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CONTROL OF A GRID TIED MULTI PORT INVERTER FOR A MICROGRID WITH RENEWABLE ENERGY SOURCES

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Abstract: The proposed project present modelling and control of a two-stage grid-tied inverter for integration of different energy sources to the utility grid. The focus of this work is to develop two-level controllers on the AC side so that it can work in both grid-connected mode and standalone mode. The control strategy utilizes the d-q rotation frame and a droop controller to regulate the voltage and frequency of the micro grid.

Then the system-level droop controllers are developed to achieve the power sharing among converters in the micro grid. The multiport inverter can interface with multiple renewable energy sources, such as solar panels and wind turbines, and is capable of managing the power flow between the micro grid and the utility grid. Simulation results show that the proposed control strategy is effective in maintaining stable voltage with the load side while also ensuring optimal power sharing among the different renewable energy sources.

Index Terms – Photovoltaic system, Battery, Wind system, Microgrid, inverter, Multi-port converter.

1. INTRODUCTION:

Electricity infrastructure is the foundation of every country all over the world. The traditional power systems are centralized and built far away from the costumers. The sources like coal are limited in supply and unfriendly to the environment. In addition, it may need a long time to restore if there are power outages caused by natural disasters such as floods and hurricanes. For example, Hurricane Sandy left million customers without power for serval days across 15 states in August 2003. The widespread power outages in the wake of Hurricane Sandy cast light on the weakness of a centralized electric power system. As the demand for electricity grows, the penetration of distributed generation (DG) is gradually increasing in developed countries worldwide. Due to the merits of renewable energy, RESs, such as wind turbine generators (WTGs) and photovoltaic (PV) panels are widely used to generate electricity. Microgrids are introduced into electric power systems for managing the widespread penetration of renewable energy and DGs in power distribution networks. The microgrids concept assumes a cluster of loads and micro sources operating as a single controllable system that provides both power and heat to its local area. This concept provides a new paradigm for defining the operation of distributed generation. Power electronic converters play an important role in integrating various RESs, such as PV and wind energy systems, and ESS, such as batteries, into a microgrid and managing the power flows among different sources and the microgrid.

The background for this paper is presented in this chapter: Multiport converters must be created in order to integrate energy storage systems (ESSs) and renewable energy sources (RESs) of various sorts and capacities into the electrical grid. Solar and wind energy, which are the fastest-growing sources of power and the third-largest source of electric-generating capacity additions, are being exploited due to their clean and alternative characteristics. More and more photovoltaic (PV) panels and wind turbine generators (WTGs) are being installed with the decline of the energy price. Power electronics converters play an important role in integration of these distributed renewable energy sources (RES) to the current utility grid. However, due to the intermittence characteristic of the renewable energy, the energy storage system (ESS), e.g., battery, is used to make the overall energy conversion system work regardless the existence of the grid. When a utility grid is not available, these energy resources can be integrated to isolated microgrids with power converters to meet local energy needs i.e., the microgrid works in the islanding mode and provides the uninterruptible power source for local loads. In those applications to integrate different energy sources, a converter which has multiple input ports is desired since it can achieve higher power density and more compact structure and using the multiple individual two-port converters.

A number of isolated multiport converters with different topologies have been proposed for renewable energy systems integration. These topologies include full-bridge converter half-bridge converter and their derivations, these converters can achieve high efficiency because they can be soft-switched. However, aforementioned topologies are DC-DC converters which cannot be directly connected to the existing utility grid or AC microgrid without an inverter. It is necessary to add a DC-AC conversion as well as develop the system-level control so that it can participate the grid-level power management. In this project, a two-stage DC-DC-AC multiport converter is proposed to interface a PV panel, a WTG, and battery to the AC microgrid.

2. METHODOLOGY:

A grid-tied multiport inverter is a device that can manage multiple renewable energy sources, integrate them into the electrical grid. To control the inverter, a combination of techniques is commonly used, including the d-q transformation. The d-q transformation, also known as the Park's transformation or the Park's vector approach, is a mathematical tool used in the analysis of three-phase AC electrical systems. A two-stage DC-DC-AC multiport converter is proposed to interface a PV panel, a WTG, and a battery to the AC microgrid. This project is to develop controllers for the multiport converter at different levels so that it can work in both standalone mode and grid connected mode.

2.1. HYBRID MICROGRID:

Hybrid AC-DC microgrids (HMGs) have been studied recently in order to exploit AC and DC microgrids (MGs) simultaneously. This dissertation develops control techniques for an interlinking converter (IC) which is utilized to link MGs in HMGs. With the proposed control techniques, IC simultaneously manages various AC and DC voltage quality issues and power flow among MGs. Microgrids are helpful structures because they enable the effective administration of decentralized resources like renewable energy sources and small-scale distributed generators. Utilities can run more efficiently by utilizing a microgrid, which might lead to less pollution and fewer power outages. Power electronics interfaces, alternating current (ac) and direct current (dc) loads, and other components can all come together to form a microgrid. Microgrids are localised, scaled-down versions of the larger grid. Microgrids combine several power sources (both renewable and non-renewable) with storage to provide reliable, localised electricity. The microgrid can function alone or in tandem with the larger grid (known as a grid-connected mode). There is some wiggle room in the definition of a microgrid, although it is generally accepted as meaning the same thing. Microgrids can function autonomously. Secondly, a master controller is required to manage distributed energy resources (DERs) and loads as a single controllable entity within the established electrical boundary. Finally, the peak load capacity of the system must be lower than the total generation capacity for islanded mode operation to be possible. In other words, the microgrid can function autonomously without needing the main power grid. In order to provide a solution that is as accurate to the real-world system as feasible, an optimal power flow algorithm should consider all ac and dc components. "In Microgrid, it is assumed that a cluster of loads and micro-sources is working as a controllable unity system which supplies power as well as heat to its local area." - This idea yields a new prototype for operating distributing generations.

1. Residential Microgrid: This type of microgrid is utilised in communities, residential houses, and campuses. The only problem associated with this type is that it can cause an impulse to the grid voltage and frequency when switching from grid connected to islanding mode. Therefore, the stability and reliability of the system is a matter of concern in residential microgrids.

2. Remote Microgrid: As the name suggests it can be applied in rural areas or islands where it is difficult for utilities to maintain an adequate energy supply. This type of microgrid prevents transmission and distribution line losses and CO₂ emissions of the utilities. The only problem with this type is that the system should be self-sustainable enough.

3. Mobile Microgrid: This type is applied in military-based camps or naval systems. Thus, the system's flexibility is the main reason for using this MG, as it can be easily moved from place to place as and when needed.

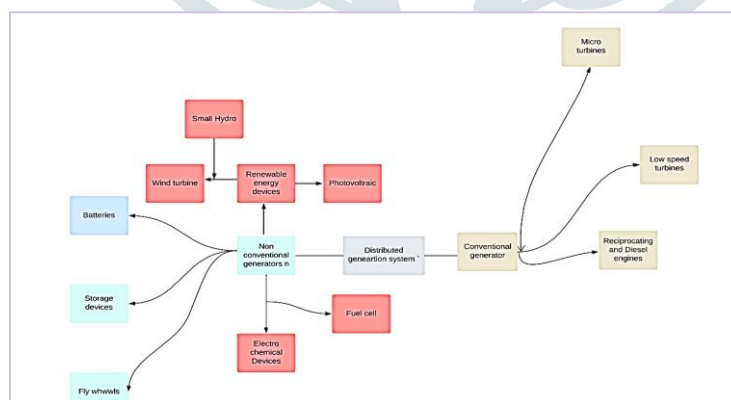


Fig 2.1 Classification of DG and technology.

In AC-DC hybrid systems, renewable energy sources predominate. This type of resource is easily accessible and can be used to its full potential. Batteries, wind turbines, and diesel were the only technologies previously available to supply the load, but they were insufficient for load management because the system was unstable under various conditions. Therefore, a controller is utilised in conjunction with installing a PV module to get around this issue. The efficiency of PV arrays and their resulting power output is highly context-dependent on the amount of sunlight available at any given site.

2.2. MICROGRID AND SMART GRID:

Microgrid is a localized system in which mostly local energy is produced and/or grid-taken for a very small area for a locality. The Microgrid can be separated from the main grid in case of any difficulty, and it keeps operating independently. This is very useful locally for renewable energy, or for local incorporation of solar or wind energy for larger main grid. Smart grid is a combination of micro and mini grids with fine branch and supply systems control. It senses changes in loads, fluctuations in different generation and transmission lines (both voltage and frequency), and takes corrective action alone to preserve system reliability and quality of supply.

2.2.1. DC MICROGRID:

In DC Microgrid, a common DC bus connects to the grid through an AC/DC converter. The operation principle of a DC Microgrid is like AC Microgrid. Compared with AC Microgrid, DC Microgrid is a good solution to reduce power conversion losses because it only needs one power conversion to connect the DC bus. Therefore, DC Microgrid has higher system efficiency, lower cost and system size. Moreover, DC Microgrid is better compatible with the integration of distributed energy resources (DERs) and has better stability due to the absence of reactive power.

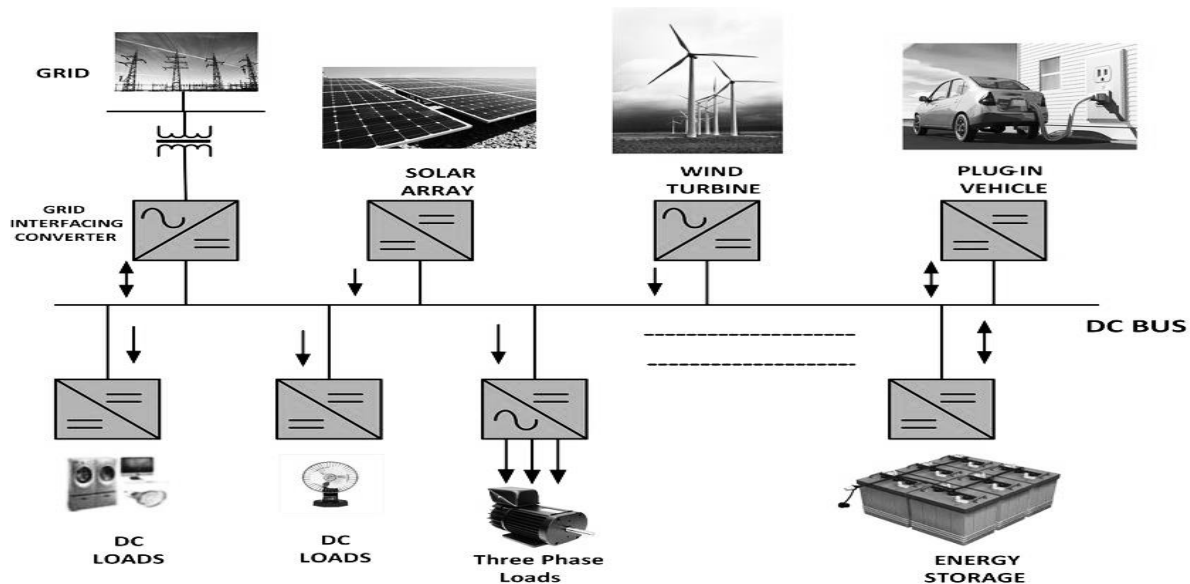


Fig 2.2 Structure of basic DC Microgrid

2.2.2. AC MICROGRID:

AC Microgrids have a common AC bus which is generally connected to mixed loads (DC and AC loads), distributed generations, and energy storage devices. AC Microgrids are easily integrated into conventional AC grids because most of the loads and grid itself are AC. Therefore, it has better capacity, controllability, and flexibility. However, DC loads must be connected to the AC bus via DC/AC inverter, which causes a significant decrease in efficiency.

Microgrids can function in grid-connected and off-grid modes, as demonstrated by the illustrative setup shown above, which involves connecting the MG to the mains via an intelligent transfer switch. Each DG includes an inverter system, micro-source (such as solar panels, wind turbines, fuel cells, etc.), and energy storage devices, as shown in the image. Microgrids like these have fewer losses and greater power-delivery versatility.

I. THE PHOTOVOLTAIC SYSTEM:

Photovoltaics is a technology and research field dealing with devices that directly convert electricity into electricity using semiconductors. Photovoltaic effect the creation of electricity in a material when an electric current is applied to it.

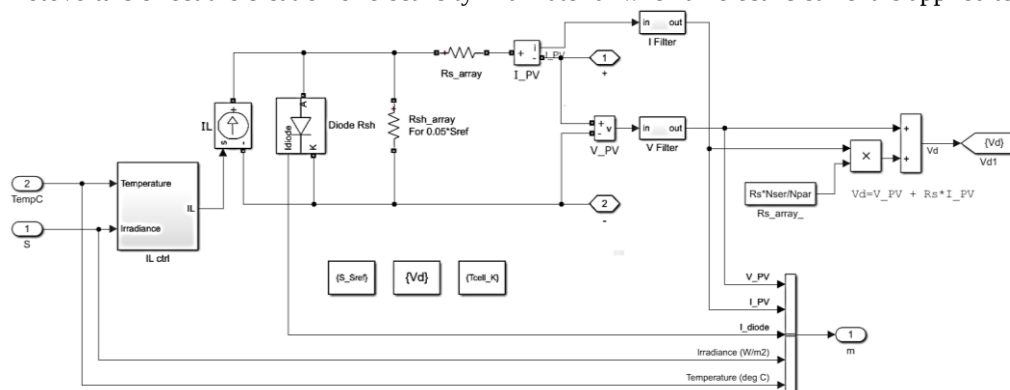


Fig 2.3 Simulink diagram of photovoltaic technology.

The photovoltaic cell is the primary element of a photovoltaic module and is the part of the module that is accountable for the transformation of photons and rays of sunshine into electric current. A typical photovoltaic (PV) cell's equivalent circuit is represented in Fig.2.4.

A current source, an anti-parallel diode, a series resistance, and a shunt resistance are all components that make up this thing. The I_{pv} - V_{pv} characteristic equation of a PV cell can be expressed by the following equation, which is derived from the Shockley and Queisser diode equation.

$$I_{pv} = I_{ph} - I_0 \left[\exp \left(\frac{V_{pv} + R_s I_{pv}}{n V_T} \right) - 1 \right] - \frac{V_{pv} + R_s I_{pv}}{R_p} \quad \text{.....(2.1)}$$

Where I_{ph} is the current generated by the incident solar radiation, I_0 is the reverse saturation or leakage current of the diode; the following expression gives it

$$I_0 = \left[\frac{I_{cc}}{\exp \left(\frac{V_{co}}{n V_T} \right) - 1} \right] \quad \text{.....(2.2)}$$

R_s is the intrinsic series resistance of the solar cell, R_p is the equivalent shunt resistance of the solar array (its value is usually very large), and V_T is the thermal voltage of the PV module; it is given by the following equation:

$$V_T = \frac{K T_c}{q} \quad \text{.....(2.3)}$$

Where K is the Boltzmann constant, which is equal to 1.38×10^{-23} J/K, q is the electron charge, which is equal to 1.6×10^{-19} C, T_c is the absolute temperature in Kelvin, and n is the diode ideality factor, which ranges from 1.0 to 1.5. In other places, the value of the short-circuit current is given by where it is expressed for different variables of sun intensity and temperature.

$$I_{cc}(G) = I_{ccref} \frac{G}{G_{ref}} \quad \text{..... (2.4)}$$

$$I_{cc}(G) = I_{ccref} (1 + \alpha (T - T_{ref})) \quad \text{.....(2.5)}$$

where G_{ref} , T_{ref} , and I_{cref} are the standard values of solar intensity, cell temperature and short-circuit current, respectively, and α is a temperature coefficient (A/K). Similarly, the saturation current is expressed, for a given temperature level, as

$$I_0(T) = I_0(T_{ref}) \left(\frac{T}{T_{ref}} \right)^{\frac{3}{n}} \left(\exp \left(\frac{-q E_g}{n K} \right) \left(\frac{1}{T} - \frac{1}{T_{ref}} \right) \right) \quad \text{.....(2.6)}$$

PV cells that are connected in parallel to one another boost the overall output current of the PV module, whereas PV cells that are connected in series to one another boost the overall output voltage of the cell.

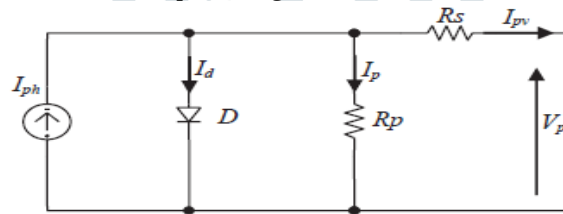


Fig. 2.4. Equivalent circuit of a PV cell.

The voltage measured across an open circuit (V_{OC}) and the current measured across a short circuit (I_{SC}) are the two most essential parameters that are used to characterise the electrical performance of the cell. Due to the fact that the equations I just presented are implicit and nonlinear, it is quite difficult to find an analytical solution that accounts for the particular temperature and irradiance. Normally $I_{PH} \gg I_S$, so by neglecting the small diode and ground-leakage currents under zero-terminal voltage, the short-circuit current is approximately equal to the photocurrent, i.e.

$$I_{PH} = I_S \quad \text{.....(2.7)}$$

The parameter for the open-circuit voltage can be derived by presuming that there is no output current. It is possible to calculate the reverse saturation current by using the known open-circuit voltage at the reference temperature and ignoring the shunt-leakage current. The calculation is as follows:

$$I_{RS} = I_{SC} / [\exp (q V_{OC} / N_s k A T_c) - 1] \quad \text{.....(2.8)}$$

Additionally, the maximum power can be stated as

$$P_{max} = V_{max} I_{max} = \gamma V_{OC} I_{SC} \quad \text{..... (2.9)}$$

II. BATTERY SYSTEM MODEL:

When modelling a battery, several different inputs are taken into consideration, including temperature, current capacity, and state of charge (SOC). During the process of charging and discharging the battery, each of these characteristics of the battery will change. The source of variable voltage that is connected in series with a resistive element is known as the battery model. It is applicable to a battery that uses electromechanical energy. Figure 2.6 presents the model for your perusal. The utilization of this model is simple. Using the dynamic simulation programme MATLAB/Simulink, it is put into action in order to simulate the type of battery.

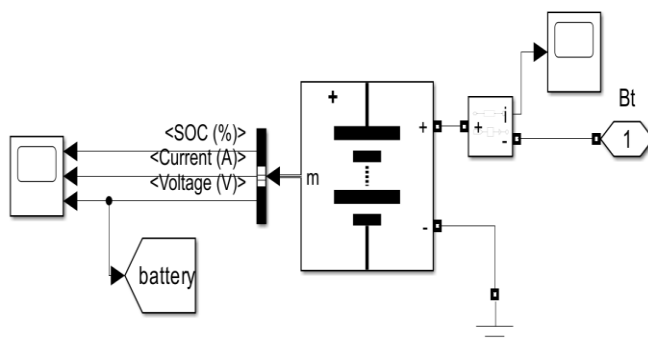


Fig 2.5 : Simulink diagram of battery model

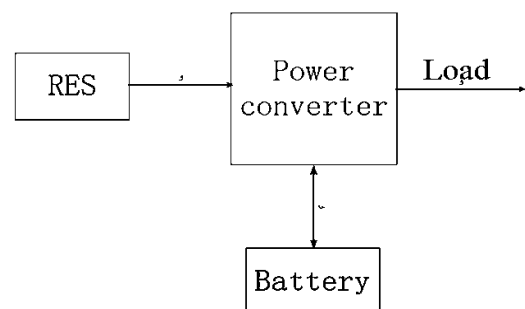


Fig 2.6 A typical power system with battery ESS

The controlled voltage is expressed as

$$V_{oc} = E_o - K \frac{Q}{Q - \int i dt} i - R_o i \quad \dots\dots\dots(2.10)$$

Where,

E_o = Battery open circuit EMF (V)

V_{bat} = Battery voltage (V)

$\int i dt$ = Actual battery charge (Ah)

Q = Battery capacity (Ah)

i = Battery current (A)

R_{int} = Internal resistance (Ω)

K = Polarization resistance coefficient

A = Amplitude exponential zone (V)

B = Time constant inverse of an exponential zone (Ah^{-1})

The nonlinear term is the $\frac{Q}{Q - \int i dt}$ in shepherd equation. This word refers to the battery's voltage changes depending on the charge level and the current. Therefore, when there is no current flow and the battery is almost totally depleted, the voltage of the battery rises to a level that is close to E_o . As soon as a current begins to flow through the battery again, the voltage is suddenly reduced. This behavior is indicative of a real battery; however, the mathematical model that makes it possible to simulate this scenario also causes the simulation to become unstable and generates an algebraic loop.

$$V_{bat} = E_o - K \frac{Q}{Q - \int i dt} i + A \exp(-B * it) \dots\dots\dots(2.11)$$

As shown in Fig. 2.6, the power flow of the battery is bidirectional, this will ensure the whole system energy supply continuously and improve the reliability of the system. When the power generated by the RES is higher than the load, the battery is charged to store the surplus energy; when the RES power is not sufficient to supply the load, the battery will be discharged to provide the deficient power.

III.I. STATE OF CHARGE (SOC) ESTIMATION:

Estimating the battery's state of charge, also known as SOC, can be done by comparing the current capacity of the battery to its nominal capacity. This ratio is abbreviated as "current capacity ratio." The quantity of unused battery capacity may be accurately estimated by SOC thanks to their years of knowledge in the field. When performing an evaluation of the performance of the battery, the SoC is an important metric to take into consideration. If the state of charge (SOC) estimation of the system is understood, the lifespan of the battery can be increased, and it will be protected from harm that is caused by overcharging or over discharging the battery. The following items make up the

$$SOC: SOC(t) = 1 + \frac{\int_0^t I_{bat} dt.}{Q_o} \quad \dots\dots\dots(2.12)$$

One of the most important parameters that needs to be maintained is the state of charge (SOC), which refers to the amount of power that is stored when the battery is being charged. The suggested supervisory system needs to be able to determine the level of charge of the battery in order for decisions to be made based on the battery's status and the amount of power that is required. The proportional relationship between the battery's nominal capacity Q and the charging current I_{bat} determines the ampere-hours that can be stored in a battery over some length of time t . The quantity of power that is available, the demand, and the SOC are the factors that decide how often the battery needs to be charged and discharged. When determining the energy restrictions of the battery, the state-of-charge limits of the battery are consulted.

$$SOC_{min} \leq SOC \leq SOC_{max} \quad \dots\dots(2.13)$$

Where SOC_{min} and SOC_{max} represent the lowest and highest levels of state of charge that are acceptable for the battery's safety. It should be noted that the model of the BSS converter is as follows:

$$\frac{V_b}{L_b} = \frac{dI_b}{dt} + U_3 \frac{V_{dc}}{L_b} - D_5 \quad \dots\dots(2.14)$$

$$\frac{dV_{dc}}{L_b} = U_3 \frac{I_b}{dt} - \frac{I_{ob}}{C_{dc}} + D_6 \quad \dots\dots(2.15)$$

Where, I_b denotes the current of the battery, V_b denotes the voltage of the battery, U_3 denotes the controller signal, D_5 and D_6 denotes dynamics uncertainty in the energy stage parameters.

III. WIND POWER GENERATION:

Horizontal axis wind turbines and vertical axis wind turbines are the two primary categories that make up the broader category of wind turbines. As seen in the illustration to the right, the blades of a machine with a horizontal axis rotate on an axis that is parallel to the ground. A machine with a vertical axis has its blades revolving about an axis that is perpendicular to the ground. There are a variety of different designs that may be used for either one, and each type has its own set of benefits and drawbacks. On the other hand, compared to the sort of machines that have a horizontal axis, there are very few vertical-axis machines that are offered commercially.

III.I. HORIZONTAL AXIS:

This type of wind turbine is by far the most prevalent design. The axis of rotation of the blades is, in addition to being parallel to the ground, parallel to the direction in which the wind is blowing. Some machines are built to run with the blades facing upwind of the tower, which is referred to as an upwind mode. In situations like this, a tail vane is typically utilised to ensure that the blades continue to face the direction of the wind. Other designs function in a mode called "downwind," which causes the wind to go around the tower before it hits the blades. A motor-driven mechanism is utilised in certain very large wind turbines.

This mechanism is responsible for turning the machine in response to a wind direction sensor that is positioned on the tower. Aero-turbine mills, which have an efficiency of 35%, and farm mills, which have an efficiency of 15%, are both common types of horizontal-axis wind mills.

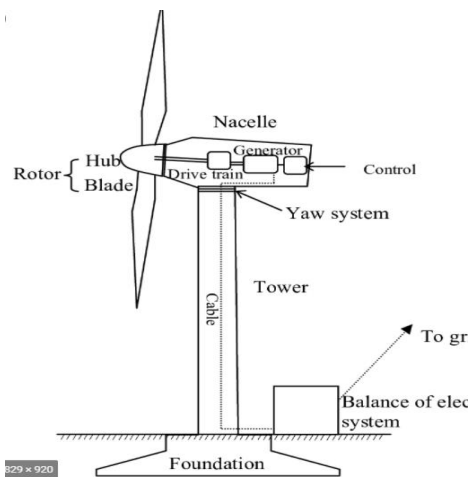


Fig 2.7. Horizontal axis

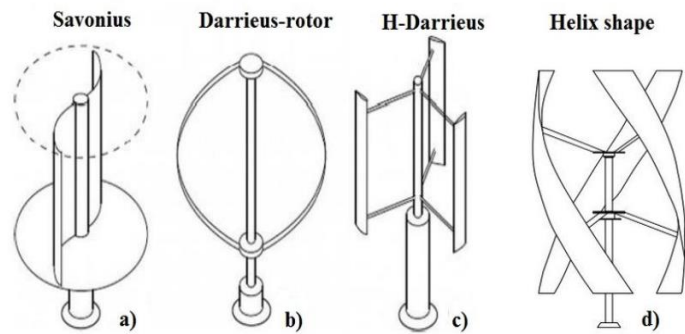


Fig 2.8. vertical axis

III.II. VERTICAL AXIS:

Even though they have been around for decades, wind turbines with a vertical axis are not nearly as prevalent as their horizontally oriented cousins. The primary reason for this is that vertical axis turbines are unable to capitalise on the greater wind speeds that can be found at greater heights above the earth in comparison to horizontal axis turbines. The Darrieus design, which has curved blades and an efficiency of 35%, the Giromill design, which has straight blades and an efficiency of 35%, and the Savonius design, which employs scoops to collect the wind and has an efficiency of 30% are the fundamental designs for vertical axis wind turbines. It is not necessary to orient a machine with a vertical axis with respect to the direction the wind is blowing.

Because the shaft is vertical, the transmission and generator may be positioned at ground level. This makes maintenance much simpler and allows for a tower that is both lighter and more cost effective. Even though they have these benefits, vertical axis wind turbines are not as effective as horizontal machine designs when it comes to gathering energy from the wind because of the way their blades are designed. There is one more kind of windmill, known as a cyclogyro windmill, that has an efficiency of roughly sixty percent. On the other hand, it is prone to instability and is extremely sensitive to changes in wind direction. The construction of it is likewise exceedingly difficult.

(a). WIND GENERATOR:

The PMSG receives its input of mechanical energy from the wind turbine whenever there is sufficient wind to drive the turbine. Through the production of AC voltage, it changes the form of mechanical energy into electrical energy. After being rectified, the AC voltage is converted into a DC voltage that is always 120V. The MPPT gathers information about the voltage and current and then generates a duty cycle with a predetermined pulse width to be used as input to the converter. The DC-DC converter brings the voltage down to 48V DC, and then it is given to a DC grid. The DC grid is connected to a battery to store energy, DC loads such as LEDs, electrical vehicle charging, etc., and an inverter is connected to the DC grid. The inverter converts the DC supply to a three-phase, 440V AC supply, which can then be connected to AC loads.

(i) PMSG:

We are utilizing the Permanent Magnet Synchronous Generator (PMSG), which has a permanent magnet serving as its stator. This will allow us to successfully complete the project. It does not require a separate DC excitation, there is no need for a slip ring, there is no loss of copper, and it does not have an issue with the frequency changing depending on the load. Other advantages include the absence of carbon brushes. Because there is no possibility of providing supply to the field winding, it can be employed in inaccessible locations.

(ii) WIND TURBINE:

Kinetic energy (E_k) produced by the wind turbine is given by

$$E_k = \frac{1}{2}mv^2 \quad \dots\dots\dots(2.16)$$

Where

$$m = \rho A_d$$

m = mass of the air

d = wind distance

C = density of air

A = area swept by rotor blade.

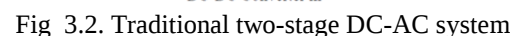
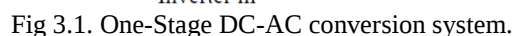
Wind turbine mechanical power (P_w) is given by

$$P_w = \frac{1}{2}\rho A d v^3 \quad \dots\dots\dots(2.17)$$



With the increasing demand of energy, microgrids are becoming a promising technology for integrating RESs [9]. Microgrids can operate at both grid-connected and stand-alone modes. There are two types of microgrids: AC and DC microgrids. AC microgrids are connected to the utility at the point of common coupling (PCC); DC microgrids can generate power from PV panels to some DC loads e.g. LED lighting [10]. But one of the biggest challenges of RESs is their uncertainty. This challenge will bring an adverse effect on microgrid control and operation. To avoid and mitigate this disadvantage, there are several ways to solve the problem. One solution is to develop a RES prediction system which will provide information on how much renewable energy can be expected at a given point in time [11]. A good renewable energy prediction method will help achieve grid stability [11]-[15]. The other solution is to add EESs, such as batteries, in the microgrid. This is called hybrid microgrids by combining DC and AC systems. Nowadays, hybrid microgrids are growing rapidly and widely applied in power systems, like residential areas. According to the power conversion stage, there are two solutions to integrate RESs of different types and capacities to a microgrid: a one-stage DC-AC system and a two-stage DC-DC-AC system.

Fig shows the configuration of this system, Due to this one stage of power conversion, this solution has high efficiency. However, in this solution, the double-line-frequency issue is inherited [16]. In one-stage DC-AC power conversion system, each source is directly connected to a DC-AC inverter. And then, the DC power from the renewable source will be converted to the AC required by the microgrid.



In a two-stage DC-DC-AC power conversion system, it consists of DC-DC converters and DC-AC inverters. First stage is a DC-DC converter which is used to step up the low time-variant voltage of each source to the high constant voltage. Second stage is DC-AC inverter to regulate the DC link voltage to AC for grid. There are two ways of this system. Fig.3.2. shows the traditional way that each source will connect to one DC-DC converter. Another way is using a multiport DC-DC converter to interface all the sources. Fig. 3.3. shows the multiport two-stage system. Compared to the traditional one, a multiport DC-DC converter has lower cost and higher power density. In this project, multiport DC-DC converters of different topologies are developed for the DC-DC-AC power conversion system.

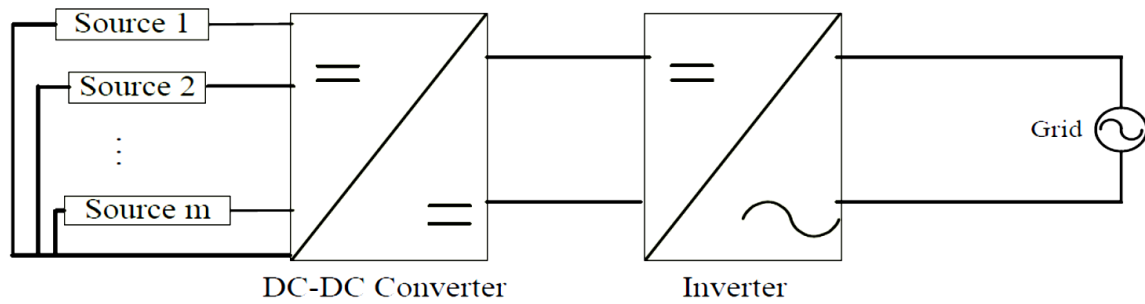


Fig 3.3 Multiport two-stage DC-AC system

3.3. MULTI-PORT CONVERTERS:

Nowadays, the commonly used RESs are wind energy and solar energy. The most promising device in ESSs is battery which will also be applied. The multiport converters which share some components have lower cost and higher efficiency than conventional ones. Therefore, in many applications, converters at least have three ports to integrate different types of energy sources to a power grid. The first stage multiport DC-DC converters can step up the low, time-variant voltage to high, constant voltage required by the AC side. The second stage is a grid-connected DC-AC inverter which can regulate the voltage from DC to AC.

The multiport DC-DC converter topologies can be classified into two categories: non isolated and isolated. Non isolated converters include various boost-type converters. Their voltage ratios can be further increased by using the cascaded or coupled-inductor technique. When the voltage regulation ratios are high, the isolated converters are preferable than non-isolated converters by properly designing the transformer's turn ratio. In addition, the isolated converters provide isolation between the input and output which is good for the safety. The main types of DC-AC inverters include single-phase and three-phase. Normally, three-phase systems are used when the electrical power is distributed to the industry or commercial buildings. Single-phase systems are used primarily in low voltages such as residential.

4. MODELING AND CONTROLLER DESIGN OF PROPOSED INVERTER:

Single-phase PV inverters have been widely installed in residential power systems to meet full or partial load demand. This work employs a typical topology with two-stage four-port converters. As shown in Fig. 5.1, the multiport converters consist of a boost DC-DC converter which interfaces with three ports, wind turbine, PV panel and batteries in first stage and a DC-AC inverter in second stage. The function of the boost converter is voltage amplification and maximum power point tracking (MPPT). After stepping up the time-variant, low-level source voltages to a constant high-level voltage which is required by the cascaded DC-AC inverter, the inverter can generate sinusoidal waveform then inject to the load or grid. The proposed DC-AC inverter is based on full-bridge with capacitor and inductors.

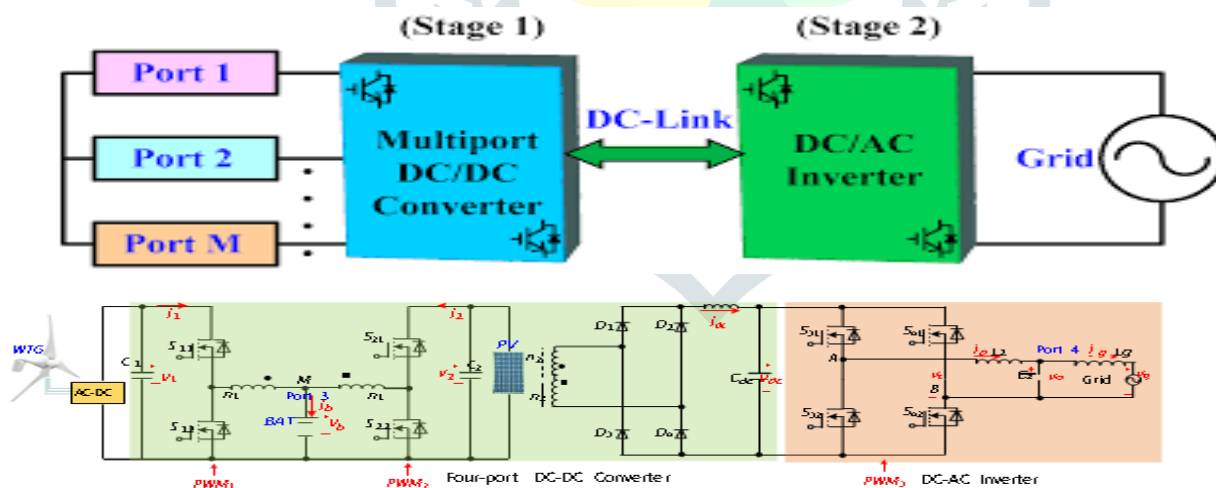


Fig. 4.1. Topology

Multi-port DC-DC converters are gaining more prominence in interfacing multiple sustainable energy sources, storage systems and loads with one integrated topology. They feature reduced size, lower cost, and better efficiency due to single power stage, faster response, and compact centralized control. This paper proposes a tapped boost derived DC-DC converter for interfacing a solar PV source, battery energy storage system and load. Multiport converters attracted in interfacing the independent energy sources utilized in grid-connected and electrical vehicle applications. Furthermore, compared this leads to; reduce the complexity and cost of the converter and higher power density. Therefore, MICs are a good choice for grid-connected systems, renewable energy sources (RESs), and EV applications to several separate DC-DC converters.

4.1 THE PROPOSED DC-AC INVERTER:

The proposed inverter designed in this work is single-phase based on full bridge with controllable switches and output filters. The full bridge is also known as H-bridge. It consists of four controllable switches like metal-oxide-semiconductor field effect transistor (MOSFET) or GaN board, capacitors, and inductors.

To avoid creating a short circuit of the DC source, the signals are generated in each leg of the bridge reversely. The bottom gate control is the inverse of the top, but the same to the top of the parallel leg. That means the signals of S31 and S32 in Fig. 5.1 are in complementary manner, but S32 and S41 are correspondingly same. But S31 and S32 are never closed at same time, otherwise it would cause a short circuit from V_{dc} to the ground. To avoid this shoot-through, a dead time is implemented in real switches. If the dead time is too long and the voltage loop decreases, it will cause the voltage loss and crossing zero distortion. In this work, 0.2 microseconds dead time is selected.

The gates of the H-bridge are driven by a PWM generator. The switching frequency f_{sw} of PWM signals is usually chosen as high as possible to reduce current ripple in the inductor. In this work, the period time of switching, i.e., T , is 10 microseconds. When the switches are on and off, the proportion of "ON" time to the period time is defined as duty cycle (d). If d_3 is defined as the ON time of S_{31} , then $v_A = v_{dc} \cdot d_3$, $v_B = -v_{dc} \cdot (1 - d_3)$. Therefore, the control voltage $v_c = v_{dc} \cdot (2d_3 - 1)$. Fig. 4.2 shows the drive waveform for four switches. To control the output voltage of inverter, we can control the duty cycle.

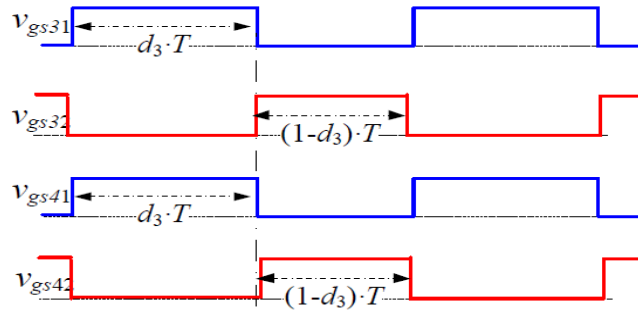


Fig. 4.2 Drive waveform for switches

Since the inverter requires an output filter to limit the high frequency current ripple, the LCL output filter is selected at grid-connected mode. For the standalone mode, the inverter will connect with the resistive loads. Fig. 4.4 shows the simplified circuits at two modes. Once one single-phase DC-AC inverter working well, parallel connected inverters can simulate the grid system. The inverters need to detect the voltage and frequency from the grid, then generate different output with power need. One inverter can be simulated as the source because of it's the stable output at standalone mode.

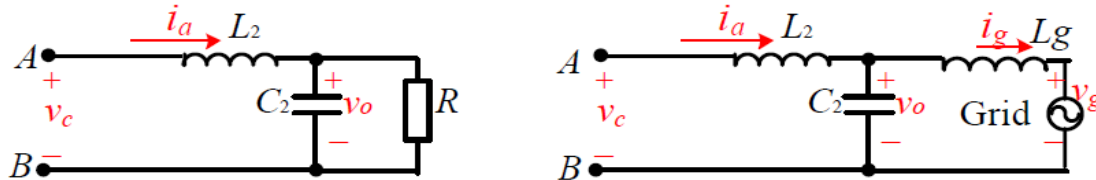


Fig 4.3. Simplified inverter circuits at standalone and grid-connected mode.

4.1.1 MODELLING OF PROPOSED INVERTER:

The main part of the whole work is modelling and designing the control method. How to design the controller is the key to the power electronics systems. Before designing the controller, the converter needs to be modelled. The most popular way of modelling is to use state space averaging method (SSAM) which is based on the small-signal model of the whole system. By using a formal method for deriving the small-signal AC equations of a switching converter, the differential equations in the different operation stages can be expressed. In addition, there are some computer programs existing which utilize the SSAM, example Matlab/Simulink.

As shown in fig 4,3, the state space models of inverter connecting with load R can be found as follows:

$$\begin{cases} v_c = v_o + L_2 \frac{di_o}{dt} \\ i_o = C_2 \frac{dv_o}{dt} + \frac{v_o}{R} \end{cases} \quad \dots\dots\dots(4.1)$$

where v_c is the control voltage of the H-bridge between nodes A and B; i_a is the current flowing through the inductor of L_2 ; v_o is the voltage of the inverter; r is the resistance of L_2 .

Then the small-signal model with $\dot{x} = A \cdot x + B \cdot u$ form can be expressed as follows:

$$\dot{x} = \begin{bmatrix} \frac{-r}{L_2} & \frac{-1}{L_2} \\ 1 & \frac{-1}{R \cdot C_2} \end{bmatrix} x + \begin{bmatrix} \frac{V_{dc}}{2} \\ 0 \end{bmatrix} u \quad \dots\dots\dots(4.2)$$

Here $A = \begin{bmatrix} \frac{-r}{L_2} & \frac{-1}{L_2} \\ 1 & \frac{-1}{R \cdot C_2} \end{bmatrix}$, $B = \begin{bmatrix} \frac{V_{dc}}{2} \\ 0 \end{bmatrix}$ where $x = [i_a, v_o]^T$ and $u = d_3$.

4.2. STANDALONE MODE:

Based on the modeling and controller designing, it's easy to build a simulation of the standalone inverter in Matlab Simulink.. In the, standard combination for voltage and frequency is 110 V (RMS value) and 50 Hz. Since the control of duty cycle, the reference value of DC link voltage is chosen as 190 V.

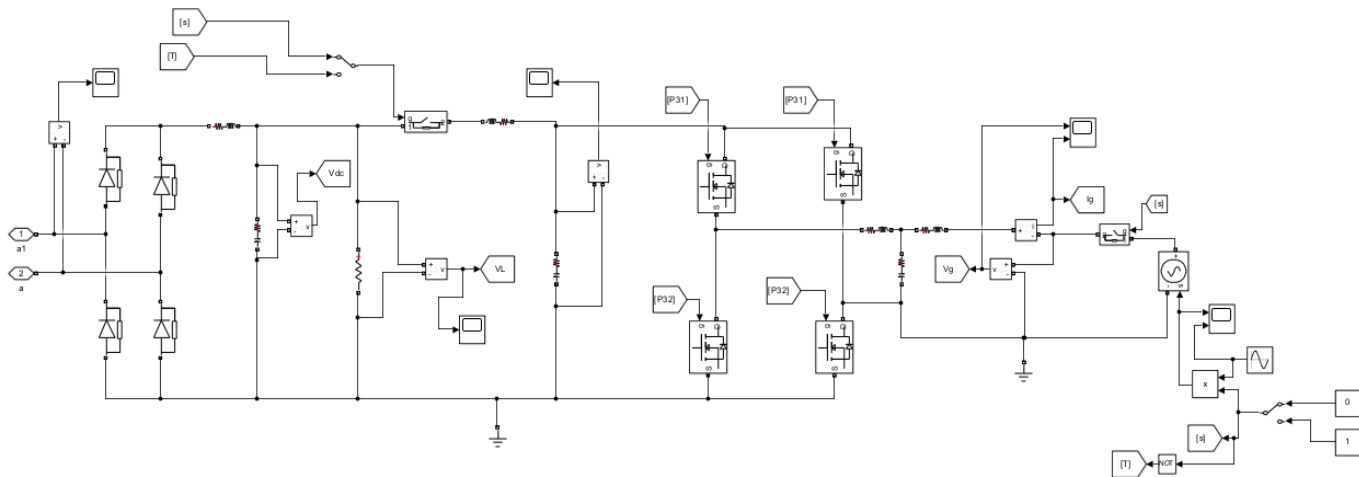


Fig 4.4. Simulation diagram of AC Grid system.

The power can be defined by setting the numbers of parallel strings and series- connected modules of per string. The input of sun irradiance and cell temperature can simulate the situation in real life. Standalone mode is a mode of operation where a device or application is able to function independently without requiring any external connectivity or support. It can operate without internet or network connectivity, and without the support of other devices or systems to perform its functions.

In standalone mode the output voltage from load side is Vdc i.e; 190V. The grid output voltage and current is zero.

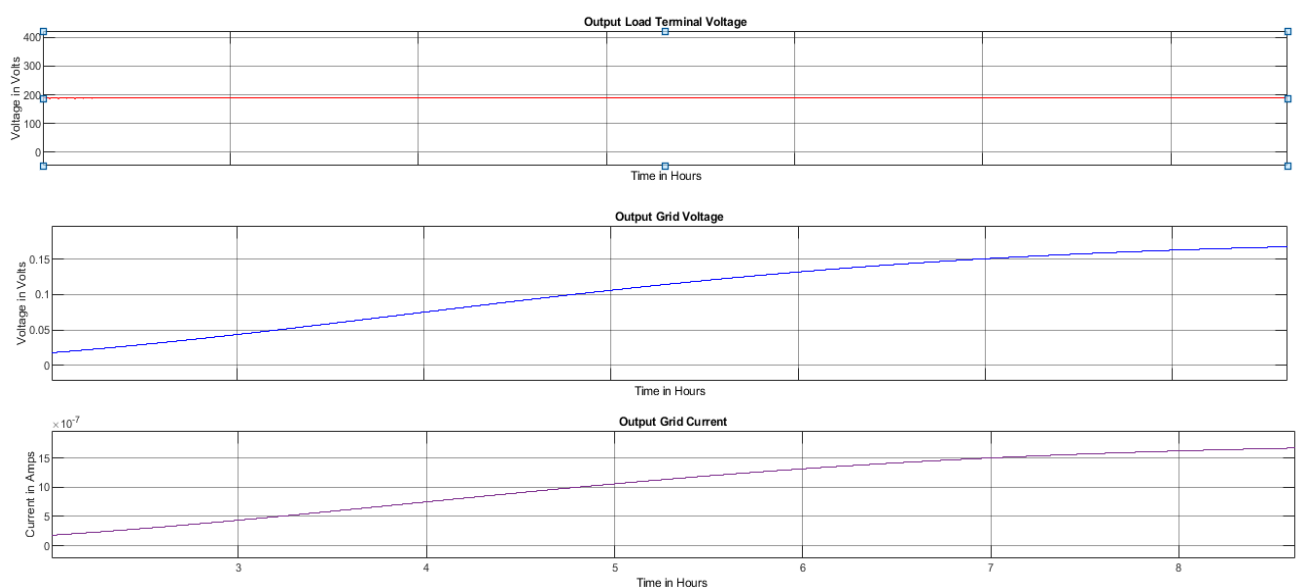


Fig 4.5 The Output Load Terminal Voltage of Standalone Mode Condition

In standalone mode the output voltage from solar is 200Volts DC. The output voltage from wind is 200Volts and finally the battery discharging is 203volts to 202volts.

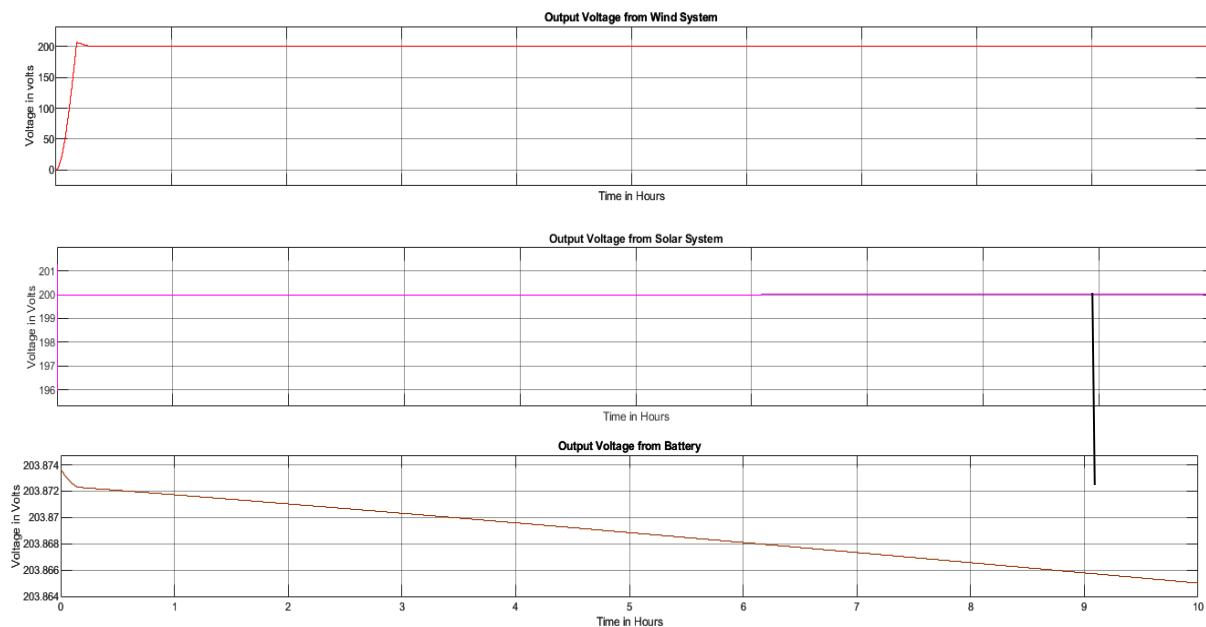


Fig 4.6. The Output Wind, Solar and Battery Voltages in Standalone Mode Condition

Both inverters supply the power to the load at the beginning, then one inverter is removed at $t = 0$. Therefore, $ig1 = 0$ and the current of the other inverter $ig2$ increases quickly to supply the load power. The DC-link voltage drops to 200 V and then goes back to normal. V_{dc} is still controlled to be 190 V.

4.3. GRID CONNECTED MODE:

Grid-connected mode refers to a type of power system where an electrical power source, such as a solar panel or wind turbine, is connected to the larger electrical grid. In this mode, the power generated by the renewable energy source is used to supply the electricity demands of the local area while any excess power is exported to the grid. This mode allows for efficient and sustainable use of renewable energy while still maintaining a stable and reliable electrical supply for the surrounding community.

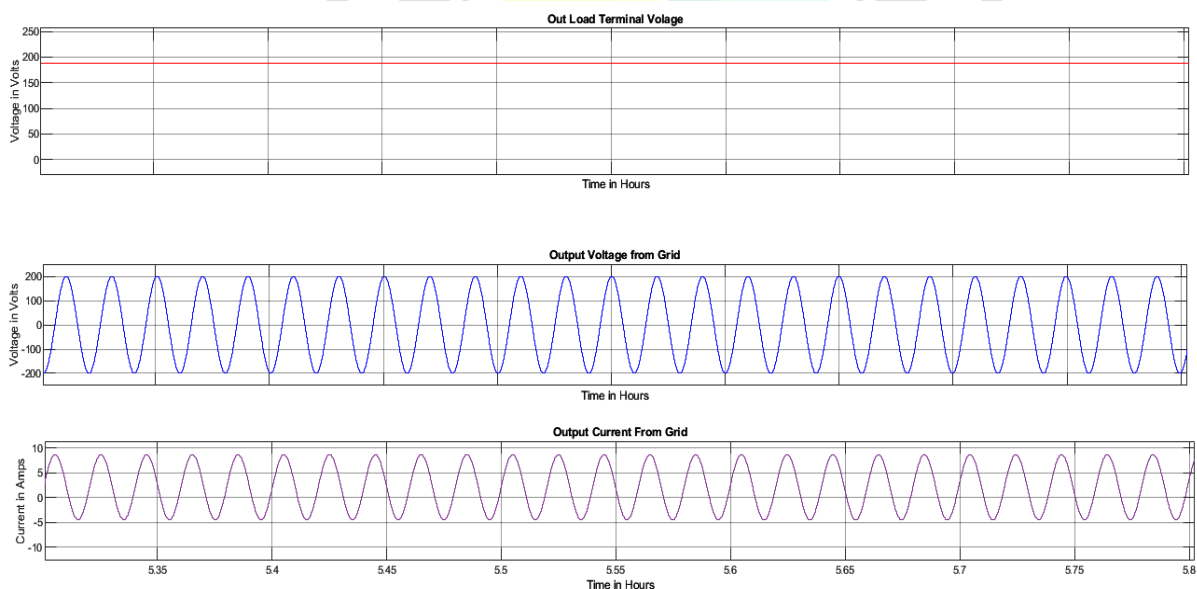


Fig 4.3 The Output Load terminal Voltage of Grid Connected Mode

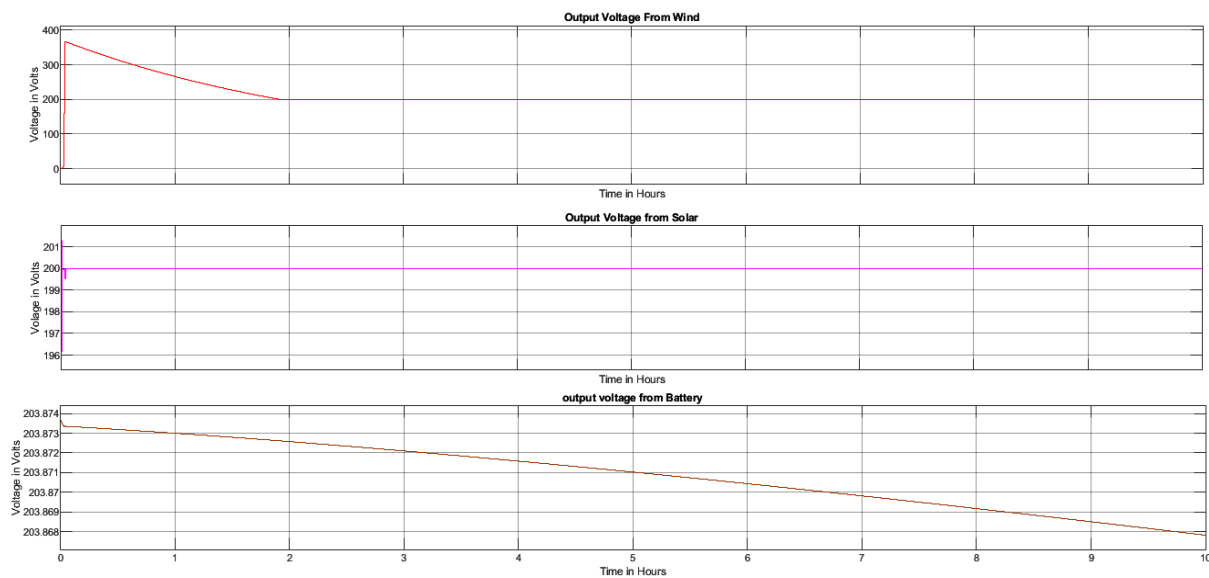


Fig 4.4 The Output Wind, Solar and Battery Voltages in Grid Connected Mode Condition

There are two parallel-connected converters, one is the multiport converter which connected with a PV simulator, a WTG simulated by two back to back connected electric machines, battery and the load; the other is a H-bridge inverter directly connected to a DC voltage source. The same droop controller is adopted in both inverters. The open-circuit voltage V_{oc} and the short-circuit current I_{sc} of the PV panel are 36.3 V and 7.35 A (at 25°C, 1 kW/m²) respectively, the nominal battery voltage is 200 V, and the output voltage of WTG is around 200 V, the reference DC link voltage V^*_{dc} is 190 V, and the switching frequency is 100 kHz. the steady-state waveform when the inverter works in the grid connected mode is shown in above fig 5.3 i_{g1} and i_{g2} are the output current of two parallel connected inverters. The output voltage is 200V with 50 Hz. The mean value of DC-link voltage V_{dc} is controlled to be 190 V. The currents are in phase with v_g and the magnitude is close, i.e., i_{g1} and i_{g2} which peak-to-peak values are 3.43 A and 3.46 A, respectively. This indicates two units are sharing power equally.

5. CONCLUSION:

The objective of this paper is to develop multiport converters for renewable energy integration and micro grid application. The proposed converters have the advantages of using less ports to integrate different types of renewable energy sources and working with and without the grid.

This project introduce the two-level control of a two-stage grid-tied four-port converter for micro grid with different energy sources.

At the converter level, PI controllers are designed to regulate the DC-link voltage and grid current based on the model derived in the d-q rotation frame; at the system level, Droop controller is used to distribute the power when the inverter relates to the grid. Simulation results show that with the two-level controllers, the converter can work and switching from grid-connected mode and the standalone mode.

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