

DESIGN OF DC MICROGRID AND ANALYSIS

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Abstract

In the evolving era, microgrid wins the heart in all power fields. Among that DC configuration achieved more demand because of its less complex structure, low cost, more reliability, and more power quality and last but not the least the control scheme is less complex than AC microgrid. Management of power and energy are the evolving traits adopted by researchers now a days. This project mainly aims at the comparative analysis of different topologies, structure, and operational mode of DC microgrid. Despite the global energy crisis and the increasingly atmospheric pollution, distributed generation integration with renewable energy is becoming a potential trend in technology. Finally, attention has been paid to the recent challenges to the DC microgrid system.

DC loads have proliferated rapidly on the market today and DC micro grids with renewable energies are being built as a potential solution to meet the rising demand for electricity. As different energy sources such as solar, wind, fuel cell, and diesel generators can be incorporated into the DC grid, it is important to control the power flow between the sources. An attempt is made in this project to study the hybrid system consisting of a three energy sources, namely wind energy, photovoltaic power source and Battery. Each of the three energy sources is controlled to deliver uninterrupted power supply to the load. A control strategy for the management of power flows with solar and wind energy sources in DC micro grid are discussed. Given that voltage profile regulation is critical in a standalone system, a dedicated converter should be used to maintain the voltage of the DC connection. The battery circuit regulates DC charging voltage, while the full power is derived from Solar and Wind to power the attached DC bus charges. An algorithm is developed to manage power flow between three outlets. The algorithm is evaluated in MATLAB/ SIMULINK environments for different charging conditions and variations in solar and wind energy.

Keywords: DCMG (DC Microgrid) structures, Multiterminal DC Microgrid, Multi-bus DC Microgrid, Islanded Mode, Distributed Generation (DG).

1. INTRODUCTION

Alternating current is used as the energy source in previous days of electricity. The number of consumer goods is growing because of the modernization and the demand for electricity has increased. The rising demand for fossil fuels is driving people into renewable sources of energy. The use of solar and wind energy for power has been made viable by recent advances in semiconductor technology. Since most electronic loads need a DC supply, the ac power is converted into DC within the device itself to supply the load. The DC voltage of the solar panel is converted to alternating current and returned to DC prior to charging. PV is a DC power generation system. Due to additional converters reducing the performance of the device tremendous amount of power is wasted. There is a simpler way to directly supply the power from the source. DC micro grid is then applied. More performance and reliability can be accomplished by using this method. When power from solar or wind systems are not sufficient, the micro grid can receive power from the batteries. The area and the grid can be

supplied with voltage, frequency, and energy quality by means of Microgrid controls. In order to efficiently leverage available sources of renewable energy, it is important always function in MPPT mode. Different management of power flow algorithms for grid connected systems was stated. In standalone systems, it is important to maintain the voltage profile that the MPPT mode is sacrificed. In this project, the DC link voltage is controlled with the battery charge /discharge device circuit, while maximum renewable energy sources are extracted. The developed Power Flow Management algorithm can decide the mode of operation depending on whether solar and wind power is available while taking account of the battery voltage and demand to ensure the reliable and uninterrupted power to the load. The proposed DC Microgrid consists of solar PV array, Wind energy conversion system, battery bank, power converters for interfacing with the DC bus. Fig.1 shows the block diagram of DC Micro grid considered for study. The output of the PV array is connected to the DC grid through

the DC-DC boost converter. The power from the wind turbine is generated through the PMSG. The generated power rectified to DC and fed into the DC bus through a power converter. MOSFET is used for the switching purpose.

The output from the DC-DC boost converter is connected to the DC micro grid where the loads are connected. The charging and discharging of the battery is done by bidirectional buck-boost converter which also regulates the DC link voltage.

Block Diagram

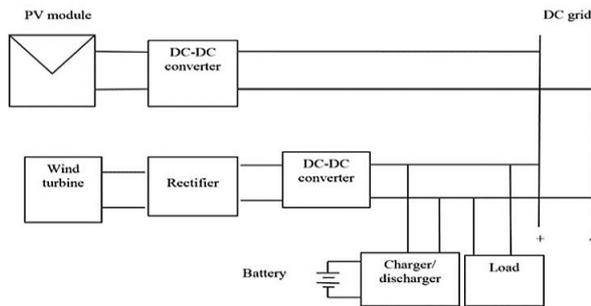


Figure 1 Block diagram of the DC microgrid with Solar and wind

Circuit Diagram

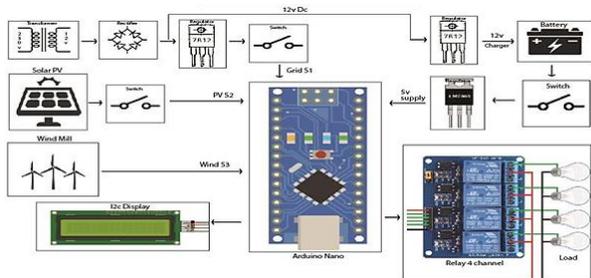


Figure 2 Circuit diagram

2. LITERATURE SURVEY

After going through the papers published by different authors on the topic of industrial power con, we can conclude that from 1990 to 2012, worldwide access to electricity increased from 75.6% to 84.6%, representing a net electrification of nearly 200 million individuals. South Asia and Sub-Saharan Africa, the regions with the lowest historical electrification rates, increased by 28% and 13%, respectively. These improvements are due in large part to efforts by the international community. In 2005, the UN commissioned a report investigating the links between lack of modern energy services (including both electricity and cooking fuels) and the Millennium Development Goals (MDGs), originally proposed in 2000, which focus on improving eight human development indicators such as poverty, gender equality, health, and education. The paper makes the case that without modern energy infrastructure, efforts to fully accomplish any of the goals are hampered. Following this finding, in 2012 the UN, partnering with the World Bank, launched the "Sustainable Energy for All" initiative (abbreviated SE4All, SE4ALL, or SEforALL in the literature). The goals of this paper are implementing universal electricity access, doubling the share of renewables in the energy sector, and doubling the rate at which energy efficiency improves annually. Along with these efforts, the World Bank and independent researchers have also investigated outcomes and best

practices for rural electrification (RE). Research indicates that improvements in areas such as income inequality, poverty rates, and economic growth are not inherently a result of increasing electrification, but that carefully designed projects can bring about measurable improvements.

Modelling

The operation of the individual components of the microgrid will be analyzed using MATLAB/Simulink. Simulink has an environment called Sims cape which can be used to model dynamical systems. Simulink, an add-on product to MATLAB, provides an interactive, graphical environment for modeling, simulating, and analyzing of dynamic systems. It enables rapid construction of virtual prototypes to explore design concepts at any level of detail with minimal effort. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams. It includes a comprehensive library of pre-defined blocks to be used to construct graphical models of systems using drag-and-drop mouse operations. The user is able to produce an "up-and-running" model that would otherwise require hours to build in the laboratory environment. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or hybrid of the two. Since students learn efficiently with frequent feedback, the interactive nature of Simulink encourages you to try things out, you can change parameters "on the fly" and immediately see what happens, for "what if" exploration. Lastly, and not the least, Simulink is integrated with MATLAB and data can be easily shared between the programs.

Dc-Dc Converters

DC-DC converters will be used in conjunction with components of the microgrid to help stabilize the voltage and generate maximum power. Three DC-DC converter types will be investigated

- Buck converter
- Boost converter
- Buck-Boost converter

These DC-DC converters operate by periodically opening and closing a switch. The buck converter reduces the input voltage, and the boost converter increases the input voltage. It is called a boost converter because the output voltage is larger than the input voltage. The buck-boost converter has the ability to increase or decrease the input voltage but with a polarity reversal. These DC-DC converters can be seen in Figure 3.

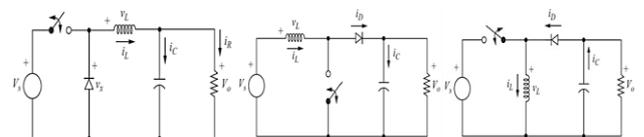


Figure 3 Converters

The converters contain a low pass filter after the switch at the output in order to obtain a purely DC output. The output voltage is changed by varying the duty cycle. The output of the buck, boost and buck-boost converters are calculated by Equations 3.1 to 3.3 respectively with the responses plotted in Figure.

$$V_o = V_s D$$

$$V_o = \frac{V_s}{1 - D}$$

$$V_s = V_o \frac{D}{1 - D}$$

The Bidirectional Converter

A converter is required to allow the flow of power from and to the batteries in the microgrid. The previous buck and boost converters do not have the capability for bidirectional power flow. This is because they all have diodes in their designs which prevent reverse current flow. A bidirectional converter can be designed by combining the capabilities of the buck and boost converters and replacing their diodes with switches. The top switch is used to operate the converter as a buck converter, transferring power from the high voltage side to the low voltage side and the bottom switch is used to operate the converter as a boost converter, transferring power from the low voltage side to the high voltage side.

The design was simulated in Simulink. The bidirectional converter will be controlled by a charge controller which will determine whether energy needs to be sent to or from the battery in order to smooth out the fluctuations of renewable energy sources and stabilize the voltage. The same values as the buck converter design were used for the bidirectional converter except for the inductor value. It was found that having a large inductor value inhibits the voltage stability of the system therefore a lower value was chosen. The lower ripple will help to charge and discharge the batteries with higher efficiencies increasing their lifetime.

Photovoltaic Cell

PV cells convert sun light into a voltage by the photoelectric effect. A load connected across a PV array will draw current from the device and the PV array will deliver power to the load. The PV array is constructed of n-type and p-type material in order to generate current flow in an external circuit. When light hits the PV cell a photon is absorbed which generates an electron-hole pair. Due to the external circuit connecting the n-type and p-type material the electron will travel from the n-type material to the p-type material via a connection by an external circuit creating current flow. A single cell only generates a voltage in the range of 0.5 - 0.8 V which is not enough to power the load therefore many cells are connected in series and parallel to increase the voltage and current respectively. A photovoltaic cell can be modelled as a current source. The Simulink block for the PV cell is based on the two-diode model. The array data tab lists the number of parallel and series strings in order to modify the PV array voltage and current. The Module data tab has specific operating information for the PV array. This data can be selected from many manufacturers, or you can manually enter the specific data. The model parameters tab then lists the specific parameters for the PV array

$$I = I_{ph} - I_0 \left(e^{\frac{q(v + 1Rs)}{nkT}} - 1 \right) - \frac{V + 1Rs}{Rsh}$$

Where

I_{ph} - Photo-generated current

I_0 -Diode saturation current

R_s, R_{sh} - Series and shunt resistances

n - Ideality factor

T -Temperature

q - Electron charge

k - Boltzmann constant

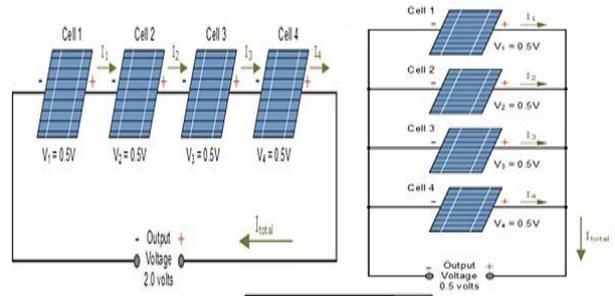
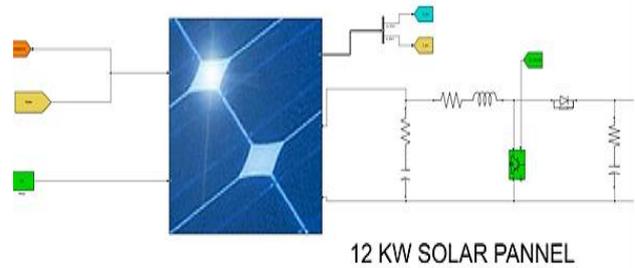


Figure 4 pv array

Pv Connected Buck-Boost Converter

In this scenario with a buck-boost connected the power is increased in each scenario because the buck-boost converter has the ability to increase or decrease the operating voltage. In real applications a boost converter is sufficient because most loads are much higher than this simulated case



12 KW SOLAR PANNEL

Figure 5 Simulink of pv

Wind Turbine

Wind power is produced by extracting energy from wind through aerodynamic forces on the blades of the wind turbine. The blades are connected to a drive shaft which rotates through a generator creating variable AC electricity. The blades rotate at a variable speed to extract maximum power from the wind resource therefore; the power is usually converted from AC to DC and then back to AC at a specific frequency. The wind resource originates from the uneven heating of the atmosphere by the sun, irregularities in the earth's surface and the rotation of the earth. The uneven heating of the atmosphere causes air in the heated regions to expand decreasing its pressure. This causes a pressure gradient and air will flow from the high-pressure regions to the low-pressure regions.

The power generated by a wind turbine is shown in Equation 3.14. The power generated from a wind turbine is proportional to the cube of the wind speed therefore wind turbines should be placed in areas of high mean annual wind speeds. If wind speeds are too high pitch control can be applied where the angle of the blades are adjusted to reduce the speed of the blades. The Simulink

diagram of a wind turbine is shown in Figure which is based on Equation.

$$PM = \frac{1}{2} \rho A C_p(\alpha, \beta) V^3 \omega$$

Where ρ is the air density, A is the rotor area that is swept, V is the wind speed and $C_p(\alpha)$ is the power factor coefficient. $C_p(\beta)$ is a measure of the amount of energy extracted from the wind resource. The Betz limits states that the power factor coefficient has a limit of 59.7%. The tip speed ratio is the relative speed of the rotor and the wind speed. The pitch angle is the relative angle between the rotor and its axis

Wind turbines start to produce power at wind speeds of around 10-12 m/s and are stopped in high wind speeds approximately above 20-25 m/s. Figure shows an example power curve of a pitch regulated wind turbine. The power starts to increase from the cut-in speed until it reaches its rated power where extra wind speeds create a speedy power output until the wind speeds reach a maximum that is safe for the wind turbine therefore it is cutout. Wind speed measurements were downloaded from the NREL database for the area of interest in Coye Chapel. The wind speeds are generally in the area of 3-6 m/s which may not be high enough to make wind turbines feasible for the microgrid as compared to the solar resource because wind speeds are the critical factor in regard to wind power generation

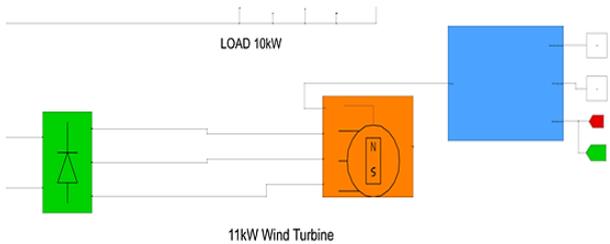


Figure 6 Simulink of wind

Grid

Grid is also modeled in Simulink using by a three-phase source at 11kV and then it is stepped down using a three-phase step down transformer to 220

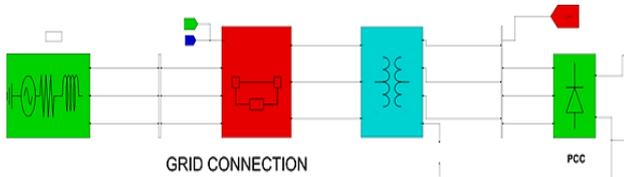


Figure 7 Simulink of grid

Energy Storage

Energy storage is a critical component in a microgrid that is based on renewable energy. Energy storage will help to maintain voltage stability and smooth out the fluctuations of renewable energy generation. Batteries which make use of a reversible chemical reaction to store energy and convert chemical energy into electrical energy will be used as the energy storage element in this DC microgrid. Batteries are not as fast at responding than super capacitors, but they have the ability to store more energy which is a critical design consideration in microgrids. The response time is quicker with supercapacitors because the electrical energy can be stored directly without a chemical

process. The response time is not as critical in a DC microgrid because we don't have to worry about frequency regulation. Batteries can be damaged due to deep discharge therefore the state of charge should be limited to a reasonable region.

A battery can be modelled as a non-linear voltage source where the output voltage depends on the current and also the battery state of charge (SOC). The SOC is a non-linear function of the current and time. The internal resistance and voltage depend on the battery SOC. The SOC can be defined as the ratio of the ampere-hour remaining in the battery to the total ampere-hour of the battery. The internal resistance of a battery is nearly constant until the SOC reaches 90% then it increases exponentially. A diffusion capacitance builds up within a battery due to concentration difference between chemical species. The two diffusion layers have opposite charges with the electrolytes behaving as a dielectric which produces a capacitance effect called the diffusion capacitance. When a battery is charged faster than the chemical energy conversion process can handle side reactions take place. This causes the battery to be heated and hydrogen and oxygen gasses are produced in a process known as gassing.

Charge Controllers

Charge controllers are used to regulate the flow of current to and from batteries in a microgrid. They are essential to protect the batteries and regulate the DC bus voltage. In this DC microgrid project a charge controller will control a bidirectional converter lowering the PV output voltage produced to the level required by the batteries and when the PV output drops to zero the charge controller will activate the bidirectional converter to send the power from the batteries to the microgrid. Figure shows the proposed logic for a charge controller in a DC microgrid. Most batteries are designed to operate in the region of 30-90%. Therefore, the logic in the controller will check if the batteries are in the region of 30-90% and if they are depending on the power balance between the generation and load the batteries will either charge or discharge. If the batteries are at a low SOC of below 30% and if the power generated is greater than the required load the batteries will be charged but if the load is higher than the power generated load shedding should be considered to protect the batteries. The last case is if the batteries are at a high SOC of above 90%. In this case if the microgrid is generating excess power the current will be sent to a dump load to protect the batteries from overcharging and the DC bus voltage from increasing.

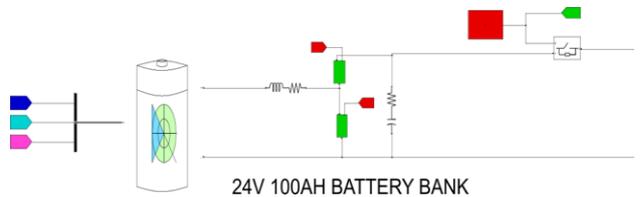


Figure 8 Charge controllers

Pi Controller

A microgrid can be controlled by voltage-based droop control or communication-based control. In this project we will use the communication-based control method based on a proportional-Integral (PI) controller. A PI

controller will be used as the control mechanism for the charge controller. A block diagram of a PI controller is shown in Figure. This is a commonly used control mechanism which calculates the error $e(t)$ between the output $y(t)$ and the desired set point Ref. A proportional and integral correction is made to the error signal and the combination of these corrections forms the control variable $u(t)$. This control variable is used to reduce the error in the system and the process is continued to decrease the error. In the DC microgrid design the reference will be the desired DC voltage of 250 V and the monitored output $y(t)$ will be the DC bus voltage. The control variable $u(t)$ will operate the bidirectional converter which will control the flow of power between the microgrid and battery in order to stabilize the DC bus voltage. The proportional term generates a proportional response relative to the error. If there was no error signal in a proportional only controller the bidirectional converter would not be activated, and the DC voltage would deviate once a zero steady state error is reached due to inertia in the system. Therefore, we also use an integral response which adds a control based on the past errors. A P controller will exhibit a faster response, but a PI controller has a better power regulation and zero steady-state error.

Pi Controller Design

The PI controller was implemented into Simulink using objects. The proportional block was selected to be 0.02 and the integral block was selected as 3. The terms were added together, and a limit was applied between 0.95 and -0.95 because the output will operate a bidirectional converter which has a maximum duty ratio of 1 but problems occur with infinity at 1 so 0.95 was chosen for the limits. The output is fed to the output y and the error is fed back into the import u . The output y will either be positive or negative depending on if the DC voltage needs to be increased or decreased. Therefore, logic will be used to transmit the positive signals to the boost control and the negative signals to the buck control of the bidirectional converter.

Control Techniques for Dc Microgrid

The DC Microgrid Control topologies as shown in Fig.2 plays a key role in the better, stable and efficient operation of DC MG. The power electronic converters act as an interface to properly control the grid with better voltage regulation and current sharing. They not only act as interfaces but also facilitate the proper interconnection among various units present in the DC MG. A better control strategy needs to be developed so as to reduce the non-linearity effect created by the power converters due to its constant power behavior. The rapid rise in non-linear loads and distribution generation made the control structure more complex which is inevitable too.

The various control targets are

- Smooth switching from islanded to the grid connected method of operation.
- Regulation of voltage and current sharing.
- Stable operation with linear constant power load.
- Optimizing the Micro Source (MS) production to participate in the energy market.

- Controlling the power flow among MG and the rest of the network using an effective and proper Energy Management Scheme (EMS).
- Efficient load power-sharing and proper
- Communication medium between DERs.
- Proper control mechanisms to prevent grid failure and potentiality to black start.
- Generation cost optimization and economic dispatching of loads.
- Maximizing the potentiality of DERs and reducing the transmission losses.
- Capability to provide uninterrupted power supply to critical loads like hospitals, industries, and other crucial utilities.

3. SIMULATION RESULTS

Simulation results show DC Bus voltage = 250V DC Bus current = 40A Load (resistive) = 10kW

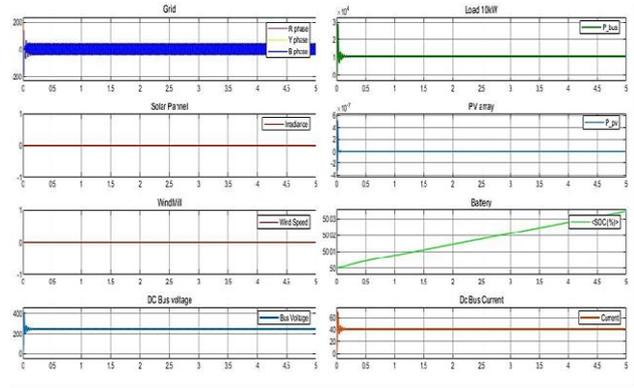


Figure 9 Grid Connected Mode

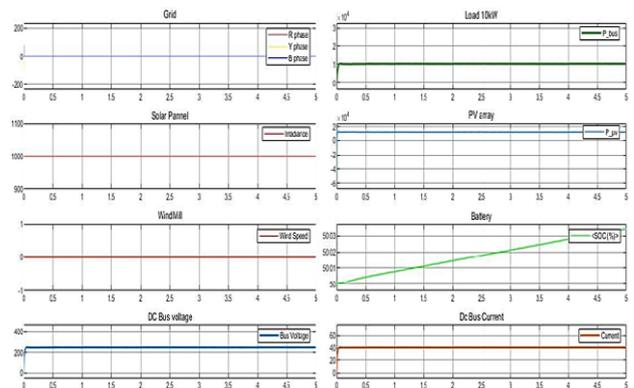


Figure 10 Islanded Mode: PV only

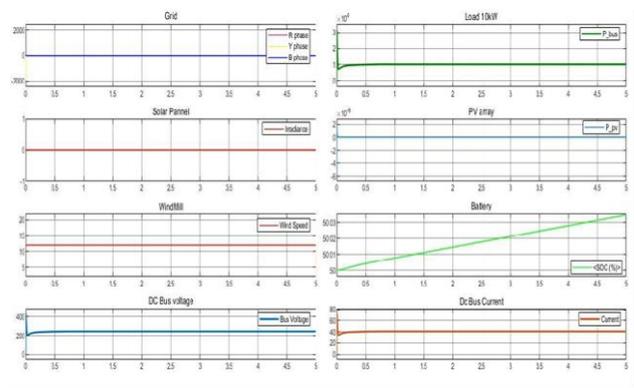


Figure 11 Islanded Mode: Wind only

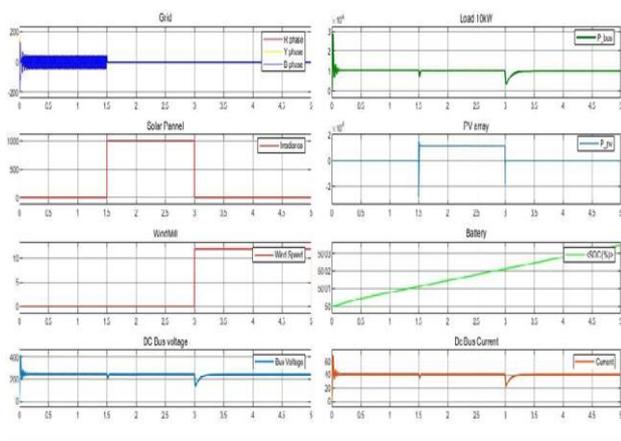


Figure 12 Switching in grid connected mode

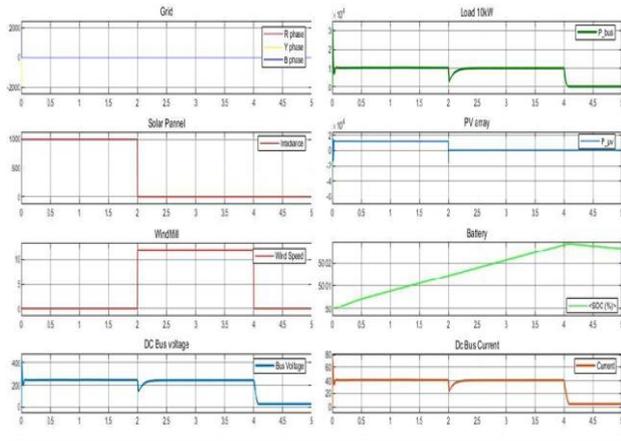


Figure 13 Switching in islanded mode

Table 1 Simulink Blocks

Three phase sources	Current measurements	IGBT/DIODE
Three phase breakers	Battery	Diode
Three phase transformers	Series RLC branch	Step
Three phase voltage measurement	MOSFET	PID controller
Universal bridge	Ideal Switch	Add
Filter	Permanent magnet synchronous machine	Multiply
Load resistive	Wind turbine	Add
Voltage measurement	PV array	Switch

4. RESULTS AND DISCUSSION

It is mandatory for isolated DC microgrids to be able to provide constant, reliable power supply as compared to grid connected microgrids. Hence, this paper presents a DC microgrid that is highly adaptable toward varying irradiances, whilst utilizing optimized storage capacity. Furthermore, an energy management control scheme (EMCS) is employed to enhance the charging and discharging operations of the microgrid. Using MATLAB/Simulink environment, the proposed DC microgrid is modelled for electrification of a small town. The acquired simulation results have exhibited stable DC voltage waveforms under different operating conditions despite variations in solar irradiance. It is found that the PV array, battery and wind complement each other effectively to ensure that the DC bus voltage is maintained at 250V, under transients. The beneficial traits and novelty of this microgrid design enable it to be exploited in a variety power distribution application.

5. CONCLUSION

In view of the economic efficiency of the entire electric power system including power transmission and distribution, PV generation that has intrinsically low working rates should be installed dispersedly in the demand area. Based on this idea, we have proposed the DC micro grid system as a solution for the major installation of PV generation and stabilization of power flows in the commercial grids. To demonstrate the key technique of the system, balancing power supply and demand, we have conducted an experiment using the DC micro grid system utilizing a RF battery. This experiment has demonstrated the technical feasibility of the DC micro grid system. In response to social needs and trends, we are going to develop this system into practical application and improve its economic efficiency.

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