Pv Powered –Power Electronics Based Energy Management System

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Abstract- *This paper deals with the energy management system. Since energy savings and energy efficiency have become top priorities, this EMS includes battery and VSI which can be controlled as both voltage source and current source depending on the status of the ac grid and user's preference. This paper is to be implemented by comparing the performance of Solar PV Panel instead of battery which has more reliability and efficiency. The energy management system guarantees that the critical loads are powered when the ac grid fails in which case; the VSI is controlled as a voltage source. It also accomplishes peak power control by supplying the power to the local loads while they are powered by the ac grid if the loads get large.*

Keywords- Energy management systems (EMS), energy storage, peak power control, voltage source inverters (VSI).

I. INTRODUCTION

Sun is the source of all energies on earth. All living beings on earth rely on solar energy for their survival. The solar energy is of many forms on earth such as fossil fuels, plants, etc., and is being used by the human beings for different purposes. The fuel that is required for transport, industries as well as for domestic purposes is mainly from fossil fuels such as coal and petroleum. They are being used since from years and this lead to heavy pollution of the environment and also these sources are about to extinct.

The renewable sources such as wind (kinetic energy of air); solar (irradiation) are replacing the fossil fuels in the generation of electricity and also other needs. The solar energy is converted to electrical energy with the help of solar cell that works on the principle of photovoltaic effect. The PV device directly converts the incident solar radiation into electrical energy without any form of disturbance to the environment. The wind energy also generates electricity using different types of turbines.

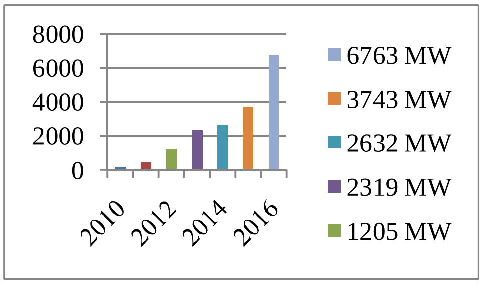

Fig.1 Installed solar PV plants

1.1 SOLAR PV SYSTEMS

French physicist, Edmund Becquerel, was the one to note the photoelectric effect back in 1839. He found that certain materials have property to produce small amounts of electric current when exposed to sunlight. In 1905, Albert Einstein described the nature of light and the photoelectric effect which has become the basic principle for photovoltaic (PV) technology. The first photovoltaic module was built by Bell Laboratories in 1954.

PV cell is basically semiconductor diode. This semiconductor diode has a p-n junction is exposed to light, illuminated by sunlight it generates electric power. PV cells are made up of various semiconductor materials. But mono-crystalline silicon and poly-crystalline silicon are mainly used for commercial use

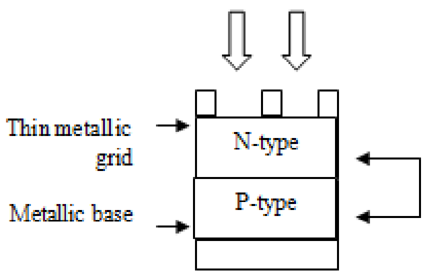

Fig .2 Basic PV cell structure

1.2 PHOTO VOLTAIC MODULE:

The power produced by a single PV cell is not enough for general use. So by connecting many single PV cells in series (for high voltage requirement) and in parallel (for high current requirement) can get us the desired power. Generally a series connection is chosen. This set of arrangement is known as a module. Generally commercial modules consist of 36 or 72 cells. The modules consist of transparent front side, encapsulated PV cell and back side. The front side material is usually made up of low-iron and tempered glass. The efficiency of a PV module is less than a PV cell. This is due to the fact that some radiation is reflected by the glass cover and frame shadowing.

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 a single module is seldom enough for commercial use. So modules are connected to form array to supply the load. The connection of the modules in an array is same as that of cells in a module. Modules can also be connected in series to get an increased voltage or in parallel to get an increased current. In urban uses, generally the arrays are mounted on a rooftop. In agricultural use, the output of an array can directly feed a DC motor.

1.3 WORKING OF PV CELL

Working of a PV cell is based on the basic principle of photoelectric effect. Photoelectric effect can be defined as a phenomenon in which an electron gets ejected from the conduction band as a consequence of the absorption of sunlight of a certain wavelength by the matter (metallic or non-metallic solids, liquids or gases).

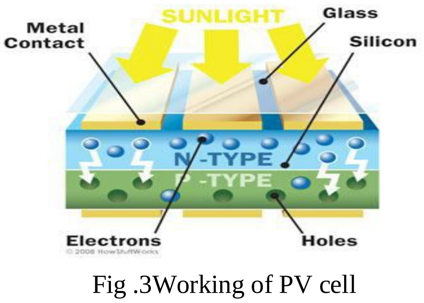

Fig .3Working of PV cell

So, in a photovoltaic cell, when sunlight strikes its surface, some portion of the solar energy is absorbed in the semiconductor material. If absorbed energy is greater than the band gap energy of the semiconductor, the electron from valence band jumps to the conduction band. By this, pairs of hole-electrons are created in the illuminated region of the semiconductor. The electrons thus created in the conduction band are now free to move. These free electrons are forced to move in a particular direction by the action of electric field present in the PV cells. These flowing electrons constitutes 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.

1.4 CHARACTERISTICS OF A PV CELL

In a PV characteristic there are basically three important points open circuit voltage (OCV), short circuit current (SCC) and maximum power point (MPP).

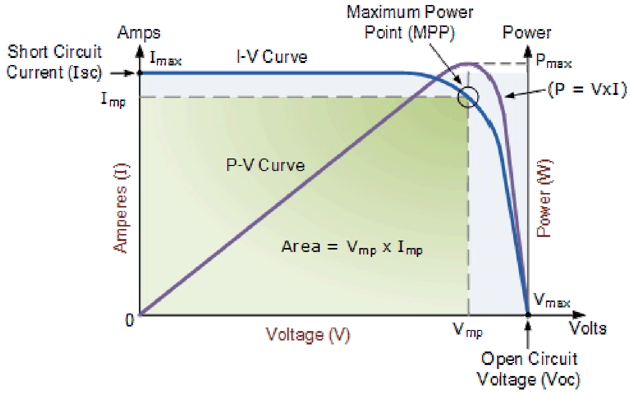

Fig .4 Characteristics of a PV cell (Both I V and P V)

The maximum Power that can be extracted from a PV cell is at the maximum power points. Usually manufacturers provide these parameters in their datasheets for a particular PV cell or module. By using these parameters one can build a simple model but for more information is required for designing an accurate model.

1.5 MAXIMUM POWER POINT OF SOLAR CELL

The maximum electrical power one solar cell can deliver at its standard test condition. If we draw the V-I characteristics of a solar cell maximum power will occur at the bend point of the characteristic curve. It is shown in the V-I characteristics of solar cell by PM.

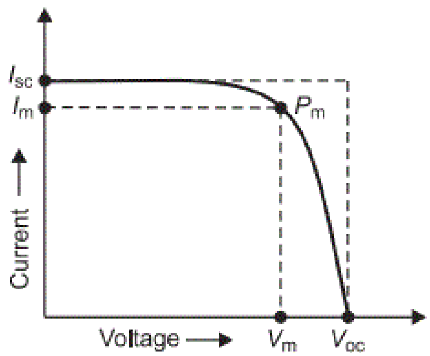

Fig.5 I-V characteristics of Solar cell

II. ENERGY MANAGEMENT SYSTEM

Energy savings and energy efficiency have become top priorities all around the world. Additionally, energy security is a necessity for many installations such as military bases and health care facilities where reducing energy consumption must be accomplished while keeping critical electrical loads serviced at all the times. Energy management system is presented to accomplish peak power control in a single phase power system while considering the continuous service to critical loads at the same time. This peak power control is also known as peak shaving, is a method to reduce electricity charges for users with the time of use (TOU) contracts and those who pay for the demand charges.

This EMS can be very useful in grid connected systems where there is a limit on the user's power consumption and it can also manage the energy stored and energy drawn from the grid to reduce consumption when the power rates are higher. The power system need to be a micro grid, meaning that distributed generation does not need to be a part of the power system. However if the DG units such as PV panels or diesel generators, are part of the installation of EMS can manage these resources .Another innovative feature of the EMS which is presented is the use of a single off-the-shelf three leg integrated power module to accomplish all the required tasks including battery charging peak shaving , and fault tolerance .

2.1 ENERGY STORAGE:

Energy storage is the capture of energy produced at one time for use at a later time. A device that stores energy is sometimes called as an accumulator or a battery. Energy comes in multiple forms including radiation, chemical, gravitational potential, electrical potential electricity, elevated temperature, latent heat and kinetic. Energy storage involves converting energy from forms that are difficult to store to more conveniently or economically storable forms. Bulk energy storage is currently dominated by hydroelectric dams, both conventional as well as pumped. The continuous increase in the electrical energy with the clean environment needs the decentralized renewable energy production. The increasing energy consumption may overload the distribution grid as well as power station and may cause the negative impact on power availability, security and quality. The only solution to overcome this problem is integrating the utility grid with the renewable energy systems like solar, wind or hydro. The grid can be connected to the renewable energy system as per the availability of renewable energy sources. Recently the solar power generation systems are getting more attention because solar energy is abundantly available, more efficient and more environment friendly as compared to the conventional power generation systems such as fossil fuel, coal or nuclear.

The PV systems are still very expensive because of higher manufacturing cost of the PV panels, but the energy that drives them -the light from the sun- is free, available almost everywhere and will still be present for millions of years, even all non-renewable energy sources might be depleted. One of the major advantages of PV technology is that it has no moving parts. Therefore, the PV system is very robust, it has a long lifetime and low maintenance requirements. And, most importantly, it is one solution that offers environmentally friendly power generation.

2.2 PEAK POWER CONTROL:

Residential and commercial TOU electricity rates include different rates at different time of the day (such as on-peak and off-peak) and also demand charges. Demand charges are based on the customer's peak demand on a given month, usually averaged over a 15-min period TOU rates are devised by the power companies to encourage customer to shift their loads away from the peak demand times and in general reduce their peak power consumption. The ideal customer would draw constant power at all hours of the day. Reducing the peak Power consumption results in significant cost savings. Peak shaving is a known technique used to achieve this objective by use of stored energy. Electrical energy is stored during the times when electricity cost is lowest (typically at night) and used during the times when electricity cost is highest, in order to reduce the overall electricity charges. While it may not be cost effective to acquire a battery pack with the sole purpose of peak shaving, if storage is part of an existing EMS installed to improve the reliability of the local power system, then using it to accomplish peak shaving is very cost effective.

III. BLOCK DIAGRAM

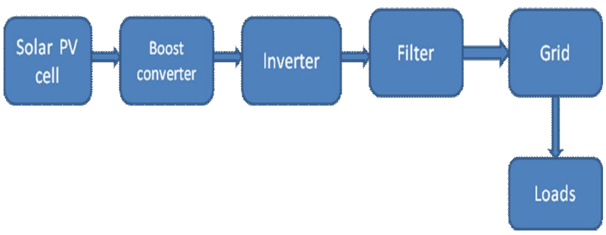

Fig.6 Block diagram of EMS

The above Proposed System is to be implemented by considering the performance and additional properties of Solar PV over DC Battery. By using PV panel, we can directly convert sunlight into Electricity without using any other conversion techniques. We have many advantages of a solar PV over a dc battery which includes size, life span and Energy Storage System.

In order to get better efficiency of usage the above existing system is to be modified by replacing the battery with Solar PV panel. Photo Voltaic cell is a component which converts sunlight directly into electricity. Solar cells are made from semiconducting materials such as silicon. When PV cells assembled they form a PV module or panel and installation of panels is called PV array. We get dc voltage or power from PV panel.

3.1 BOOST CONVERTER:

A Boost Converter (step-up converter) is a DC-to-DC power converter steps up voltage (while stepping down current) from its input (supply) to its output (load). Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A boost converter is a DC to DC converter with an output voltage greater tha L source voltage.

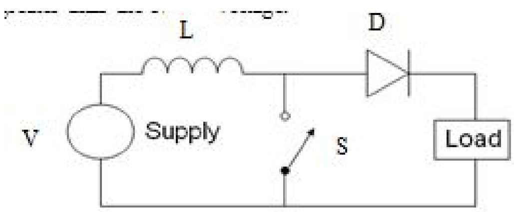

Fig.7 Basic diagram of Boost Converter

Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step up converter since it "steps up" the source voltage.

3.2 WORKING PRINCIPLE:

The basic principle of a Boost converter consists of 2 distinct states;

In the On-state, the switch S (see figure 8) is closed, resulting in an increase in the inductor current;

In the Off-state, the switch is open and the only path offered to inductor current is through the Fl The basic principle of a Boost converter consists of 2 distinct states (see figure 9)

- In the On-state, the switch S (see figure 8) is closed, resulting in an increase in the inductor current;
- In the Off-state, the switch is open and the only path offered to inductor current is through the flyback diode D, the capacitor C and the load R. These results in transferring the energy accumulated during the On-state into the capacitor.
- The input current is the same as the inductor current as can be seen in figure 9. So it is not discontinuous as in the Buck converter and the requirements on the input filter are relaxed compared to a buck converter.
- Fly back diode D, the capacitor C and the load R. These results in transferring the energy accumulated during the On-state into the capacitor.

The input current is the same as the inductor current as can be seen in figure 9. So it is not discontinuous as in the buck converter and the requirements on the input filter are relaxed compared to a buck converter. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field.

In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in Figure 8.

a) When the switch is closed, electrons flow through the inductor in counter-clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.
b) When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch. The switch must of course be opened again fast enough to prevent the capacitor from discharging too much.

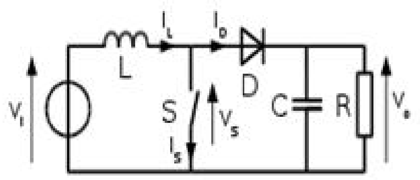

Fig.8 schematic diagram of boost converter

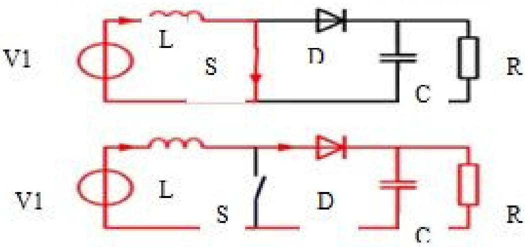

Fig.9 operational diagrams of boost converter during ON &OFF periods

IV. VOLTAGE SOURCE INVERTER

The simplest dc voltage source for a VSI may be a battery bank, which may consist of several cells in series parallel combination .Solar PV cells can be another dc voltage source. A dc voltage supply, after rectification into dc will also qualify as a dc voltage source .A voltage source is called stiff, if the source voltage magnitude does not depend on load connected to it. All voltage source inverters assume stiff voltage supply at the input.

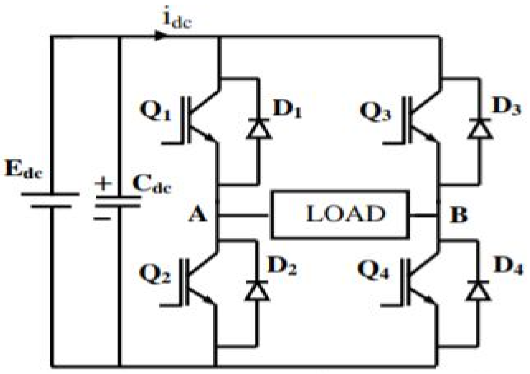

Fig. 10 Topology of a 1-phase full bridge VSI

The above fig. represents the topology of a single phase half bridge VSI. The topology requires only a single dc source and for medium output power applications the preferred devices are n-channel IGBTs .Edc is input dc supply and a large link capacitor Cdc is put across the supply terminals. Capacitors and switches are connected to dc bus using short leads to minimize the stray inductance between the capacitor switches. Need is say that physical layout of positive and negative bus lines is also important to limit stray inductances. Q1, Q2, Q3 etc. are fast and controllable switches. D1, D2, D3 etc. are fast recovery diodes connected in anti parallel with the switches. 'A','B' and 'C' are output terminals of the inverter that get connected to the ac load. If the dc input is a voltage source, then the inverter is called as a voltage source inverter. It is the one, in which the dc input voltage is essentially constant.

It consists of one dc voltage source, transistors for switching and one large dc link capacitor. Some examples where voltage source inverters are used are uninterruptable power supply units, adjustable speed drives for ac motors, electronic frequency changer circuits etc .Most of us are also familiar with commercially available inverter units used in homes and offices to power some essential ac loads in case the utility ac supply gets interrupted. In such inverter units battery supply is used as a input dc voltage source and the inverter circuit converts the dc into ac voltage of desired frequency. IGBT switches are easier to use, are much faster and are available in higher voltage and current ratings.

V. PULSE WIDTH MODULATION

Generally the output voltage of VSI is not controlled & containing harmonics.PWM is a technique is used as internal voltage control of inverter output so that there is no need of extra circuits. In this method a fixed voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting on and off periods of the inverter component.

5.1 WORKING PRINCIPLE:

Pulse-width modulation uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform. If we consider a pulse waveform $f(t)$, with period T, low value y_{min}, a high value y_{max} and a duty cycle D (see figure 1), the average value of the waveform is given by:

$$y = \frac{1}{T}\int_0^T f(t)\,dt.$$

$$\bar{y} = \frac{1}{T}\left(\int_0^{DT} y_{max}\,dt + \int_{DT}^{T} y_{min}\,dt\right)$$

$$= \frac{D \cdot T \cdot y_{max} + T\,(1-D)\,y_{min}}{T}$$

$$= D \cdot y_{max} + (1-D)\,y_{min} \quad 3$$

This latter expression can be fairly simplified in many cases where $y_{min} = 0$ as $\bar{y} = D \cdot y_{max}$. From this, it is obvious that the average value of the signal is directly dependent on the duty cycle D.

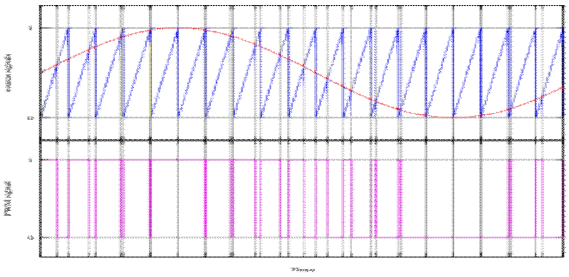

Fig.11 PWM pulse

The simplest way to generate a PWM signal is the interceptive method, which requires only a saw tooth or a triangle waveform (easily generated using a simple oscillator) and a comparator. When the value of the reference signal (the red sine wave in figure 11) is more than the modulation waveform (blue), the PWM signal (magenta) is in the high state, otherwise it is in the low state.

The PWM is a technique which is used to drive the inertial loads since a very long time. The simple example of an inertial load is a motor. Apply the power to a motor for a very short period of time and then turn off the power: it can be observed that the motor is still running even after the power has been cut off from it. This is due to the inertia of the motor and the significance of this factor is that the continuous power is not required for that kind of devices to operate. A burst power can save the total power supplied to the load while achieving the same performance from the device as it runs on continuous power.

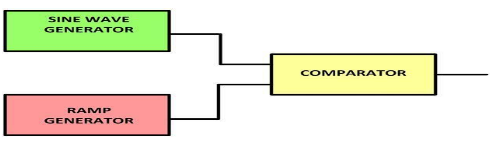

Fig.12 PWM Block diagram

6.4 EMS BLOCK DIAGRAM:

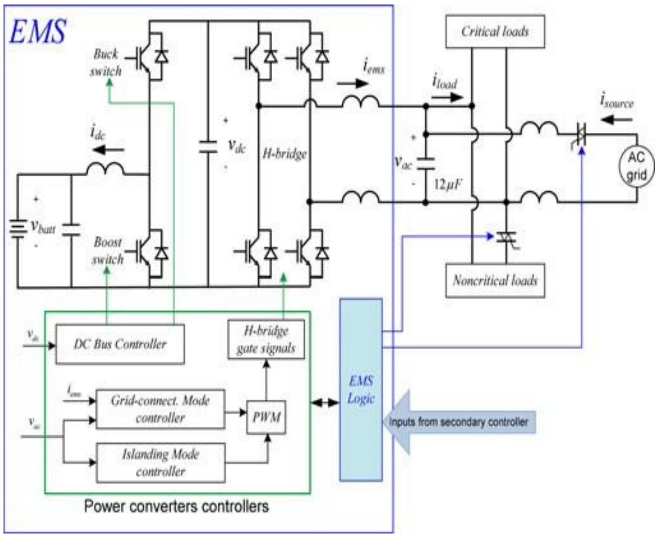

Fig.13 Energy management system architecture

Usually this Energy management system is presented to provide a continuous power supply to the critical and non critical loads in case of ac grid failure at all the time without any interruption. Whenever the ac grid gets failed, the EMS gets operated with the continual action where there will not have disturbance in the power supply to the loads. Critical loads are those loads that must be powered at all times because they are critical to the mission.

Non critical loads are connected in parallel to vac, however, they can be shed when necessary using a thyristor switch. This increases the control of the power that can be directed to the critical loads when necessary. The ac grid can also be disconnected from vac if needed to island the operation of the EMS. Typically islanding mode occurs when the ac grid fails. In this mode of operation, power to critical loads is guaranteed by drawing energy from the battery pack. So in order to have more energy storage and to supply more power, Solar PV is introduced in place of battery where power to the loads will be guaranteed by drawing energy from the Solar PV cell.EMS can also ensure power to critical loads is maintained during a fault by managing energy storage.

5.2 EMS CONTROL SYSTEMS:

It is important to distinguish the different levels of control for the EMS. The primary control system includes the power converter module controllers, which generate the gate drive signals given reference voltages and currents. The secondary control system is a higher level controller, which can include the user input and makes decisions based on factors such as battery state of charge and lifetime, cost of electricity, time of day, load priority, etc.

Islanding or stand-alone mode occurs when the ac grid is reenergized or the EMS is disconnected from the ac grid. The control algorithm for this mode of operation is shown in Fig..The amplitude of the ac voltage, vac, is set to 110 Vrms. The electrical angle, θ, identified by integrating the angular frequency, which is set to 60 Hz. Unipolar pulse width modulation (PWM) is used to drive the H-bridge IGBTs. This open-loop control algorithm does not compensate for RMS output voltage deviations or provide any active damping but these capabilities are easily implemented as required.

5.3 DC BUS ALGORITHM:

The dc bus that powers the H-bridge and the buck–boost switches is controlled as shown in Fig. Only one IGBT is modulated at any given time so that when the buck or boost converter is in discontinuous conduction mode, the current does not cross zero. This improves the efficiency compared to driving both switches all the time. Whenever battery charging mode is chosen, current is injected into the dc bus by the H-bridge and the dc-bus controller operates in buck mode to deliver the energy to the battery pack. When the EMS is in current injection mode, the power delivered to the ac bus is drawn from the dc bus and the dc-bus controller operates in boost mode to hold the dc bus up using battery power. The IGBT module that is being used has charge pumps to provide energy to the IGBT gate drives. This is a significant simplification and cost saving feature of the power module. In order to energize the buck switch for battery charging, the boost switch must first be exercised to pump charge into the upper IGBT gate drive circuit. This is accomplished in about 500 µs just prior to charging mode.

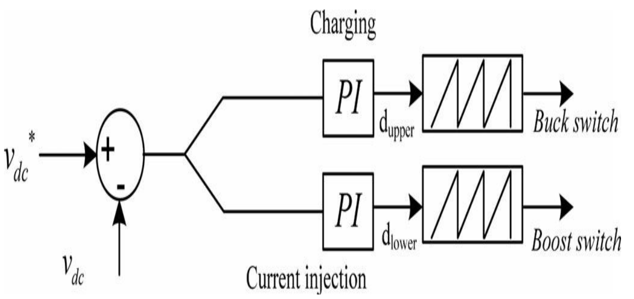

Fig.14 Dc bus algorithm

6.6 EMS Powering Critical Loads When the AC Grid Fails-Islanding Mode Of Operation:

In order to provide power to critical loads when the ac grid fails, the EMS detects grid failure and acts as a voltage source for the critical loads. In this mode of operation, noncritical loads can be shed depending on the state of charge of the batteries and other factors determined by the user or by the secondary control system. Noncritical load shedding is easily accomplished by the EMS by opening the thyristor switch connected to the noncritical loads. When the ac grid is available again, and then the EMS restores the loads to the ac grid, therefore, terminating the islanding mode of operation. At this point, if non critical loads had been previously disconnected they can be restored as determined by the secondary control system. The secondary control system determines if the EMS should try to reconnect to the ac grid or not.

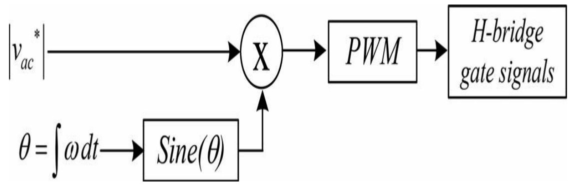

Fig.15 Control Algorithm for islanding mode

VI. SIMULATION CIRCUITS & RESULTS

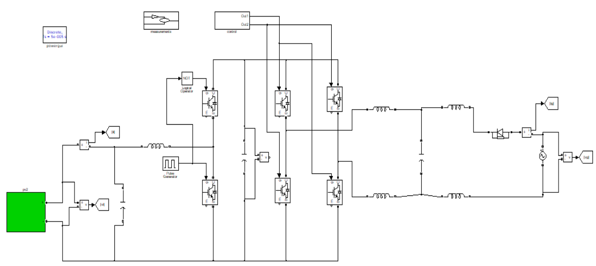
Fig. 16 Simulation circuit

6.1 SIMULATION RESULTS:

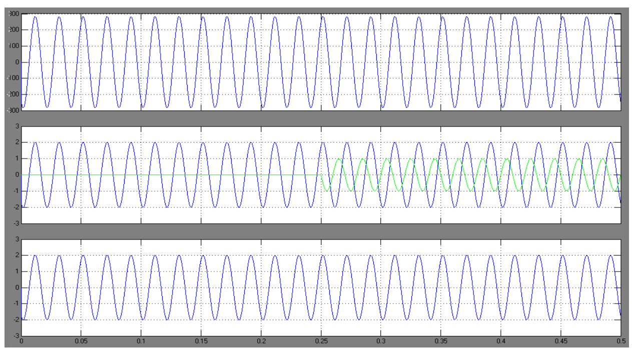
Fig.17 (1) Peak shavings with the EMS providing some of the load current from the battery pack when the load increases. Load 2 steps from 1200 to 85.7 Ω (A), and then, the EMS turns ON (B). The loads are linear.

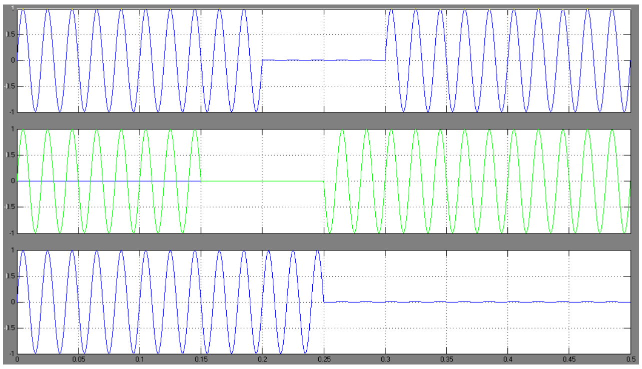

Fig.18 (2) Experimental waveforms showing ac grid failure (A) and the EMS taking the loads into islanding mode (B), α = 20π

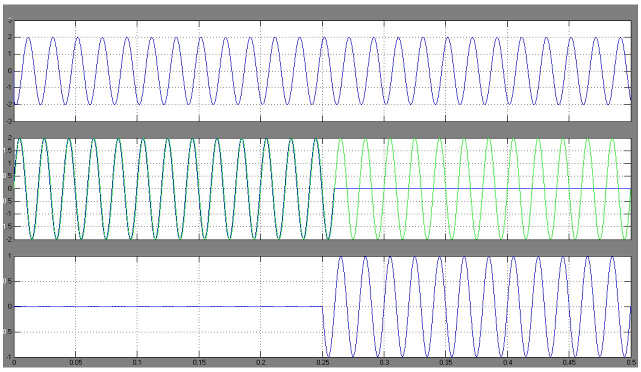

Fig.19 (3) Experimental wave forms showing the ac grid being restored at t =0

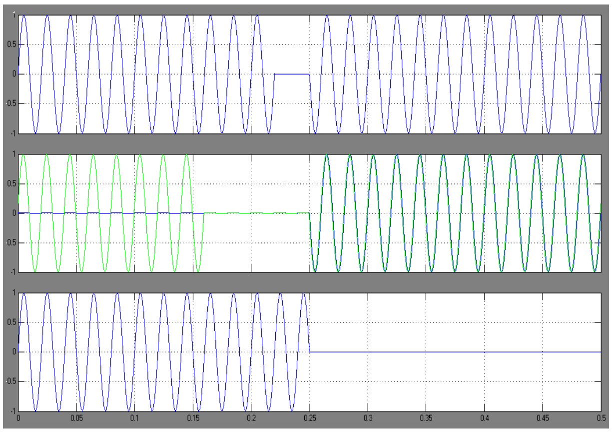

Fig.20 (4) Experimental wave forms showing ac grid failure (A) and the EMS taking the loads into islanding mode (B), α = 60π.

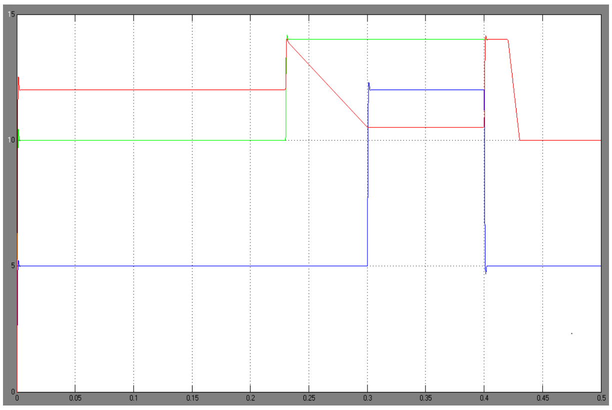

Fig.21 (5) TOU rates and power consumption with and without EMS

VII. CONCLUSION

The functionality of a power-electronics-based EMS is demonstrated with a laboratory prototype. The control system designed to perform the experimental implementation of typical scenarios is presented in detail. Experimental data are shown to demonstrate how the EMS supports critical loads when the ac grid becomes unavailable and how the connection to the ac grid is restored by the EMS when the ac grid becomes available again. Additionally, the EMS can accomplish other advantageous tasks such as peak shaving. Experimental measurements with linear and nonlinear loads demonstrate how the EMS, controlled in current mode, provides some of the power to the loads to accomplish peak shaving, thus reducing the cost of electricity.

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