Control of Hybrid Distributed Energy Resources with Storage Connected to Microgrid

Md Musabbir Ferdous¹, Jagadeesh Pasupuleti¹

¹College of Engineering, Universiti Tenaga Nasional, Jalan Ikram – Uniten, 43000 Kajang, Selangor, Malaysia

E-mail: tain.mf@gmail.com; jagadeesh@uniten.edu.my

Abstract. Renewable energy based distributed generators (DGs) assume an overwhelming role in electricity creation, with the expansion in global warming. Distributed generation dependent on wind, solar energy, diesel generator the utilization of energy units and battery energy storage will give significant force in the near future. Advantages like environmental friendliness, expandability, and adaptability have made distributed generation, controlled by different renewable and nonconventional micro-sources, an attractive alternative for designing current electrical system. A microgrid consists of a group of loads and distributed generators that work as a single controllable system. The microgrid idea presents the decrease of numerous reverse conversions in an individual AC or DC grid and encourages associations with variable renewable AC and DC sources and loads to power systems. To the customer the microgrid can be designed to meet their special requirements; such as enhancement of local reliability, reduction of feeder losses, local voltages support, increased efficiency using waste heat, correction of voltage sag or uninterruptible power supply. Here photovoltaic system, wind turbine, generator, and battery are utilized for the advancement of the microgrid. Additionally, control systems are actualized for the converters to appropriately facilitate the AC to DC and DC to AC. However, the performance of the optimal fuzzy controller is also justified by comparing with the PI based controller. The outcomes are obtained from the MATLAB/SIMULINK condition.

1. Introduction

In recent years, the offer of renewable energy sources (RESs) has been increasing in the electricity generation mix with a command to reduce greenhouse gas emanations that are discharged from burning fossil fuels. The world vitality utilization is relied upon to develop about 57% in the following two decades. The world energy utilization by fuel type in 2002 also appears. Unmistakably a vast part of the all-out energy is given by petroleum derivatives (about 86% in 2002). To be sure, an extensive offer of electricity from renewable resources is required to de-carbonize the electricity division. With the development of smart grids and microgrids, compelling and effective entrance of renewable generation, for example, wind and solar oriented can be accomplished [1]. Distributed generation technologies are the main part in microgrid and has been placed much emphasis because these technologies produce energy with less environmental impact, easy to site, and are highly...
efficient. There is a wide range of advantages circumstances in utilizing a hybrid renewable energy source device, for example, PV, Wind, diesel generator device is safe, static, reliable, environmentally clean and requires less repair and maintenance [2]. Hybrid Renewable Energy systems (HRES) and the interconnection of various energy sources, for example, wind power, photovoltaic power, fuel cell, and micro-turbine generator power to nearby energy loads decline the reliance on non-renewable energy sources. HRES is accepted to be a superior alternative for displaying of present-da electrical systems. These technologies can work as stand-alone sources or as a part of hybrid systems or distributed generation (DG) connected with a microgrid/national grid. A renewable hybrid system is viewed as a blend of RE sources operating in a synchronized and independent manner. The mix of various energy sources empowers enhancement for the system productivity, consistency of the energy supply and diminishes the energy storage needs, contrasted with a system with single source RE supply [3].

![Image](image.png)

**Figure 1. Hybrid Renewable Energy system**

2. Model descriptions

The components of the system were wind turbines, PV modules, battery energy storage and diesel generator an inverter and other controllers. These components combined together to provide energy.

2.1. PV module model

The photovoltaic system can create direct current electricity without ecological effect when is presented to sunlight. The fundamental structure square of PV arrays is the solar cell, which is essentially a p-n junction that legitimately changes over light energy into electricity. The output normal for the PV module relies upon the cell temperature, solar irradiation, and output voltage of the module. The figure 2 demonstrates the proportional circuit of a PV array with a load [4].

![Image](image.png)

2
Figure 2. Equivalent circuit of a solar cell

The P-V and I-V curves are important two indicators to characterize properties of solar cell. Figure 3 shows effect of solar irradiation variation on P-V and I-V curves for the solar cell used in this project.

![P-V and I-V curves](image)

Figure 3. (a) I-V and (b) P-V curves

2.2. Wind turbine model

The wind turbines produce electricity to drive an electrical generator. Typically, wind disregards the sharp edges, creating lift and applying a turning force. Inside the nacelle the rotating blades transform a pole at that point goes into a gearbox. The gearbox helps in increasing the rotational speed for the activity of the generator and uses magnetic fields to convert over the rotational energy into electrical energy. At that point the output electrical power goes to a transformer, which converts the electricity to the fitting voltage for the power collection system. A wind turbine extracts kinetic energy from the swept area of the blades [5]. Wind turbine equivalent circuit is given below,
2.3. Diesel generator model

Renewable energy systems are portrayed by intermittent output and are hence coordinated with customary power sources to guarantee conveyance of ceaseless power output. Diesel generator (DG) is a steady source of intensity in different HRES. The DG systems are designed to supply the load and charge the battery energy storage system if the renewable energy source along with battery is unable to supply the load. Appropriate energy balance is required for ideal system task as the utilization of fuel is relative to the power being provided by the DG. The representative attempts to keep the generator speed approximately steady at any load level. Figure 4. demonstrates the fundamental segment of the diesel generator control [6].

![Figure 4. Wind turbine equivalent circuit](image)

2.4. Inverter and Charge Controllers

Inverters are devices used to convert over direct current into the alternating current. They are utilized in hybrid systems to fulfil the AC load, the input supplied from the PV module. The charge controllers are devices that control and manage the charge condition of the batteries that are utilized in hybrid systems; these techniques permit the current to go into the batteries to charge and prevent the flowing current when the batteries are fully charged [7].

2.5. Microgrid (MG)

[9]. Due to the innovation advancement and condition security, some distributed energy resources (DER), for example, gas turbines, microturbines, photovoltaic, fuel cell, and wind control [8]. A superior method to understand the rising capability of generation and related loads is a subsystem call Microgrid (MG). Microgrids are associated with a distribution grid at a single point known as the Point of Common Coupling (PCC). Each microgrid has an Energy Management System (EMS) which oversees the advancement of its operation just as the maximization of the microgrid’s welfare. The
MG is expected to work in the accompanying two distinctive working conditions: normal interconnected mode and emergency mode (island mode). In the grid-connected mode, the MG can supply or draw power from the local grid dependent upon the generation and load request of the system [9]. Normally, a MG is connected to the main grid by means of a solitary point of common coupling (PCC) viewed as the purpose of interconnection and is typically connected to a distribution system at low or medium voltage (MV) levels. In islanded mode, the MG is isolated from the upstream distribution grid and gives dependable power supply to customers based on DG offers. With the joining of a BESS into the MG system, the unwavering quality and proficiency of the system increments, and the system can smooth out power fluctuations in renewable energy generation.

Figure 6. Structure of micro-grid

3. Methodology

A. Modelling hybrid renewable energy sources (HRES) with battery energy storage system (BESS) (DG system). The microgrid is divided into four important parts. A diesel generator, acting as the base power generator. A PV farm combined with a wind farm, to produce renewable energy. The diesel generator balances the power consumed and the power produced. We can determine the frequency deviation of the grid by looking at the rotor speed of its synchronous machine. There are two sources of renewable energy in this microgrid. First, a PV farm produces energy proportional to three factors: the size of the area covered by the PV farm, the efficiency of the solar panels and the irradiance data. Second, a simplified model of a wind farm produces electrical power following a linear relationship with the wind. When the wind reaches a nominal value, the wind farm produces the nominal power. The wind farm trips from the grid when the wind speed exceeds the maximum wind value, until the wind gets back to its nominal value. The load is composed of an asynchronous machine that is used to represents the impact of an industrial inductive load on the microgrid. One energy storage also combined with a PV and wind farm.
B. Simulation Model of Hybrid Renewable Energy System with Inverter In MATLAB/Simulink (DG system)

The three-stage inverter system model is developed and implemented in MATLAB/Simulink software condition. This includes the joining of the inverter model and the fuzzy logic-based inverter system control algorithm.

Figure 7. Flowchart of HRES

Figure 8. Hybrid Renewable Energy System with Inverter Simulink model
After running the MATLAB/SIMULINK software, there are a few results that have been obtained to achieve the objective of this research. The result of placement of DG’s in several weak bus and the impact the DG’s on the voltage profile will be discussed. So, we can use IEEE 14 bus system with connected to DG system. The MATLAB/SIMULINK simulation software is executed to discover the voltage of each bus and the power losses of the system. The best size of DG units is chosen when the voltage at the bus is ideal and the power losses of the system are minimum. There are some cases are studied to find the best size of the distributed generation (DG) and the impact of the size on the voltage profile and the total power losses of the system.

C. The Stabilize IEEE 14 Bus System

The simulation model of IEEE-14 bus system composed of 14 buses and 13 lines was developed using MATLAB/SIMULINK software. The system consists of 1 Slack bus (or swing bus) which located at Bus number 1 and 13 load buses. All the loads are treated as a constant PQ spot load for voltage profile and power losses studies. The system has 13 loads totalling 1156.40 KW and 1179.70 KW, real and reactive power loads respectively.

D. Placement of DG in the Weakest Bus

To determine the optimal placement of DG in the IEEE-14 bus system, the DG must be placed at the weakest bus so that it will improve the voltage of all busses in the system. Theoretically, when DG is placed at certain bus, the voltage of the bus and the other busses that connected to the respective bus will increase. This is because due to the capability of DG that supply real power into the system. For this first test, the simulation of DG that have been placed to the three weakest bus will be conducted and the voltage profile will be analysed.

4. Results

The results that were obtained from the application and the implementation of the methodology. The results include the analysis of load flow and results at each bus to ascertain the optimal location for placing the distributed generation (DG) units.

From Figure 9, the graph shows the voltage of each bus in unit after running the power flow analysis. This graph is the base case system for this research. The voltage for each bus depends on the value of Generating Real Power (P Gen), Reactive Power (Q Gen), Voltage Schedule (V Sched), load at each bus and the value of line impedance of each bus that have been specified and obtained from the respective bodies, IEEE associations. The base voltage for this system is 11kV which belong to the transmission system. The range of voltage have been set between 1.06 to 0.95. The total active and reactive power generation of this system are 1.029 MW and 1.045 MVAR respectively. The total real and reactive power losses of the system are 0.0394 MW and 0.0352 MVAR respectively.
From Figure 9, we can also determine the weakness of each bus based on the voltage value. For these three buses, we can arrange the weakest bus start from 14, 9 to 3.

According to the voltage stability method that is used in this research, the results show that bus 14, 9 and 3 is the weakest bus in the test system. Hence it is considered as the optimum location to insert the DG.

In bus 14, 9 and 3 one size of DG is inserted to study the impact of the DG sizes on voltage profile and the total power losses of the system. Finally, the best DG size for this location. The results of each study are then compared with the results of the base case. MATLAB/SIMULINK method is used for studies to obtain the minimum and maximum reading for bus voltage as well as for the total power losses of the system. To summarize the three case studies, whereby different type of weak bus are used at DG system.

The total power losses of the system at bus 3 0.0257 MW and 0.0224 MVAR, bus 9 0.0280 MW and 0.0248 MVAR and bus 14 0.0267 MW and 0.0253 MVAR. In the base case, the total power losses of the system are 0.0394 MW and 0.0352 MVAR (without DG unit).
During the variation in the demand load usually changes in the voltage and current is observed. Hence the tracking of the reference voltage and current during the load changing scenario by developed inverter controller depicts the performance of the inverter controller.
Here, in the Figure 12, 13, 14 and 15 the corresponding results of the controllers FLC and PI are shown, where the current waveforms are scaled up to observe whether there is any phase difference between voltage and current. It is observed from the Figure 12 that during demand load variation in the designed inverter controllers can keep the voltage at a constant level. The load voltage magnitude is around 450V and the magnitude of the load current is found around 4000 mA.

The measured load voltage at the grid is shown with the harmonic spectrum in Figure 16(a) and 16(b) respectively for the corresponding controllers FLC and PI. These waveforms and the harmonics components generated from these harmonics’ levels are generated from the developed control algorithm.
Figure 16 Voltage harmonics during load variation from (a) FLC and (b) PI

Here, from the Figure 16 above the harmonics spectrum of the load voltage is observed in Simulink. By observing the Figure 16(a) and 16(b) the THD% in line voltages from the FLC and PI are correspondingly 11.48% and 32.32%. The frequency spectrum shows that the output waveform contains the fundamental component with 100 % in magnitude. However, the THD% in the generated output from the inverter with FLC inverter controller provides only 11.48% harmonics in this considered dynamic load condition is considerably better. Here, results illustrated above a comparative analysis between the conventional FLC and the optimized PI is illustrated. Moreover, it can be observed that the fuzzy controllers are able to provide better performance. Moreover, it can be observed optimized that the PI controllers are not able to provide better performance.
5. Conclusion

The modelling of Hybrid Renewable Energy System (HRES) with Battery Energy Storage (BES) associated with microgrid is done utilizing MATLAB/SIMULINK software. Now this work mainly includes the hybrid micro grid mode of operation. The models are produced for every one of the converters to keep up a stable system under different loads and resource conditions. MPPT is used to maximize power from solar PV. The models are produced for every one of the converters to keep up a stable system under different loads and resource conditions and the control component is considered MPPT algorithm is utilized to outfit most maximum power from DC sources and to arrange the power exchange among DC and AC grid. The hybrid micro grid can provide a reliable, high quality and more efficient power to consumer. The hybrid micro grid may be possible for small isolated industrial plants with both PV systems, wind turbine and generator as the major power supply. Distributed generation is an electric power source associated legitimately to the distribution network or on the customer side. Coordination DG units in the distribution system have distinctive specialized advantages, for example, improving the voltage profile of the system, decreasing the all-out power losses and expanding the power transfer capacity of the system. Likewise, the ongoing DG technologies are considered as an environmentally well-disposed source of electrical energy. A method to find the best size for DG in the distribution system to improve the voltage profile, reduce the total power losses and to increase the power transfer capacity of the system has been proposed in this research.

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