Study of Micro Grid Topology and Design of Voltage Source Inverter and Charge Controller

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Abstract - *This paper deals with the study, design analysis, and implementation of laboratory scale Micro grid. The overall system is simulated by using MATLAB and results are used for hardware implementation of the proposed system. The overall scheme consists of PV panel, Wind Turbine, Battery Bank, Buck Converter, Inverter, Charge Controller and various electrical loads. The various electrical loads are fed through an Inverter.*

Micro grid can operate in two modes of operation. First is Islanding Mode and other is Grid connected mode. Here only Islanding mode is taken into consideration and further grid connected mode can be implemented using a Smart Switch and a suitable Transformer.

In the Micro grid, the Distributed Energy Resources(DERs) such as Wind Turbine, Solar PV panel, Diesel Generator set, Fuel cell units, Energy storage system and different loads are arranged as one unit connected to the Grid utility via Static Transfer Switch (STS). [1] All the DERs and variety of electrical loads which are located in close vicinity to each other and a battery bank are connected to a system via Power Electronic Interface. [2]

Key Words: **Micro Grid, Voltage Source Inverter, Charge Controller**

1. INTRODUCTION

Micro grid is operated in two modes viz. islanding or Stand-alone mode and Grid connected mode. In normal condition, the Micro grid is connected to a grid utility and operated in parallel with the grid. It exchanges the power according to the demand and supply. [7] But when fault occurs, the Micro grid transfers into Islanded mode of operation via STS and acts as Isolated Island. [1][7] In both the modes of operation, Micro grid should balance the power management. In Grid connected mode, the Micro grid exchanges the power to the grid and in islanding mode it should meet the power balance when there is load scheduling. [7]

The produced Electricity by a low power Wind Turbines and PV panels can be utilized in several purposes such as Clinics, Homes, Schools, Telecommunication towers etc. However the low output can be raised and a new solution of use DC-DC Buck Converter can make the output suitable to charge controller for making the system simple, robust, and cost effective. This ensures the generator works at maximum power or close to it. [4][5] The battery is fed through a suitable designed charge controller which controls the battery voltage and current up to its specified limit. It is specially designed for Solar and Wind hybrid system.

The Inverter employed is Voltage Source Inverter (VSI) and having PWM technique for controlling. When fault occurs, the STS open to isolate both the grids. i.e. Utility and Micro grid within a half frequency cycle. The DERs now have to fulfill the load requirement and to regulate the voltage regulation. The DERs should supply the continuous power to critical loads within the Micro grid and when fault is cleared, the Micro grid has to be resynchronized with utility grid before STS can reclosed to return smoothly back to the grid connected operation from Islanding mode. [2]

1.1 Desirable Features:

The desirable features of the proposed scheme are as follows:

- The Micro grid should perform both Grid connected and Islanding mode of operations satisfactorily.
- The working of STC should be proper.
- The charge controller should be able to control the battery voltage and battery current within its specified value.
- There should be control on power transfer in both Grid connected mode and Islanding mode.
- The Micro grid should be able to satisfy the load requirement when operated in only Islanding mode.

- The Power factor of the system should be as high as possible.
- The count of Total Harmonic Distortions (THD) should be as low as possible.

2. MICRO GRID

The proposed scheme consists of DERs such as Wind Energy and Solar PV panels, Power electronics devices, Energy storage elements such as Battery bank and various Loads. The loads are fed through a VSI and Micro grid is connected to a grid utility via a suitable Transformer and a STS.

The proposed topology has following distinctive features:

- Buck Converter match the voltage output from the low power wind turbine and low power PV panels at desired level of charge controller
- At normal condition the loads are fed from the utility grid.
- When fault occurs the load demand is satisfied by the DERs by using STS.
- VSI controls the power that is being transfers during both stand alone and grid connected operation.
- Battery bank improves the overall inertia of the system and also it helps in improving the system response during transient operations.

Following fig.1 shows the schematic block diagram of proposed work.

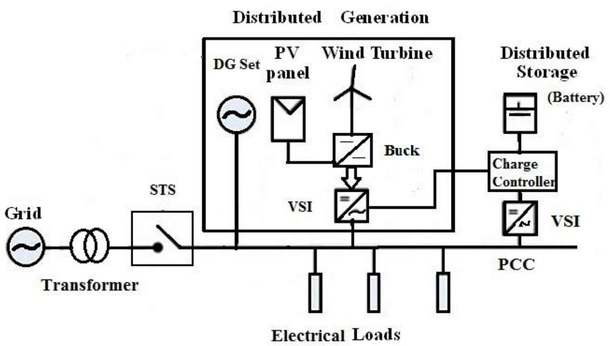

Fig -1: Block Diagram of Proposed Work

The Power Grid has become the most important infrastructure in 19th and 20th century. The economic growth of any country is significantly dependent upon the development of Power Grid. Traditionally it has been designed as hierarchical system with large generation facilities on the top and next the transmission and distribution network to distribute electrical energy to geographically dislocated end users. The control and communication in the whole Power Grid is done by Supervisory Control and Data Acquisition System (SCADA)[3]. Sometimes central approach of power grid leads to national power blackouts so there is need of intense solution for this. So such research technology has given birth to the concepts of Smart Grid concept. The term Smart Grid technology is used to identify the new scenario of power grid with the concept of decentralization in production, consumption as well as utilization of electrical energy. Now a days smart grid incorporating with new digital and advance intelligence devices to replace the old analog devices of power network to ensure the higher reliability and efficiency. Traditionally wire communication systems were employed but for this the system requires expensive communication cables to be installed and maintained regularly. So overall system was expensive.[3] But now the wireless monitoring improves the reliability and efficiency. However this needs the Trans Receivers (transmitters and receivers) to be displayed at different stages of power grid and this requires regular maintenance. Now recently the resources have focus on the development of autonomous micro grid environment with advantage of different resources and loads to interact the stabilization of common bus voltage magnitude and frequency without any communication. This is the Plug n Play operation approach. Most of Micro Grid loads are supplied by Diesel generator and renewable energy sources such as wind and solar to reduce the loading of Diesel Generator. The proposed scheme consists of DG set, Solar PV panel and wind turbine acting together for fulfill the load requirement.

The operating principle of each equipment's is shown in fig.1 is analyzed in following sections

2.1 WIND TURBINE

Wind is caused by-

- Heating and cooling of atmosphere which generates convection currents.
- The rotation of earth with respect to atmosphere and its motion around the sun.

The energy available in the wind is estimated as 1.6 X 107 Mw.

Like the weather in general, the wind can be unpredictable. It varies from place to place, and from moment to moment. Because it is invisible, it is not easily measured without special instruments. Wind velocity is affected by the trees, buildings, hills and valleys around us. Wind is a diffuse energy source that cannot be contained or stored for use elsewhere or at another time.

2.1.1 Classification:

1. Horizontal Axis: A horizontal axis machine has its blades rotating on an axis parallel to the ground.

2. Vertical Axis: A vertical axis machine has its blades rotating on an axis perpendicular to the ground.

2.1.2 Grid Connection:

Figure 2 shows how the grid connection is done.

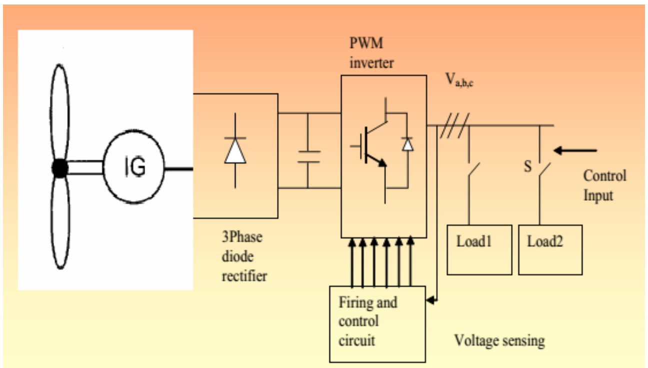

Fig -2: Grid connection of Wind Turbine

It has the following sections:

a) The rectifier.

b) The capacitor.

c) Switches.

d) Inductor.

The rectifier is required if the generated power is ac by alternator or induction generator. The capacitor is required to smooth the generated power. Switches are required to convert the power to ac to match the grid frequency. Inductors are required to develop the voltage.

3. SOLAR PV PANEL

3.1 Operating Principle

A photovoltaic cell is the basic device that converts solar radiation into electricity. It consists of a very thick n-type crystal covered by a thin n-type layer exposed to the sun light as shown in the following fig.3.

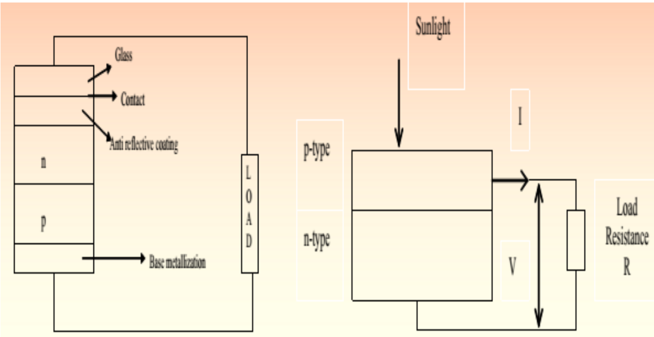

Fig -3: Operating Principle of PV Cell

A PV cell can be either circular in construction or square. Cells are arranged in a frame to form a module. Modules put together form a panel. Panels form an array. Each PV cell is rated for 0.5 – 0.7 volt and a current of 30mA/cm2.

Based on the manufacturing process they are classified as:

- Poly crystalline: efficiency of 12%.
- Amorphous: efficiency of 6-8% .

Life of crystalline cells is in the range of 25 years where as for amorphous cells it is in the range of 5 years.

3.2 PV module IV Characteristics

A PV cell behaves differently depending on the size/type of load connected to it. This behavior is called the PV cell 'characteristics'. The characteristic of a PV cell is described by the current and voltage levels when different loads are connected. When the cell is not connected to any load there is no current flowing and the voltage across the PV cell reaches its maximum. This is called 'open circuit' voltage. When a load is connected to the PV cell current flows through the circuit and the voltage goes down. The current is maximum when the two terminals are directly connected with each other and the voltage is zero. The current in this case is called 'short circuit' current. The graph between those is shown in fig.4. below.

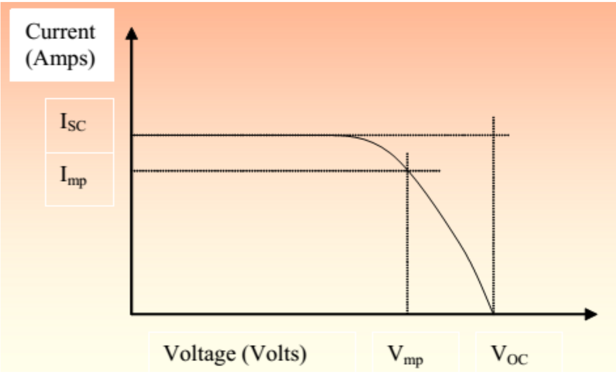

Fig -4: IV characteristics of PV panel

4. BUCK CONVERTER

The output of Wind Turbine and Solar PV panel is given to the charge controller via DC-DC buck Converter. It consists of passive Rectifier, converter DC-DC Buck [5]. The circuit diagram is as shown in fig.5.

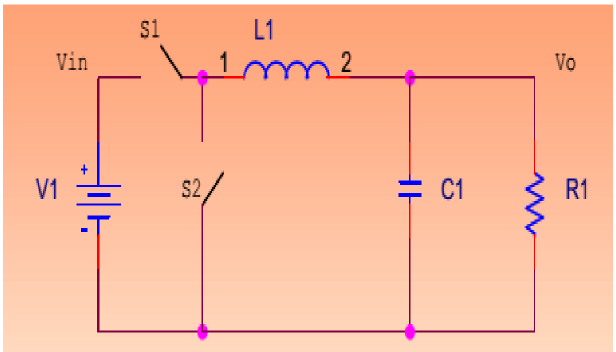

Fig -5: Circuit diagram of Buck Converter

This is a converter whose output voltage is smaller than the input voltage and output current is larger than the input current. The conversion ratio is given by the following expression

$$\frac{Vo}{Vin} = \frac{Iin}{Io} = D$$

Where D is the duty cycle. This expression gives us the following relationships:

$$Vin = \frac{Vo}{D}$$

$$Iin = IoD$$

Knowing Vin and Iin, we can find the input resistance of the converter. This is given by:

$$Rin = \frac{Vin}{Iin} = \frac{Vo/D}{IoD} = \frac{Vo/Io}{D^2} = \frac{Ro}{D^2}$$

Where R_0 is the output resistance or load resistance of the converter.

5. ENERGY STORAGE

Sizing of Battery:

Size of battery is classified in terms of charge it holds. The stored energy in a battery is given by the following expression,

$$Charge = \frac{Whr}{V} = Ahr$$

Since voltage is almost constant in a battery, Ampere-Hour is used as a basic unit in classifying a battery. Two terms one needs to know about battery are:

- Depth of discharge (DOD): Depth of charge withdrawal.
- State of charge (SOC): This is the amount of charge left in the battery.

6. VOLTAGE SOURCE INVERTER (VSI)

In most cases, local micro sources are connected to the grid through power electronic-based interfaces in order to achieve the required flexibility, as well as to insure its operation as a single aggregated system. Among such interface devices, the most used is the three-phase (or single-phase)PWM VSI, responsible for converting energy available in DC form to AC, as well as to enable the connection of diverse micro sources to the main grid. In grid-connected mode, the objective of the VSI is to control the output power of the inverter in order to follow an established reference (active and reactive power). This is achieved by controlling the output current of the inverter, since the output voltage is maintained by the bulk power system. [7]

A general overview of a VSI is shown in Fig.6. This structure represents a three-phase VSI connected to the utility grid through a third order LCL filter. In this case, the bulk power system is represented by an ideal balanced three-phase AC voltage source (representing an infinite bus). Another assumption of this model is that the DC side of the converter can be represented by an ideal DC voltage source. [7]

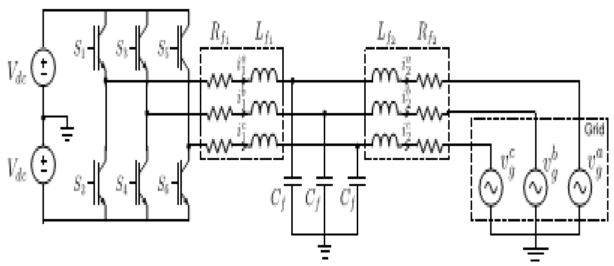

Fig -6: Overview of VSI

The output low-pass filter is employed to attenuate the inverter high frequency switching harmonics. An LCL filter is more adequate than a simple L filter in micro grid applications because, in addition to providing higher high frequency attenuation with the same inductance value, it is also suitable to inverter operation in both grid-connected and islanded modes [7].

7. CHARGE CONTROLLER

Charge Controller is the heart of Micro grid. It is required to monitor and control the power outgoing into and coming out of the battery. It must also manage the power generated by the solar panel and wind turbine to ensure it does not overcharge the battery. Voltage (V) and current (I) of the battery bank are controlled by the charge controller within specified limits of the preset values. It must also ensure that the connected loads do not over-discharge the battery; thereby damaging it. The actual block diagram is as shown in fig.7.

A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from batteries. It prevents overcharging and may prevent against overvoltage, which can reduce the battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ('deep discharging') a battery, or perform controlled discharges, depending on the battery technology, to protect battery life.

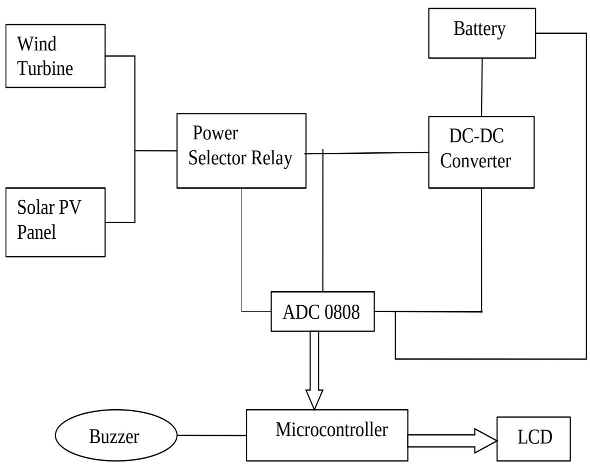

Fig -7: Block Diagram of Charge Controller

The most basic function of the charge controller is to prevent battery overcharging. If battery is allowed to routinely overcharge, their life expectancy will be dramatically reduced. A charge controller will sense the battery voltage, and reduce or stop the charging current when the voltage gets high enough. This is especially important with scaled lead acid battery where we cannot replace the water that is during the overcharging. Unlike Wind or Hydro system charge controller, PV charge controller can operate the circuit when the battery is full without any harm to the modules. Most PV charge controller simply opens or restricts the circuit between the battery and PV array when the voltage rises to a set point. Then, as the battery absorbs the excess electrons and voltage begins dropping, the controller will turn back ON. Some charge controllers have these voltage points factory preset and non-adjustable, other controllers can be adjustable.

8. MATLAB SIMULATION

8.1 MATLAB Simulation model for single phase PWM Inverter.

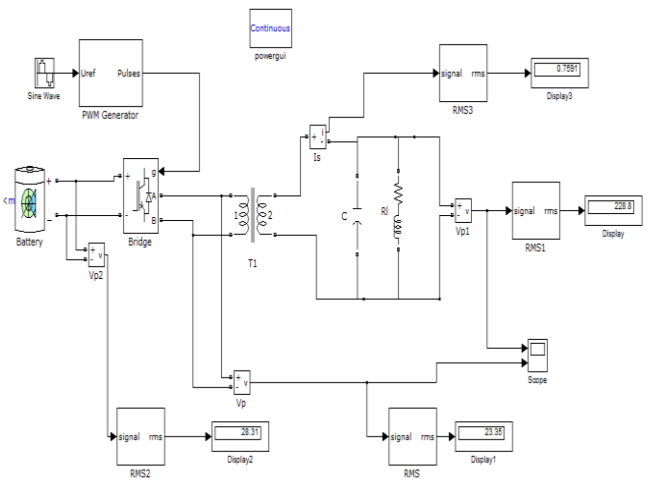

Fig -8: MATLAB simulation model of VSI

Configuring Parameters:

- Lead acid type Battery

  Nominal Voltage = 24 V

  Rated Capacity = 180Ah

- Universal Bridge

  IGBT as a Switch

- Transformer

  Nominal Power and frequency = 1kVA, 50Hz

  Winding 1 Vrms = 24V (DC)

  Winding 2 Vrms = 230V (AC)

- Capacitor

  10 Micro Farad.

- Load

Result:

The output voltage and PWM generation waves are shown in figure 9.

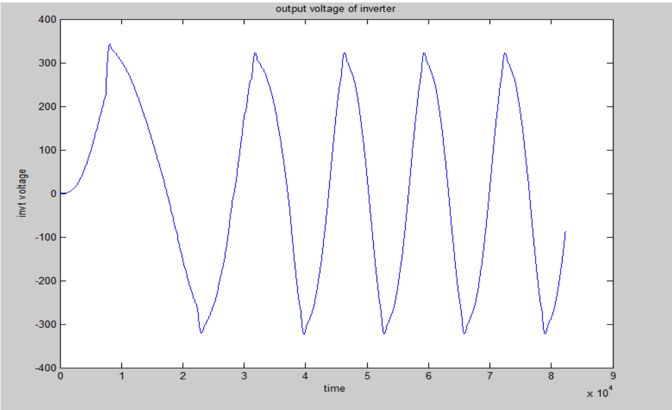

Fig -9 Output voltage and PWM generation waves

8.2 MATLAB Simulation model for Charge Controller.

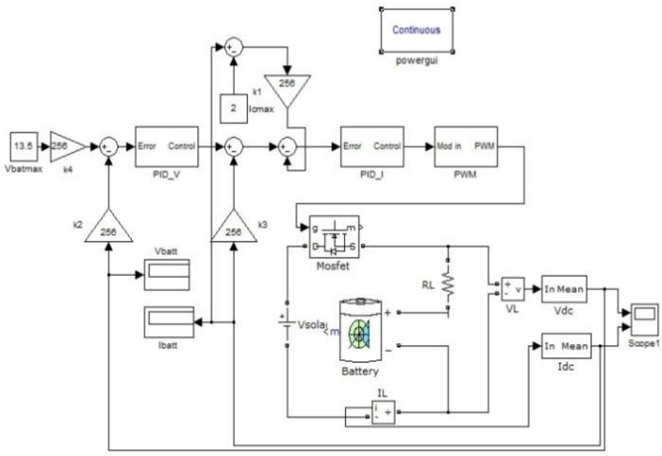

Fig-10: MATLAB simulation model of Charge Controller

Result:

The output voltage and current of charge controller are shown in figure 10.

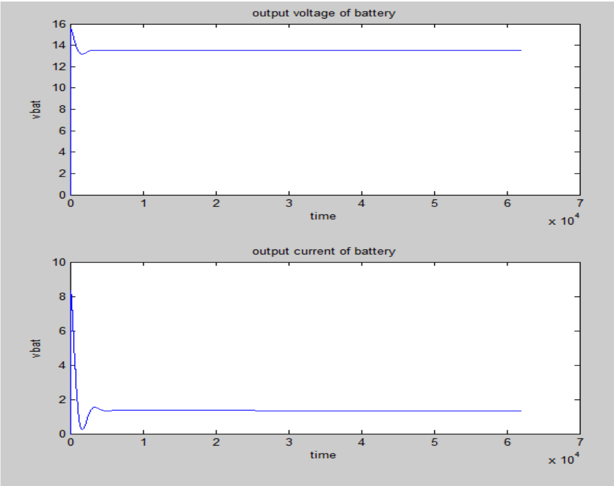

Fig -10 Output voltage and current of Charge Controller

CONCLUSION

Micro grid technology is implemented with the DERs such as Wind Turbine, Solar PV panel, Diesel Generator sets etc. by the design of charge controller and Voltage Source Inverter it is possible to use the flexible Micro grid technology for domestic, commercial and industrial purpose. This is advanced technology which is one kind of smart grid which is beneficial to share the load demand because now a days it is very important to meet the required load demand.

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BIOGRAPHIES

Priyanka Shintre is perusing post graduate in Electrical Power system from Shivaji University Kolhapur. She has completed her B.E. in Electrical Engineering with First Class with distinction from same University in 2014. This work has been carried out as a PG research scholar. Her areas of interest are Power System and Power electronics.

Dr. Anwar M. Mulla has 19 years of experience in teaching. He is Ph.D. in Electrical Engineering. He has graduated from Government college of Engg. Karad (India), and post graduated in Electrical Power systems from Walchand College of Engineering Sangli. His research interests include High Voltage Engg, Renewable Energy sources and Applications, Instrumentation and control. He has published 10 research papers in reputed International and National Journals, Conferences. Presently he is working as Principal, ADCET Ashta, India.