (RE) is used more often in the power industry, micro grid technology is advancing quickly. In this study, a hybrid energy storage system (HESS) for battery and super capacitor is used to mimic an isolated DC micro grid with solar photovoltaic (PV) as the RE source to power resistive DC charges. The suggested power management technique for managing the DC bus voltage is validated by simulations of various load and solar insulation fluctuation situations. When comparing the output waveforms with and without the HESS, a beneficial decrease in transient voltage is seen. In order to assess device output with a continuous need for load, an IEEE 9bus example is also simulated. It is found that in all cases HESS helps to minimize transients of the DC bus voltage effectively. The HESS also compensates for very large transients resulting in sudden changes in the output of PV or load demand.

Keywords: DC micro grid, HESS, renewable energy, IEEE 9bus, Battery

INTRODUCTION

Possibly defined as "an integrated, widely dispersed energy distribution network characterized by a two-way electricity and information flow, capable of monitoring and reacting to changes in everything from power plants to consumer preferences to individual appliances," a micro grid is a network that distributes energy. [1] DC charges make up the majority of electronic charges connected to the existing power system. To connect them to the AC grid, AC-DC power conditioning equipment are required, which increases system losses. The use of a DC micro grid makes it simple to reduce losses. Because they are isolated from faults, islanded DC micro grids may also supply essential loads when the main grid cannot. The DC micro grids were the subject of several studies [2–6]. Solar and Wind energy are among the most frequently harvested sources of Renewable Energy (RE) available [7]. However, storage devices are needed in micro grids because of the intermittent power available from these sources. Such devices include banks of batteries, "super capacitors (SC), flywheels and other heat storage technologies. Batteries are high in energy density and can provide long-term power. SCs have a high-power density and provide a faster charge and discharge rate. Such RE sources are either unidirectional or bidirectional power conditioningsystems attached to the DC bus. Several micro grids with combinations of different generations and energy, including PV, Fuel Cell and SC [8]. PV, wind and fuel cell [9]. PV and battery [10]. It was researched for power grid applications as well as applications for electric vehicles. Has investigated a wide range of intelligent control strategies for managing hybrid energy devices [11-14]."The idea ofhybrid storage was extensively studied, butthe control of bus voltage during storage charging and discharging modes was not considered a constraint. In [8], [15] hybrid energy storage systems (HESS) are used, but the SC bank is used in combination with the battery bank to provide power for both transient and base load. The benefit ofusing hybrid energy storage in a DC micro grid had been illustrated in thispaper. The battery banks provide thebackup power for the base charge whilethe SC banks only provide the transient power backup during abrupt changes in theuse of load power or PV. This saves SC useby discharging it during transitional time only. Using hybrid energy storage allows the DC bus voltage to be controlled more rapidly and the transient voltage peak compared to a single storage unit (battery).

LITERATURE SURVEY

Bendary, A.F.; Ismail, M.M [1], Hybrid renewable electric energy generation system become essentialto the most of electric networks and the stand-alone systems like the water pumping and telecommunication systems. Therenewable sources usually required storage system due to change in thepower outputs during the day. Due to increase in demand of using batteries, the charging process ofbattery system needed to be well managed through an adaptive controlled energy managingsystem. In this project a standalone system using photovoltaic, wind generation, fuel cell and storage batteries are contributed in supplying the desired load and the charging balance of batteries is achieved by using AI techniques to enhance battery charging controllerperformance. The main goal of thisproject is to design and implement an integrated smart artificial controller, this controller is responsible for controlling both the battery charge voltage using the boost converter and the other controller is to control the charging current of the battery through DC to DC converter using (ANFIS) and (GA) techniques.

Elavarasan, R.M.; Ghosh, A.; Mallick, T.K.; Krishnamurthy, A.; Saravanan, M [2], a hybrid microgrid framework was created with the assistance of a photovoltaic (PV) and wind turbine (WT) generator. Additionally, bidirectional control mechanismswere implemented where an AC system was integrated with permanent magnet synchronousgenerator (PMSG)-based WT and aDC system was integrated with a sliding mode algorithm controlled maximum power point tracker (MPPT)-integrated PV system. Thewind and PV interconnected microgrid system was mathematically modeled for steady-state conditions. Optimal load management strategy was performed on a chosen hybrid microgrid system. Various case studies pertaining to connection and disconnection of sources and loads were performed on the test system. The outcomes establish that the system can be kept up in a steady-state condition under the recommended control plans whenthe network is changed, starting with one working condition then onto the next.

Muriithi, G.; Chowdhury, S [3], in the near future, microgrids will become more prevalent as they play a critical role in integrating distributed renewable energy resources into the main grid. Nevertheless, renewable energysources, such as solar and wind energy can be extremely volatile asthey are weather dependent. These resources coupled with demand can lead to random variations on both the generation and load sides, thus complicating optimal energy management. In this article, a reinforcement learning approach has been proposed to deal with this non-stationary scenario, in which the energy management system (EMS) is modelled as a Markov decision process (MDP). A novel modification of the control problem has been presented that improves the use of energy stored in the battery such that the dynamic demand is not subjected to future high grid tariffs. A comprehensive reward function has also been developed which decreases infeasible action explorations thus improving the performance of the data-driven technique. A Q-learning algorithm is then proposedto minimize the operational cost of the microgrid under unknownfuture information. To assess theperformance of the proposed EMS, a comparison study between a trading EMS model and a non- trading case is performed using a typical commercial load curve and PV profile over a 24-h horizon. Numerical simulation results indicate that the agent learns to select an optimized energy schedule that minimizes energycost (cost of power purchased fromthe utility and battery wear cost) in all the studied cases. However, comparing the non-trading EMS to the trading EMS model operationalcosts, the latter one was found to decrease costs by 4.033% in summer season and 2.199% inwinter season.

Shan, Y.; Hu, J.; Chan, K.W.; Fu, Q.; Guerrero, J.M [4], In renewableenergy systems, fluctuating outputs from energy sources and variable power demand may deteriorate the voltage quality. In this project, amodel predictive control strategy without using any proportional-integral-derivative (PID) regulatorsis proposed. The proposed strategy consists of a model predictive current and power (MPCP) control scheme and a model predictive voltage and power (MPVP) controlmethod. By controlling the bidirectional dc-dc converter of the battery energy storage system based on the MPCP algorithm, the fluctuating output from the renewable energy sources can be smoothed while stable dc-bus voltage can be maintained. Meanwhile, the ac/dc interlinkingconverter is controlled by using theMPVP scheme to ensure stable ac voltage supply and proper powerflow between the microgrid and theutility grid. Then, a system-level energy management scheme is developed to ensure stable operation under different operation modes by considering fluctuating power generation, variable power demand, battery state of charge, and electricity price. Compared with the traditional cascade control,the proposed method is simpler andshows better performance, which isvalidated in simulation based on a 3.5-MW PV-wind-battery system with real-world solar and wind profiles.

Berardi, U.; Tomassoni, E.; Khaled, K [5], The current energy inefficiencies in relocatable temporary camps of the Armed Force troops create logistic challenges associated with fuel supply. The energy needs of these camps are primarily satisfied by diesel engine generators, whichimply that a significant amount of fuel needs to be continuously provided to these camps, oftenbuilt in remote areas. This project presents an alternative solution,named Smart Hybrid Energy System (SHES), aiming towards significantly reducing the amountof fuel needed and minimizing transportation logistics while meeting camp energy demands. The SHES combines the existingdiesel generators with solar power generation, energy storage, and waste heat recovery technologies, all connected to a microgrid, ensuring uninterrupted electricity and hot water supplies. All components are controlled by an energy management system that prioritizes output and switches between different powergenerators, ensuring operation at optimum efficiencies. The SHES components have been selected to be easily transportable in standard shipping 20 ft containers. The modularity of the solution, scalable from the base camp for 150 people, is designed according to available on-site renewable sources, allowingfor energy optimization of differentcamp sizes in different climates.

SYSTEM MODELING

The system under study consists of three main parts: PV system, Wind Energy Conversion System based Permanent Magnet Synchronous Generator (WECS-PMSG), and power electronic devices that connect AC and DC sides of the micro- grid system. Several controllers are required for each power electronic device. Figure 4.1 shows a schematic diagram and the system configuration for the suggested micro grid. The configuration of each part will be discussed individually in the following subsections.

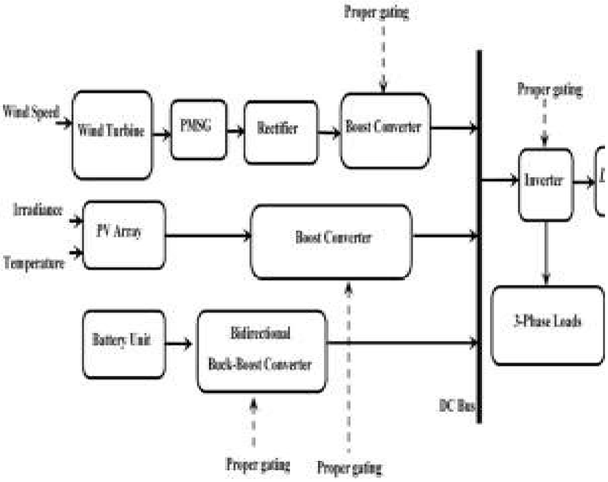


Fig.1. System configuration of the suggested microgrid.

PV System

The voltage–current (V-I) characteristics of the used PV model are given by:

$$I_{pv} = I_{ph} - I_s e^{\left(\frac{q(V_{pv}+R_s I_{pv})}{nkT} - 1\right)} - \frac{V_{pv} + R_s I_{pv}}{R_{sh}}$$

Where Iph is the photo-current, Is is the diode saturation current, q is the electron charge, T is the temperature in (K),n is P-N junction ideality factor, and Rsand Rsh are intrinsic series and shuntresistances of PV cell, respectively. A schematic diagram of this PV model is given by Figure 4.2.The connected PV system is a PV array that consists of three series and six parallel strings to generateabout 3.84 kW at full irradiance of 1000 W/m2.Figure 4.3 shows the relationship between voltage–current and voltage– power of PV modules, respectively. It isclear from this figure that the maximum power occurs close to open circuit voltage of the PV panel. The rating power of this panel at STC condition is 215W. The open circuit voltage and the voltage at the maximum power are 36.6 Volts and 29 Volts, respectively. The short circuit current and the current at the maximumpoint are: 7.84 A and 7.35 A, respectively. More details and specifications about this panel can be found.

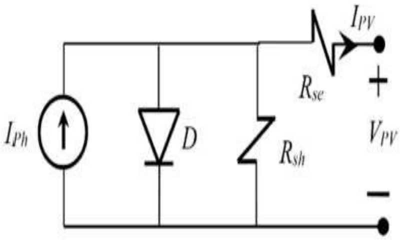


Fig.2. Equivalent circuit of a PV cell.

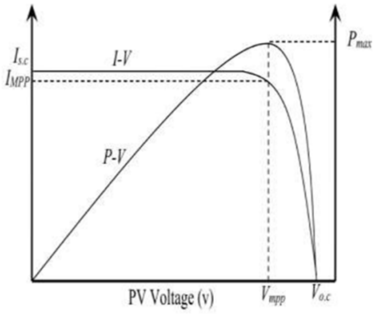


Fig.3. Characteristics of PV cells.

PMSG-Based Wind Energy System

Wind Turbines are required in any wind system. They operate as prime movers of electric generators which are connected to their shafts. They can be classified based on direction of their rotation: Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind turbines (VAWT). Another classification is based on their mode of operations: fixed speed and variable speed types. The characteristics of the wind turbine and the types of the wind generator used in the wind system are the main factors that affect the mode of operation of the WECS.PMSG is usually built with several numbers of poles in WECS. Thus, it can run at a low speed that corresponds to the wind turbine's spinning speed. As a result, the wind turbine's rotor shaft can be directly connected to PMSG. The direct- drive operation, which does not require any additional gearbox setups, is one example of this form of operation. Removal of gearboxes reduces the installation and maintenance costs and gives the system an advantage over DFIG-based systems that need the use of a gearbox. For variable speed operation, the PMSG can accommodate a wide variety of rotor speeds. The output voltage received at the stator terminals of a PMSG varies in frequency and amplitude according to the wind speed. Power electronic converters are used to link the stator to the grid. A typical PMSG based wind energy conversion system is shown in Figure 4

The utilized power converters are rated at full capacity because there is no additional rotor control, ensuring maximum wind energy conversion efficiency for a wide range of wind speeds. Furthermore, power converters with full capacity ratings help to meet various grid regulations and do not require additional equipment for fault ride-through scenarios.

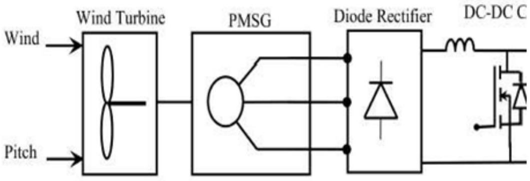


Fig.4. Typical PMSG based wind energy conversion system.

Power Electronic Devices

The power converters used are three-phase diode rectifiers, DC–DC converters to achieve the desired DC voltage level, and inverters to obtain an AC output voltage with a specific power frequency from the generated DC voltage. As a result, the PMSG's variable frequency output voltage is transformed to a grid-frequency sinusoidal AC voltage. A boost converter in the WECS is used to raise the output voltage of the three-phase diode rectifier to achieve a specific value of DC voltage. The switching signal of this boost converter is generated by a specific control algorithm which will be discussed later. The PV system uses a DC–DC converter, and the switching signal is designed for generating a proper voltage and power. Figure 4.5depicts the circuit diagram of a three-phase diode rectifier. Although the diode rectifier's output voltage is uncontrolled, there are no additional losses due to the switching of any power electroniccomponents. If diode losses are ignored, it can be assumed that the wholepower obtained by PMSG is completely converted from AC to DC. A circuit diagram of a boost converter is shown in Figure 4.6.

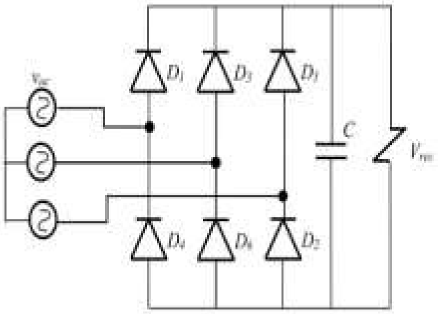


Fig. Circuit diagram for a three-phase diode rectifier.

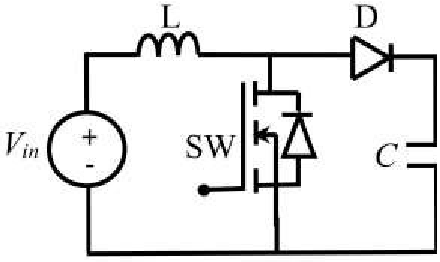


Fig. Boost converter.

Bidirectional DC–DC Converter with a Battery Storage System

In most PV power systems, lead- acid batteries are employed. The charging and discharging of these batteries are handled by a bidirectional DC–DC converter. The authors describe several topologies and configurations of bidirectional DC–DC converters used in PV systems. For charging and discharging operations, a buck–boost DC–DC converter is used in this research. The usual configuration of the bidirectional converteremployed in this paper is shown in Figure 4.7. The bidirectional converter is operatedas a buck converter with the gate signal applied to the switch S1. This mode ofoperation occurs to charge the battery system when PV output is high. When the PV system's power is low or the grid is down, the bidirectional converter acts as a boost converter, sending a gate signal to switch S2. As a result, the battery isdischarged, and energy is supplied to the load.

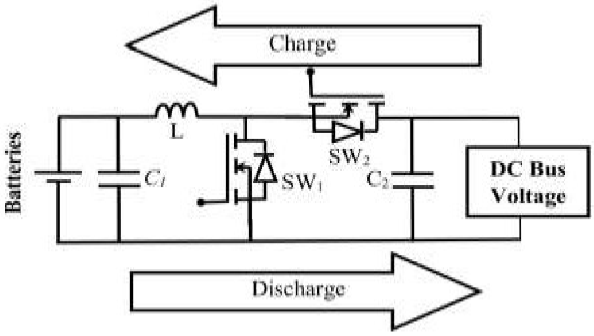


Fig. Bidirectional buck–boost converter.

Control System

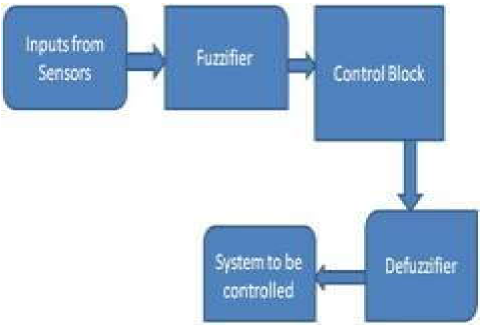
The new control system of this micro grid is divided into four subsystems: fuzzy logic-based MPPT for controlling the PV system, WECS controllers, battery unit controllers, and inverter controllers. The main purpose of the control system is to maintain serving power to load and protect batteries' health from overcharge or over discharge which harm them and shorten their lifetime. Therefore, the controller keeps the SOC of the batteries within the safe limits.

FUZZY LOGIC:

Fuzzy logic is a basic control system which relies on the degrees of state of the input and the output depends on the state of the input and rate of change of this state. In other words, a fuzzy logic system works on the principle of assigning a particular output depending on the probability of the state of the input.

Fuzzy logic works on the concept on deciding the output on the basis of assumptions. It works on the basis of sets. Each set represents some linguistic variable defining the possible state of the output. Each possible state of the input and the degrees of change of the state are a part of the set, depending upon which the output is predicted. It basically works on the principle of If-else-the, i.e. If A ANDB Then Z.

A fuzzy control system consists of the following components:



a) **A Fuzzifier** which transforms the measured or the input variables in numerical forms into linguistic variables.

b) **A Controller** which performs the fuzzy logic operation of assigning the outputs based on the linguistic information. It performs approximate reasoning based on human way of interpretation to achieve the control logic. The controller consists of the knowledge base and the inference engine. The knowledge base consists of the membership functions and the fuzzy rules, which are obtained by knowledge of the system operation according to the environment.

c) **The Defuzzifier** converts this fuzzy output to the required output to control the system.

FUZZIFICATIONAND MEMBERSHIPFUNCTIONS:

The fuzzy set is a powerful tooland allows us to represent objects or members in a vague or ambiguous way. The fuzzy set also provides a way that is similar to a human being's concepts and thought process. However, just the fuzzy set itself cannot lead to any useful and practical products until the fuzzy inference process is applied. To implement fuzzy inference to a real product or to solve an actual problem, as we discussed before,three consecutive steps are needed, which are:

- Fuzzification,
- fuzzy inference and
- defuzzification.

Fuzzification is the first step to apply a fuzzy inference system. Most variables existing in the real world are crisp or classical variables. One needs to convert those crisp variables (both input and output) to fuzzy variables, and then apply fuzzy inference to process those data to obtain the desired output. Finally, in most cases, those fuzzy outputs need to be converted back to crisp variables to complete the desired control objectives.

Generally, fuzzification involves two processes: derive the membership functions for input and output variables and represent them with linguistic variables. This process is equivalent to converting or mapping classical set to fuzzy set to varying degrees.

In practice, membership functions can have multiple different types, such as the triangular waveform, trapezoidal waveform, Gaussian waveform, bell- shaped waveform, sigmoidal waveform and S-curve waveform. The exact type depends on the actual applications. For those systems that need significant dynamic variation in a short period of time, a triangular or trapezoidal waveform should be utilized. For those system that need very high control accuracy, a Gaussian or S-curve waveform should be selected.

To illustrate the process of fuzzification, we still use the air conditioner example developed in the previous section. Assume that we have an air conditioner control system that is underthe control of only a heater. If the temperature is high, the heater control motor should be turned off, and if the temperature is low, that heater motorshould be turned on, which are common sense.

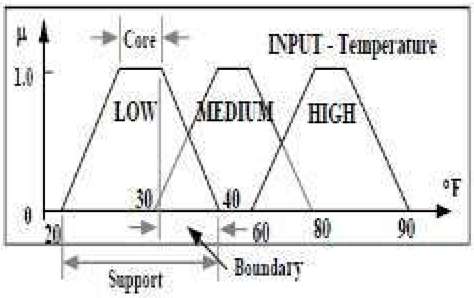
Regularly, the normal temperature range is from 20 ^{0}F to 90 ^{0}F. This range can be further divided into three sub-range or subset, which are

Low temperature: 20 ^{0}F ~ 40 ^{0}F, 30 ^{0}F iscenter
Medium temperature: 30 ^{0}F ~ 80 ^{0}F, 55 ^{0}Fis center
High temperature: 60 ^{0}F ~ 90 ^{0}F, 75 ^{0}F iscenter

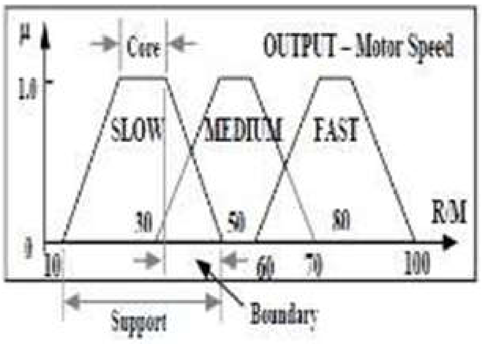
Next those three ranges need to beconverted to linguistic variables: LOW, MEDIUM and HIGH, which correspond tothe three temperature ranges listed above.

The membership function of these temperatures is shown in Figure. To make thing simple, a trapezoidal waveform is utilized for this type of membership function. A crisp low temperature can be considered as a medium temperature to some degree in this fuzzy membership function representation. For instance, 35 ^{0}F will belong to LOW and MEDIUM to 0.5 degree. Some terminologies used for the membership function are also shown in Figure.

The support of a fuzzy set, saysLOW, is the set of elements whose degree of membership in LOW is greater than 0.



(a) Membership function of the input



(b) Membership function of the output

Fig: Membership function of input and output

The core of a fuzzy set is the set of elements whose degree of membership in that set is equal to 1, which is equivalent toa crisp set. The boundary of a fuzzy set indicates the range in which all elements whose degree of membership in that set is between 0 and 1 (0 and 1 are excluded). After the membership functions are defined for both input and output, the next step is to define the fuzzy control rule.

CONCLUSION

In this study, it was suggested that a freestanding micro-grid system with a PV system and WECS be designed and controlled. Fuzzy logic-based MPPT was applied for a boost converter in order to manage and maximize the power generated by the PV system. Two PI voltage and current control loops were used to govern a battery storage system that received a consistent DC bus voltage from the PV system's output. The control system's goal is to always reach the load. The extra energy from the PV panel is utilized to charge the batteries when it is generated in excess of the amount needed by the load. The extra power is pulled from the charged batteries when the amount of energy produced by the PV panels is insufficient to meet the needs of the load. Furthermore, the controller is employed to protect the battery banks in all scenarios, including normal, overcharging, and over discharging scenarios. Each case should be handled appropriately by the controller. Regardless of the battery’s state of charge, the controller performs as expected under normal operating conditions (20% < SOC <80%). A specific order is delivered when the SOC hits 80%, which turns off the PV panel and the wind turbine. The PV panel and wind turbine cannot be connected until the SOC drops to a safe margin of 75% in this controller. Other commands are sent out to turn off the inverter and disconnect the loads when SOC falls below 20%. The inverter’s power is switched off until thebatteries are charged again to a suitablevalue. The designed stand-alone micro grid system and their controllers solved the problem of supplying the electric energy to remote areas where the electrical grid doesnot exist.

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