A Hybrid AC/DC Microgrid and It's Coordination Control

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Abstract-- This work explains about hybrid ac/dc micro grid to reduce the processes of multiple dc–ac–dc or ac–dc–ac conversions in an individual ac or dc grid. The hybrid grid consists of both ac and dc networks connected together by multi-bidirectional converters. AC sources and loads are connected to the ac network whereas dc sources and loads are tied to the dc network. Energy storage systems can be connected to dc or ac links. The proposed hybrid grid can operate in a grid-tied or autonomous mode. The coordination control algorithms are proposed for smooth power transfer between ac and dc links and for stable system operation under various generation and load conditions. Uncertainty and intermittent characteristics of wind speed, solar irradiation level, ambient temperature, and load are also considered in system control and operation. A small hybrid grid has been modelled and simulated using the Simulink in the MATLAB. The simulation results show that the system can maintain stable operation under the proposed coordination control schemes when the grid is switched from one operating condition to another.

Keywords-- *Solar (PV), Wind Energy (WECS), Hybrid System, AC/DC Microgrid, Power Enhancement, Stability, DFIG.*

I. INTRODUCTION

There are a number of noteworthy changes in electric distribution technologies that will alter the needs of energy delivery as we go into the next century. Both the demand and supply sides are pushing for these adjustments, with the latter requiring changes to account for distributed generation and peak-shaving technology [1]. This is because both the demand and supply sides want more reliable and efficient energy.
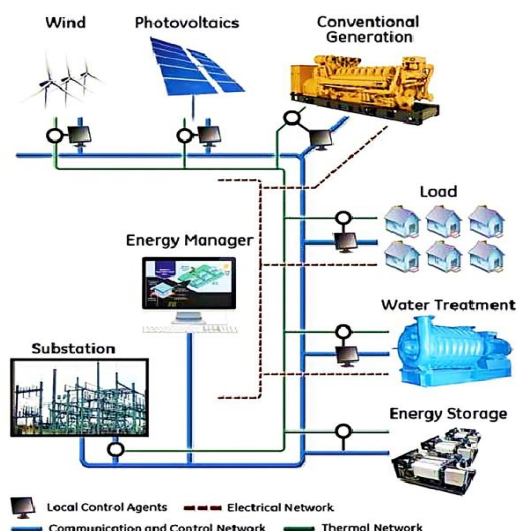

Figure 1: Microgrid power system

As a consequence of deregulation and the proliferation of distributed energy supplies, power networks are undergoing profound changes in their operational needs (DER). Many DERs take use of RES like solar, wind, or hydro power, while others rely on other technologies that allow for microgeneration. Advantages include reducing transmission losses and avoiding network congestion, both of which are enhanced by placing micro sources in close proximity to the load. Also, since neighbouring micro sources, controllable loads, and energy storage systems can run in the islanded mode in the event of severe system disturbances, the likelihood of end-customers connected to a low voltage (LV) distribution grid (in Europe 230 V and in the USA 110 V) losing power supply is reduced. These systems are now known as microgrids. Microgrids are shown in Figure 1.1. This unique microgrid is about the same size as a low voltage distribution feeder and has a maximum capacity of 1 MVA and a range of around 1 km. More than ninety percent of low-voltage residential clients are typically served by subterranean cable, with the remaining ten percent provided via overhead lines. Microgrids often use combined heat and power plants (CHP), gas turbines, fuel cells, photovoltaic (PV) systems, wind turbines, etc. to provide both electricity and heat to its clients. Batteries and flywheels are common forms of energy storage [2]. The microgrid's energy storage system is analogous to the traditional grid's rotating reserve of big generators in that it maintains power stability, particularly at peak demand or when there are sudden shifts in supply or demand [3].

Microgrids may benefit customers in a number of ways, including meeting their thermal and electrical needs, decreasing emissions, increasing power quality by smoothing out voltage fluctuations, and decreasing overall supply costs. From the perspective of utilities, the use of decentralised energy sources has the potential to lower the need for transmission and distribution infrastructure. Distributed generation that is geographically near to loads has two major benefits: it may mitigate losses and it can possibly replace infrastructure in the transmission and distribution networks. Furthermore, having generation near to demand might improve the quality of service experienced by end users. Microgrids may help the network out by reducing congestion and speeding up the repair process after an outage. Emissions may be reduced and climate change mitigated with the help of newly developed microgrids. This is because technologies based on renewable sources and micro sources, which are characterised by extremely low emissions, are readily available and are emerging for distributed generating units [4].

Microgrids provide numerous benefits to consumers, utilities, and society as a whole, including enhanced energy efficiency, decreased overall energy consumption, lower emissions of greenhouse gases and other pollutants, higher service quality and reliability, and lower replacement costs for electricity infrastructure[2].

There are significant technical hurdles associated with microgrid operation and controls. Improving complex control techniques for microgrid inverters is necessary to provide stable operation during network disruptions, maintain stability and power quality in the islanding mode of operation, and supply stable frequency and voltage in the presence of arbitrarily fluctuating loads [4]. Because of this, the idea of a microgrid has piqued the interest of many scientists and policymakers in the United States, Europe, and Japan. Although microgrids hold great promise, their integration and operation are fraught with challenges.

Features of Microgrid that Represent Technical Difficulties

The protection mechanism for a microgrid, which must respond to failures on both the main grid and the microgrid, is a significant obstacle. To safeguard the microgrid loads in the first scenario, the protection system must quickly disconnect the microgrid from the main grid; in the second scenario, the protection system must isolate the tiniest possible section of the microgrid after the fault is cleared [30]. Micro source and load controllers are necessary for a microgrid's segmentation, or the creation of several islands or sub-microgrids. Selectivity (false, unneeded tripping) and sensitivity (undetected faults or delayed tripping) issues with the protection system may become problematic under certain circumstances. There are two primary concerns when it comes to microgrid protection: the first involves the number of distributed energy resource (DER) units installed in the microgrid, and the second involves the availability of a sufficient level of short-circuit current in the islanded operating mode of microgrid, given that this level may substantially drop down after a disconnection from a rigid main grid. The authors of [30] calculated short-circuit currents for radial feeders equipped with DER and investigated the fact that the short-circuit currents used by over-current (OC) protection relays are location- and DER-specific. The circumstances will create deviations in the short circuit current's direction and magnitude. Given the nature of micro sources (wind and sun) and periodic demand change, the actual operating conditions of a microgrid are dynamic and ever-changing. It is possible to often alter the network's topology in an effort to decrease loss or accomplish other financial or operational goals. In addition, defects in such an in grid or in side microgrid might cause the formation of controlled islands of varying size and content. Since a result, generic OC protection with a single setting group may become inadequate, as it will no longer ensure a selected operation for all conceivable faults, and may cause a loss of relay coordination. Therefore, it is crucial to make sure that the OC protection relays' settings accommodate for the layout of the grid and any shifts in the location, type, or quantity of available generation. Otherwise, unintended behaviour or failure could occur under required circumstances. Microgrids dominated by micro sources with power electronic interfaces necessitate a new protection philosophy, where setting parameters of relays must be checked/updated periodically to ensure that they are still appropriate to deal with bi-directional power flows and low short-circuit current levels.

II. PHOTOVOLTAIC SYSTEM AND WIND ENERGY SYSTEM (DFIG)

A. Photovoltaic system

The photoelectric effect was first noted by French physicist Edmund Becquerel in 1839. He proposed that certain materials have property of producing small amounts of electric current when exposed to sunlight. In 1905, Albert Einstein explained the nature of light and the photoelectric effect which has become the basic principle for photovoltaic technology. In 1954 the first photovoltaic module was built by Bell Laboratories.

A photovoltaic system makes use of one or more solar panels to convert solar energy into electricity. It consists of various components which include the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output.

B. Photovoltaic arrangements
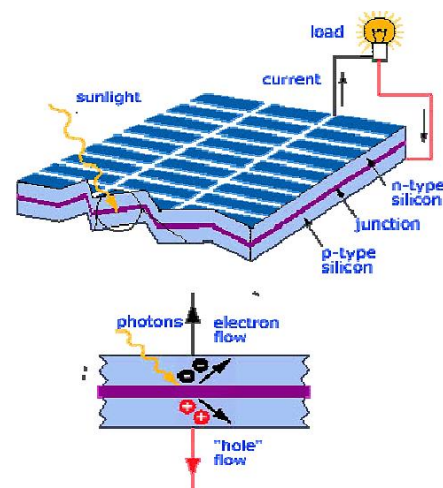
Photovoltaic cell

Figure 2: Basic structure of PV Cell

The basic ingredients of PV cells are semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer creates an electric field, on one side positive and negative on the other. When light energy hits the solar cell, electrons are knocked loose from the atoms in the semiconductor material. When electrical conductors are connected to the positive and

negative sides an electrical circuit is formed and electrons are captured in the form of an electric current that is, electricity. This electricity is used to power a load. A PV cell can either be circular or square in construction.

Photovoltaic module

Because of the low voltage generation in a PV cell (around 0.5V), several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for desired output. In case of partial or total shading, and at night there may be requirement of separate diodes to avoid reverse currents The p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics and these are not necessary. There is wastage of power because of reverse currents which directs to overheating of shaded cells. At higher temperatures solar cells provide less efficiency and installers aim to offer good ventilation behind solar panel. Usually there are of 36 or 72 cells in general PV modules. The modules consist of transparent front side, encapsulated PV cell and back side. The front side is usually made up of low-iron and tempered glass material. The efficiency of a PV module is less than a PV cell. This is because of some radiation is reflected by the glass cover and frame shadowing etc.

Photovoltaic array

A photovoltaic array (PV system) is an interconnection of modules which in turn is made up of many PV cells in series or parallel. The power produced by single module is not enough to meet the requirements of commercial applications, so modules are connected to form array to supply the load. In an array the connection of the modules is same as that of cells in a module. The modules in a PV array are usually first connected in series to obtain the desired voltages; the individual modules are then connected in parallel to allow the system to produce more current. In urban uses, generally the arrays are mounted on a rooftop. PV array output can directly feed to a DC motor in agricultural applications.
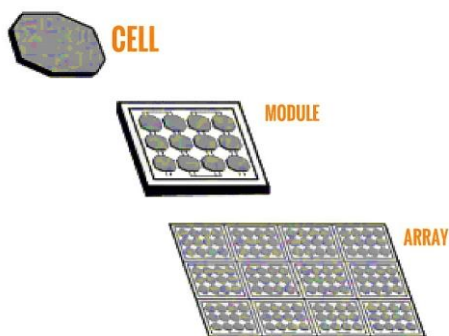
Figure 3: Photovoltaic system

Working of PV cell

The basic principle behind the operation of a PV cell is photoelectric effect. In this effect electron gets ejected from the conduction band as a result of the absorption of sunlight of a certain wavelength by the matter (metallic or non-metallic solids, liquids or gases). So, in a photovoltaic cell, when sunlight hits its surface, some portion of the solar energy is absorbed in the semiconductor material.
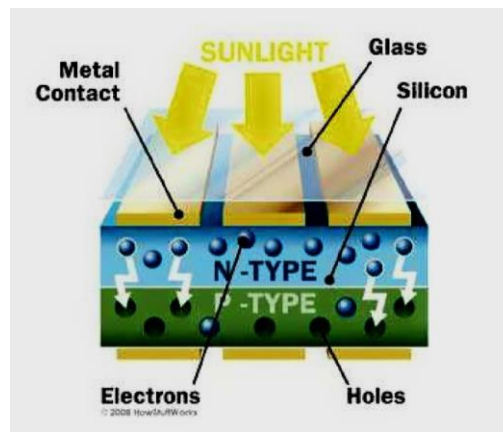
Figure 4: Working of PV cell

The electron from valence band jumps to the conduction band when absorbed energy is greater than the band gap energy of the semiconductor. By these hole-electrons pairs are created in the illuminated region of the semiconductor. The electrons created in the conduction band are now free to move. These free electrons are enforced to move in a particular direction by the action of electric field present in the PV cells. These electrons flowing comprise current and can be drawn for external use by connecting a metal plate on top and bottom of PV cell. This current and the voltage produces required power.

Wind turbines

With the use of power of the wind, wind turbines produce electricity to drive an electrical generator. Usually wind passes over the blades, generating lift and exerting a turning force. Inside the nacelle the rotating blades turn a shaft then goes into a gearbox. The gearbox helps in increasing the rotational speed for the operation of the generator and utilizes magnetic fields to convert the rotational energy into electrical energy. Then the output electrical power goes to a transformer, which converts the electricity to the appropriate voltage for the power collection system. A wind turbine extracts kinetic energy from the swept area of the blades.

DFIG system

The doubly fed induction machine is the most widely machine in these days. The induction machine can be used as a generator or motor. Though demand in the direction of motor is less because of its mechanical wear at the slip rings but they have gained their prominence for generator application in wind and

water power plant because of its obvious adoptability capacity and nature of tractability. This section describes the detail analysis of overall DFIG system along with back-to-back PWM voltage source converters.

III. SYSTEM DESIGN AND IMPLEMENTATION AC/DC MICROGRID

The concept of microgrid is considered as a collection of loads and micro sources which functions as a single controllable system that provides both power and heat to its local area. This idea offers a new paradigm for the definition of the distributed generation operation. To the utility the microgrid can be thought of as a controlled cell of the power system. For example, this cell could be measured as a single dispatch able load, which can reply in seconds to meet the requirements of the transmission system. To the customer the microgrid can be planned to meet their special requirements; such as, enhancement of local reliability, reduction of feeder losses, local voltages support, increased efficiency through use waste heat, voltage sag correction [3]. The main purpose of this concept is to accelerate the recognition of the advantage offered by small scale distributed generators like ability to supply waste heat during the time of need [4]. The microgrid or distribution network subsystem will create less trouble to the utility network than the conventional microgeneration if there is proper and intelligent coordination of micro generation and loads [5]. Microgrid considered as a 'grid friendly entity" and does not give undesirable influences to the connecting distribution network i.e. operation policy of distribution grid does not have to be modified[7].
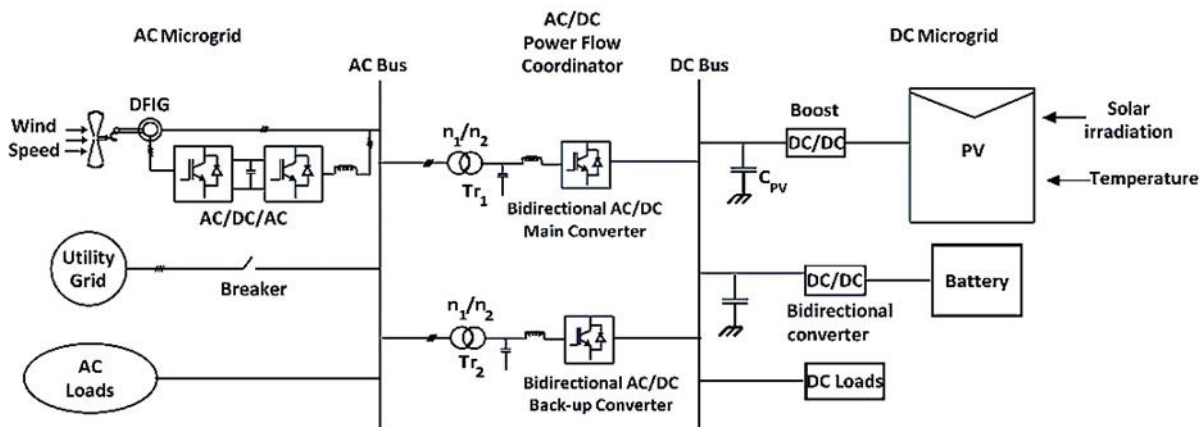
Configuration of the hybrid microgrid

Figure 5: A hybrid AC/DC microgrid system

The configuration of the hybrid system is shown in Figure 3.1 where various AC and DC sources and loads are connected to the corresponding AC and DC networks. The AC and DC links are linked together through two transformers and two four quadrant operating three- phase converters. The AC bus of the hybrid grid is tied to the utility grid.
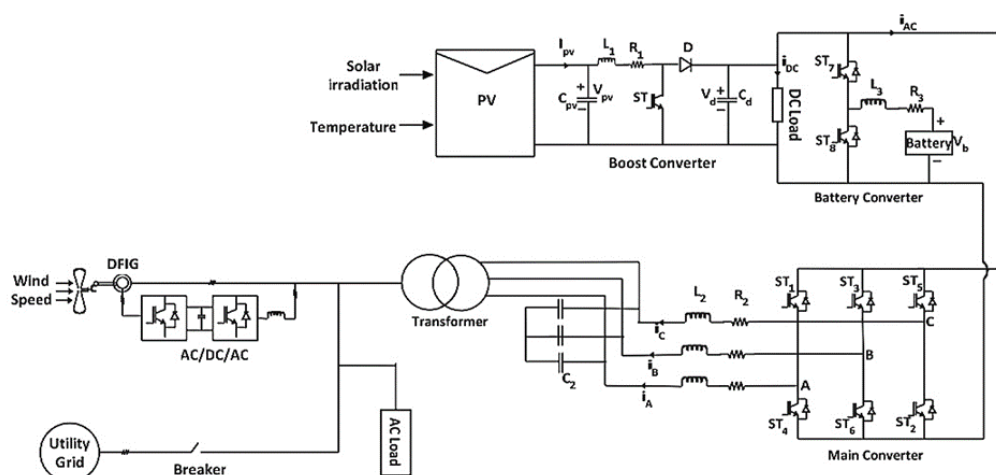

Figure 6: Describes the hybrid system configuration which consists of AC and DC grid.

The AC and DC grids have their corresponding sources, loads and energy storage elements, and are interconnected by a three phase converter. The AC bus is connected to the utility grid through a transformer and circuit breaker.

In the proposed system, PV arrays are connected to the DC bus through boost converter to simulate DC sources. A DFIG wind generation system is connected to AC bus to simulate AC sources. A battery with bidirectional DC/DC converter is connected to DC bus as energy storage. A variable DC and AC load are connected to their DC and AC buses to simulate various loads.

PV modules are connected in series and parallel. As solar radiation level and ambient temperature changes the output power of the solar panel alters. A capacitor C_{pv} is added to the PV terminal in order to suppress high frequency ripples of the PV output voltage. The bidirectional DC/DC converter is designed to maintain the stable DC bus voltage through charging or discharging the battery when the system operates in the autonomous operation mode. The three converters (boost converter, main converter, and bidirectional converter) share a common DC bus. A wind generation system consists of doubly fed induction generator (DFIG) with back to back AC/DC/AC PWM converter connected between the rotor through slip rings and AC bus. The

AC and DC buses are coupled through a three phase transformer and a main bidirectional power flow converter to exchange power between DC and AC sides. The transformer helps to step up the AC voltage of the main converter to utility voltage level and to isolate AC and DC grids.

Modeling and control of DFIG

This section explains the detailed modeling of DFIG. The state space equations are considered for induction machine modeling. The parameters and specifications of the DFIG are given in table 3.1. Flux linkages are used as the state variables in the model. Here two back to back converters are used in the rotor circuit. The main purpose of the machine-side

converter is to control the active and reactive power by controlling the d-q components of rotor current, while the grid-side converter controls the dc-link voltage and ensures the operation at unity power factor by making the reactive power drawn by the system from the utility grid to zero.

Two back to back converters are connected to the rotor circuit is shown in Fig 3.3. The firing pulses are given to the devices (IGBTs) using PWM techniques. Two converters are linked to each other by means of dc-link capacitor.
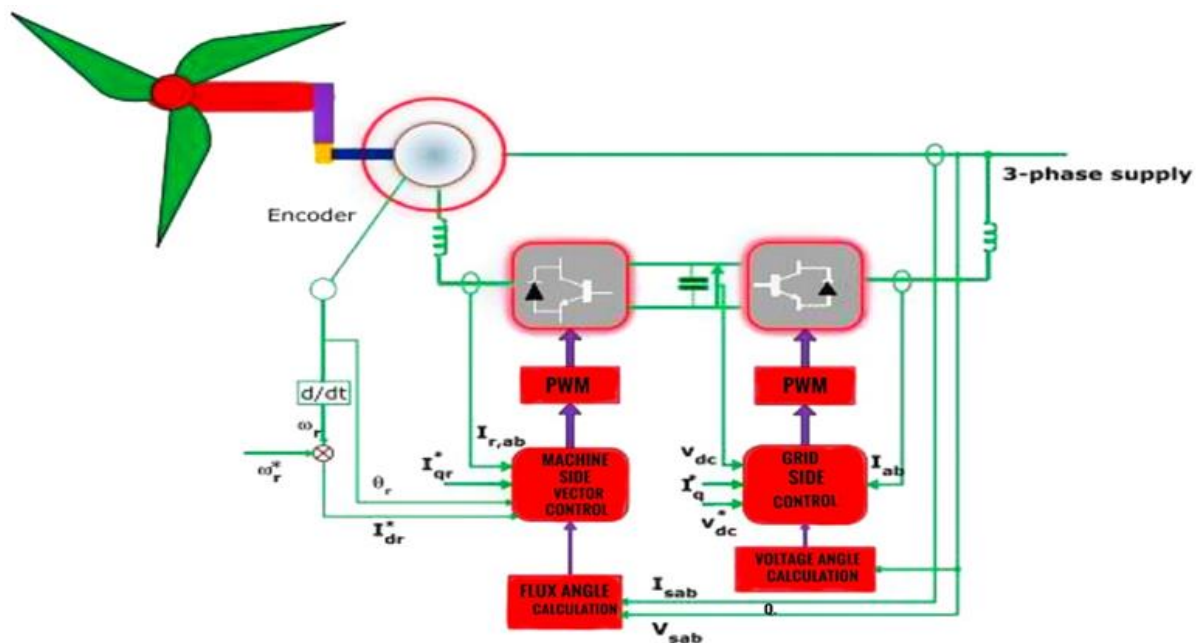

Figure 7: Overall DFIG system

IV.   SIMULATION RESULTS AND ANALYSIS

A hybrid microgrid is simulated using MATLAB/SIMULINK environment. The operation is carried out for the grid connected mode. Along with the hybrid microgrid, the performance of the doubly fed induction generator, photovoltaic system is analyzed. The solar irradiation, cell temperature and wind speed are also taken into consideration for the study of hybrid microgrid. The performance analysis is done using simulated results which are found using MATLAB.
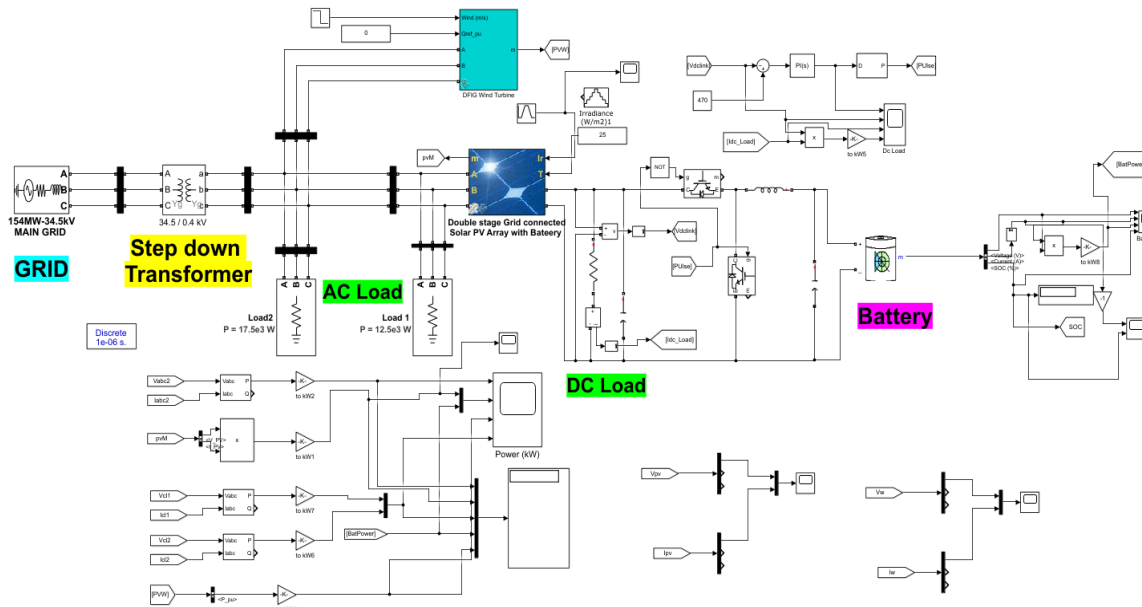
Figure 8: Hybrid AC/DC Microgrid

Simulation of PV array

Figure (4.2) -(4.3) represents P-V characteristics with variation in solar irradiation. The nonlinear nature of PV cell is noticeable as shown in the figures, i.e., the output power of PV cell depends on the cell's terminal operating voltage and temperature, and solar irradiation as well.
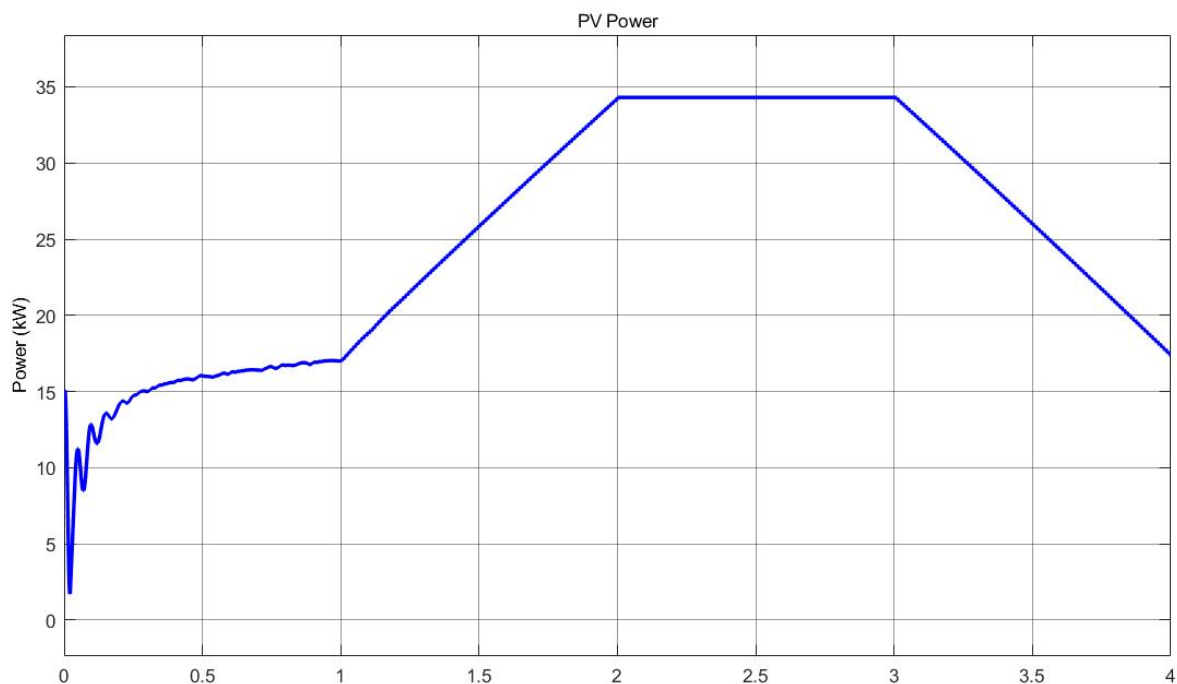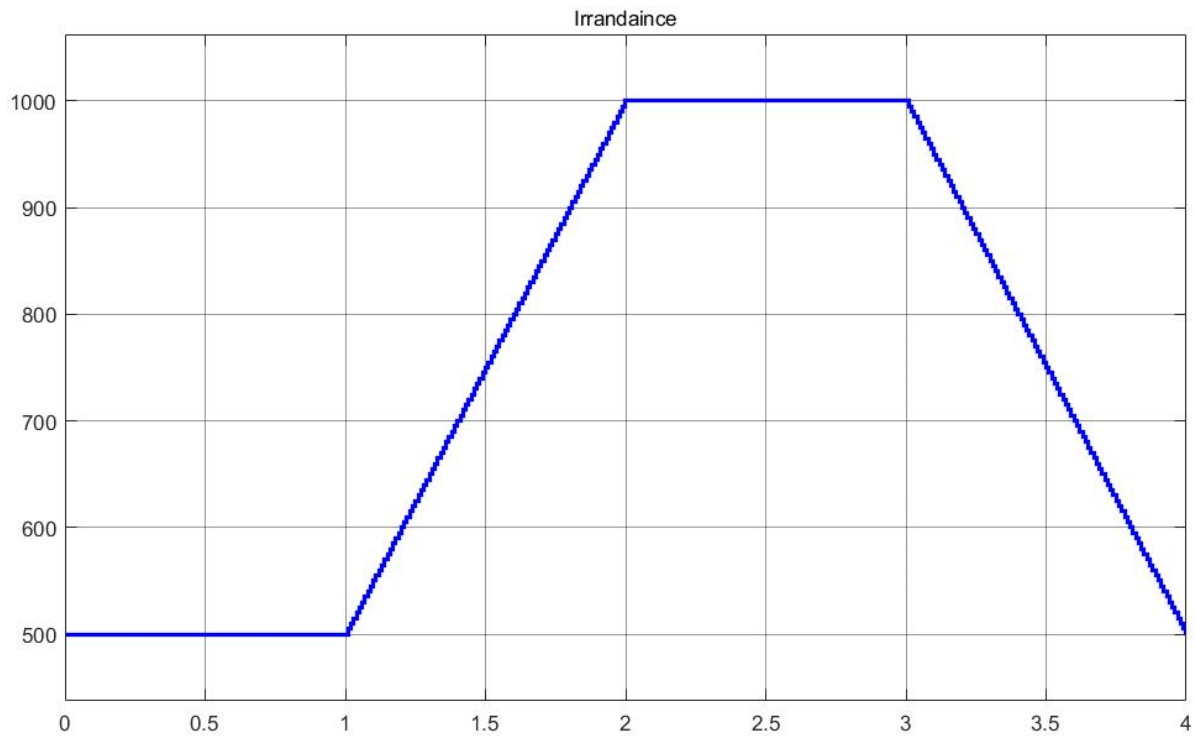

Figure 9: PHOTOVOLTAIC (PV) POWER VS TIME IN (S)

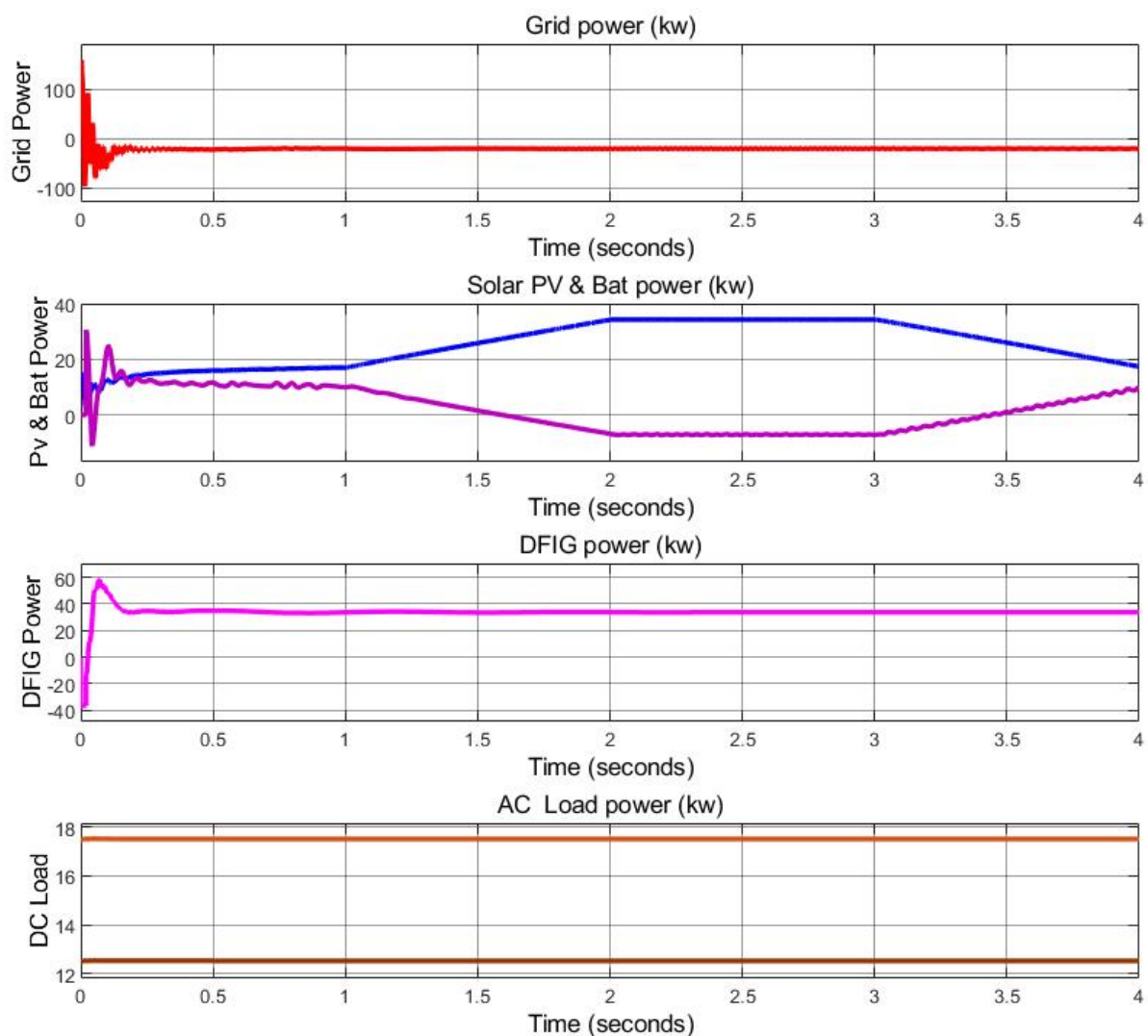Figure 10: IRRANDAINCE VS TIME IN (S)

Figure 11: GRID POWER (KW), SOLAR PV & BATTERY POWER (KW), DFIG POWER (KW) & AC LOAD POWER (KW) VS TIME IN (S)
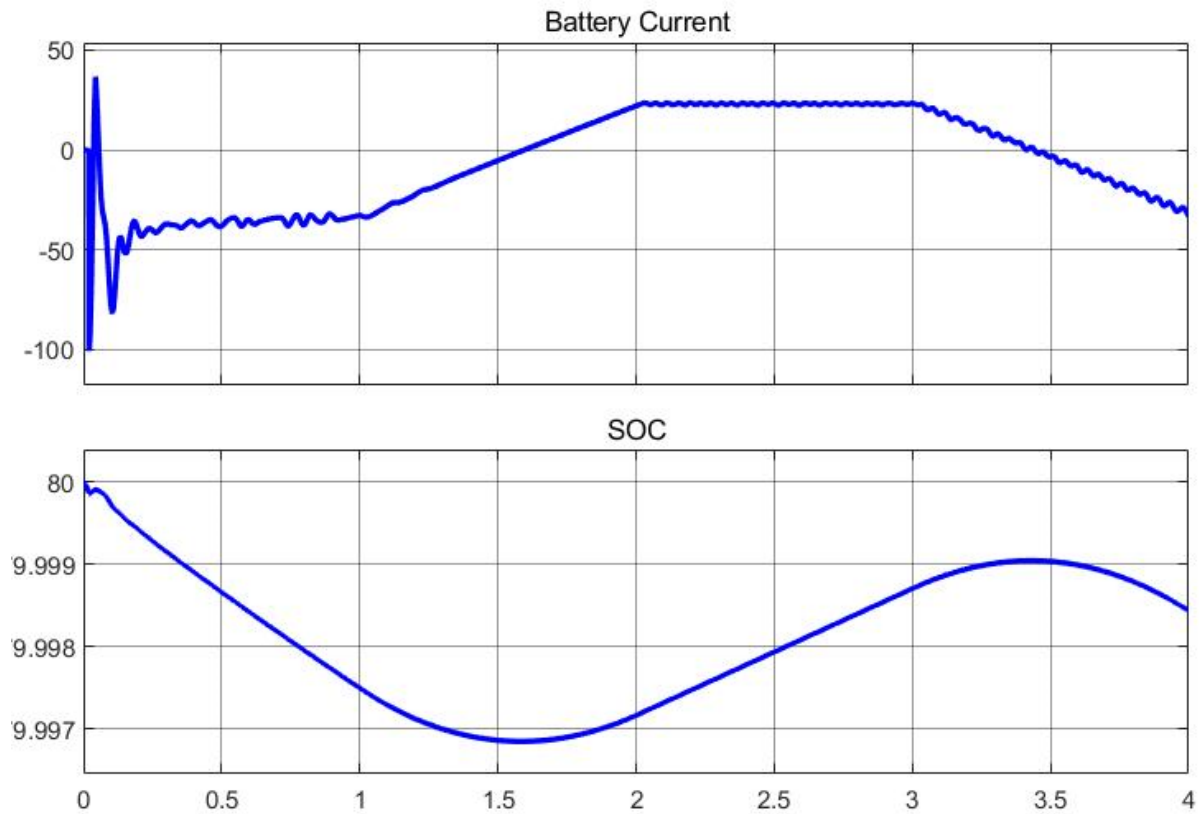
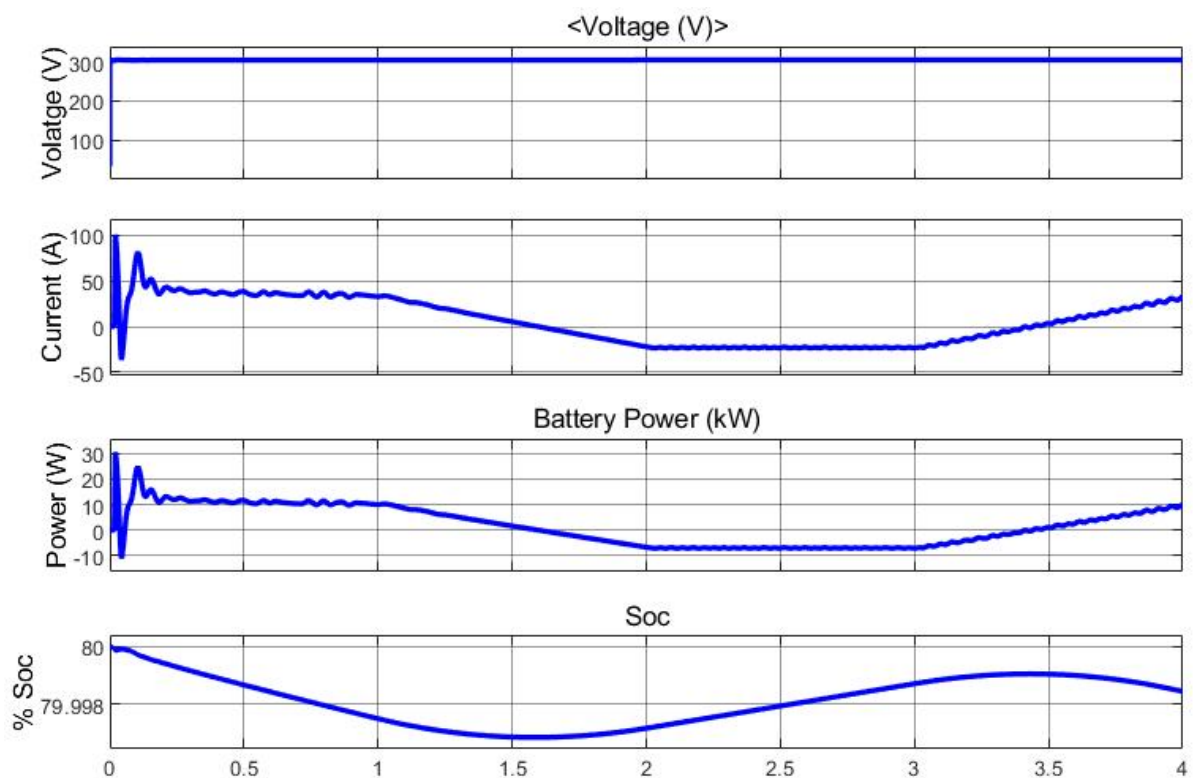Figure 12: BATTERY CURRENT & SOC VS TIME IN (S)

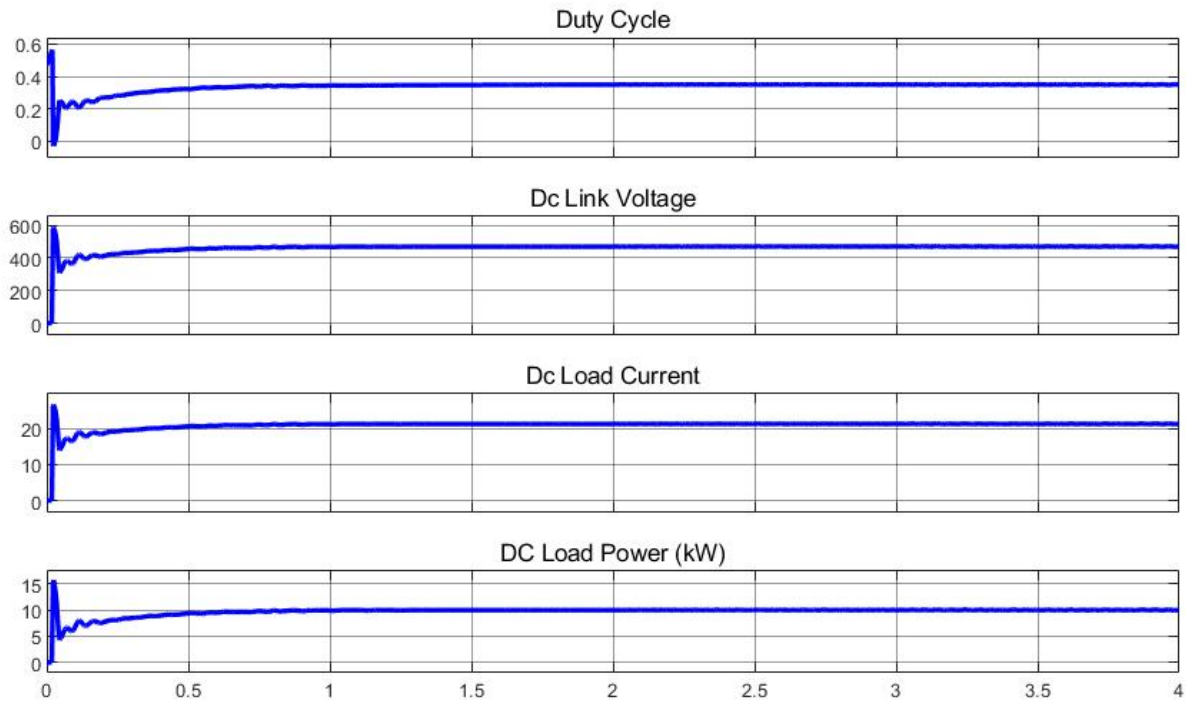Figure 13: BATTERY - CURRENT, VOLTAGE, POWER (KW) & SOC % VS TIME IN (S)

Figure 14: DUTY CYCLE, DC LINK VOLTAGE, DC LOAD CURRENT & DC LOAD POWER (KW) VS TIME IN (S)
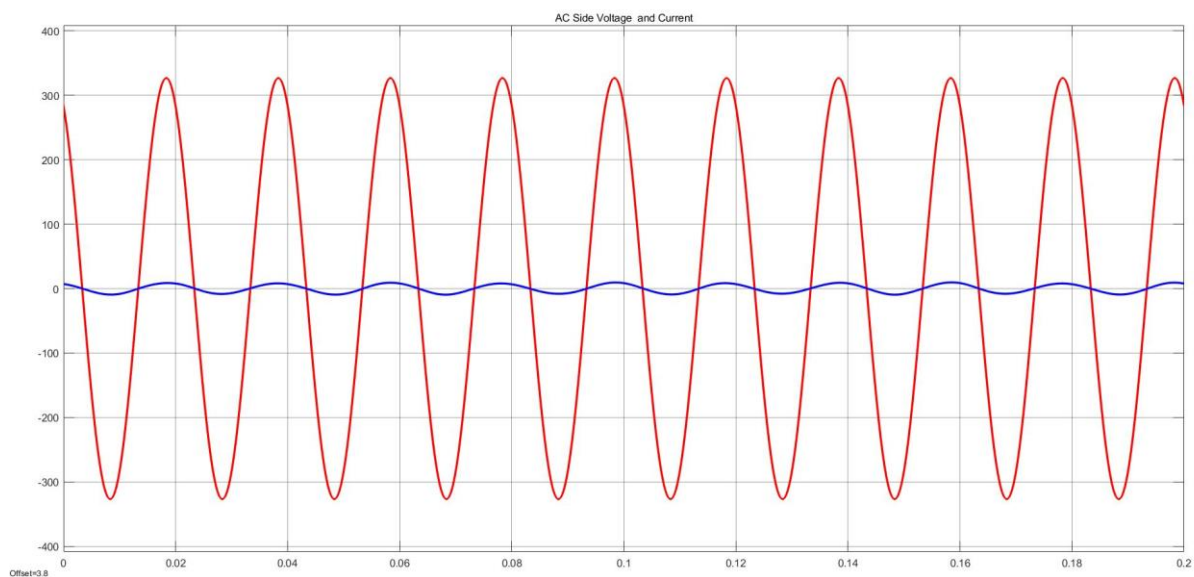

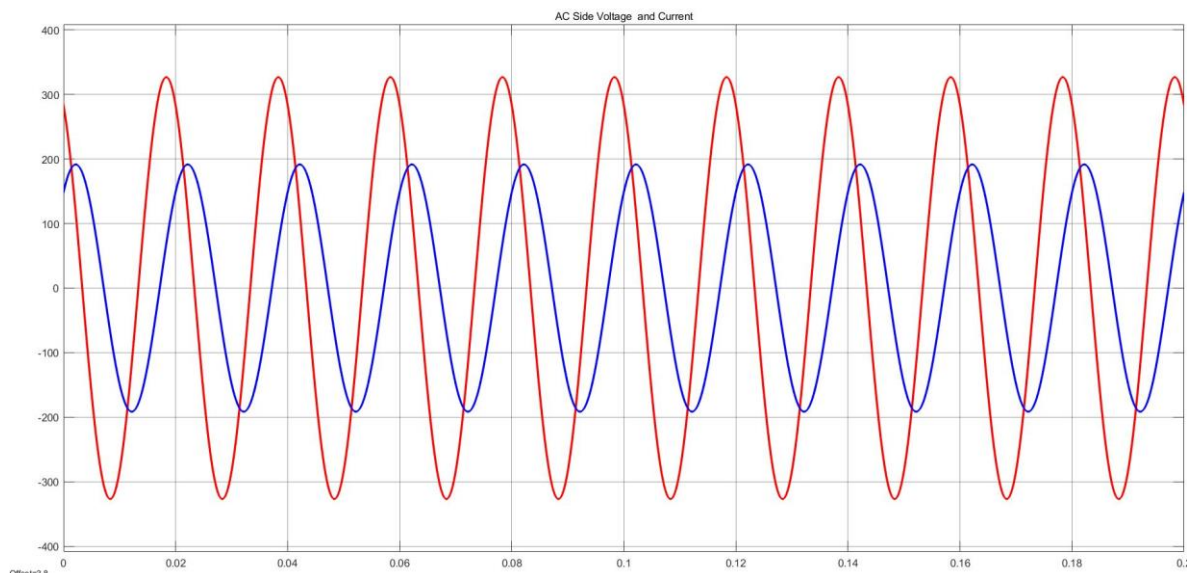Figure 15: AC SIDE VOLTAGE & CURRENT FIGURE (1) VS TIME IN (S)

Figure 16: AC SIDE VOLTAGE & CURRENT FIGURE (2) VS TIME IN (S)

CONCLUSION & FUTURE SCOPE

Conclusion

The MATLAB/SIMULINK platform is used to simulate the hybrid microgrid power system setup. The focus of the current study is on the hybrid grid's grid-tied mode of operation. In order to keep the system stable under varying loads and resource circumstances, models are created for each of the converters, and their respective control mechanisms are investigated. The maximum power point tracking (MPPT) algorithm is used to get the most energy possible out of DC sources and to regulate the flow of electricity between the DC and AC grids. Although a hybrid grid may reduce the need for DC/AC and AC/DC converters within a single AC or DC grid, implementing a hybrid grid based on the existing AC dominant infrastructure presents a number of practical challenges. Reducing conversion losses and adding an additional DC connection will improve the overall system's efficiency. Electricity from the hybrid grid is more secure, of higher quality, and uses less resources than traditional grids. For tiny, remotely located manufacturing facilities, the hybrid grid might work if the primary power source includes photovoltaic cells and a wind turbine generator.

Future Scope

The control mechanism may be created for a microgrid with unbalanced and nonlinear loads; modelling can be done for the islanded mode of operation.

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