SIMULATION OF ENERGY MANAGEMENT SYSTEM IN GRID WITH STORAGE USING CONVERTER TOPOLOGY

Mr. Dharmesh Tadvi[1], Mr.Ronak Patel[2]
[1]P.G. Scholar, [2]Assistant Professor
Electrical Department, Grow more Faculty of Engineering, Himmatnagar, Gujarat, India

Abstract: In this paper a power electronics-based energy management systems (EMS) are presented to accomplish peak power control in a single-phase power system while guaranteeing continuous service to critical loads at the same time. Peak power control, also known as peak shaving, is a method used to reduce the electricity charges for users with time of use (TOU) contracts and those who pay for the demand charges. The power system does not need to be a microgrid, meaning that distributed generation (DG) does not need to be part of the power system. However if DG units, such as photovoltaic panels or diesel generators, are part of the installation the EMS can manage these resources. The proposed system of EMS with converter topologies based on power electronics has been developed using Matlab-Simulink. The simulation results and analysis also carried out in this paper.
Keywords: EMS, Grid, Converter,etc.

I. INTRODUCTION

The current electrical grid is perhaps the greatest engineering achievement of the 20th century and is considered to be the largest machine on the planet. However, it is increasingly outdated and overburdened, leading to costly blackouts and burnouts. Current studies show that the existing electric grid converts only one-third of fuel energy into electricity. Almost 8% of the generated electricity is lost in transmission while 20% of the electric energy is generated to meet peak demands for only a short period (5%). Moreover, existing electricity networks do not contain storage units, which means that the energy generated from fossil fuels and nuclear power plants must be balanced with the energy consumed by the end users. In addition, the existing electric grid suffers from domino-effect failures due to its hierarchical topology of transmission and distribution networks. In fact, nearly 90% of power disruptions occur in power distribution networks.Energy savings and energy efficiency have become top priorities all around the world, stimulated by the Kyoto protocol and other pressing needs to reduce fossil fuel consumption. 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 times. In this paper a power electronics based energy management systems (EMS) is presented to accomplish peak power control in a single phase power system while guaranteeing continuous service to critical loads at the same time. Peak power control, also known as peak shaving, is a method used to reduce the electricity charges for users with time of use (TOU) contracts and those who pay for the demand charges [1]. The power system does not need to be a micro grid, meaning that distributed generation (DG) does not need to be part of the power system. However if DG units, such as photovoltaic panels or diesel generators, are part of the installation the EMS can manage these resources.

The EMS proposed in this paper includes energy storage in the form of batteries in order to accomplish three main goals: a) make electric power available to critical loads at all times with or without main grid service available b) reduce peak power consumption to lower electricity costs and c) store energy produced by DG units or during the time in which electricity from the grid is least expensive. Recently researchers have used power converters to implement power management or energy management systems (EMS) for AC and DC micro grids. Results in literature include power quality solutions, and also presented single phase inverters for grid interface in both grid connected and stand-alone mode of operation. This paper, while following along the same line of research, introduces the prospective of continuous service to critical loads with peak power shaving. It also includes a simple economic analysis to demonstrate the advantages of the peak power shaving method. While applications that emphasize energy security have been considered by the combination of energy security and energy cost reduction combined is new to these authors' knowledge. Furthermore this paper presents simpler control systems and different topologies than those reported in literature review papers. Another innovative feature of the EMS presented in this paper 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.

II. CHALLENGES AND RESEARCH OBJECTIVES

Technology Challenges

Given the fluctuations of power generation in micro grids as a result of unavoidable natural hazards, and also because the number of EVs charging (simultaneously) is unknown, therefore, the power sharing between neighboring micro grids must deal with the following challenges:

- Integration of intermittent renewable energy sources.
- V2G and G2V issues: Policy/protocol and intelligent mechanisms are needed for V2G operation to provide electric energy to the grid with the high price interval and for emergency power need. For consuming electricity, EVs need to charge in low price interval.
- Wireless and sensor based infrastructure is needed to monitor EVs' battery charge level, charging and

discharging schedule.

- Integration of community energy storage system (ESS).
- Communication and control required over micro grids for power generation and consumption.
- Management System for Intelligent Power Transmission and Distribution between micro grids.
- Transition between "grid connected" and "islanded" mode of micro grids.
- Smart Metering
- Frequency and voltage regulation
- Cyber security: The smart micro grids differ from the conventional communication networks because they are able to reach every equipment which resides in user premises, and return with energy control information to the micro grid central control system. The micro grids smartly determine the current energy requirement and decide to distribute and transfer according to the demand, possibly with valley filling algorithms. So the security of the user data and the secure transmission of control and electric energy demands are usual concerns.

Research Objectives: -
This paper demonstrates the functionality of a power electronics based energy management system (EMS). The EMS includes batteries and a digitally controlled single phase voltage source inverter (VSI) which can be controlled as a current source or a voltage source depending on the status of the AC grid and the user's preference. The EMS 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 battery power to the local loads while they are powered by the AC grid if the loads get large. The electricity cost savings accomplished by peak shaving are estimated. The EMS functionality is demonstrated by experimental measurements on a laboratory prototype. The control architecture and logic embedded in the EMS are discussed in detail.
The EMS proposed in this paper includes energy storage in the form of batteries in order to accomplish three main goals:-

- Make electric power available to critical loads at all times with or without main grid service available
- Reduce peak power consumption to lower electricity costs and
- Store energy produced by DG units or during the time in which electricity from the grid is least expensive.

III. ENERGY MANAGEMENT SYSTEM

Today's world has become a complete energy dependent world in which electricity is of prime importance. Electricity has made life very easy and thus its consumption is increasing day-by-day. In order to generate this electrical energy in its original form, a lot of natural resources are being used. Traditionally electricity was generated only from non-renewable energy resources but now renewables have come into picture. Although renewables are used for generation of electricity, the system and equipment needed to produce electricity from them are costly and thus can't be afforded by every common man. Hence this has led to the depletion of the natural resources. Therefore it is essential to switch to new and better options like smart grid, smart metering, and zero energy buildings that will help to reduce dependency on these reserves by reducing energy consumption and improving use of renewable energies. And in order to increase the efficiency of our power system Energy Management Systems (EMS) are essential. It is a comprehensive offering that combines energy and process optimization and, where appropriate, incorporates the solution into online advanced control and optimization strategies.This paper focuses mainly on the present scenario of energy usage systems in India and suggests some methods and techniques adopted, that will lead to the improvement of energy usage and efficiency. Also the paper depicts the case study of JK Lakshmi Cement LTD- Jaykaypuram, Sirohi Plant in India which has shown a tremendous improvement in its operating system and energy efficiency using the Energy Management System. The advantages of EMS along with the barriers faced and the solutions to deal with these barriers so that EMS can be brought into operation in the existing industries as well as residential and commercial organizations are also discussed. The next few paragraphs discuss the basics of Energy Management Systems.

What is an Energy Management System?
An Energy Management System is a series of policies, processes and procedures to manage operational energy use. Energy, in the context of organizational use, can be defined as the direct consumption of fuel (Gas, Oil, etc.) and indirect consumption of fuel (Electricity) required to perform the organizational functions. It is a strategy of adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing the total costs of producing the output from these systems. Thus EMS leads to the judicious and effective use of energy in order to maximize the profits by reducing the operational costs and hence enhance the competitive positions. Energy management systems are used by power system operators to monitor power grid operating conditions and control grids in a reliable, secure, and economical fashion. An energy management system interfaces with the grid through a supervisory control and data acquisition (SCADA) system. The SCADA system transmits thousands of measurements at critical points of a power system in real time to the energy management system and command signals from the energy management system to field devices to take control actions. An energy management system integrates application software such as state estimation, contingency analysis, automatic generation control, and economic dispatch. These applications typically operate the grid in a reactive (e.g., load following) or preventive (e.g., security constrained dispatch) fashion.

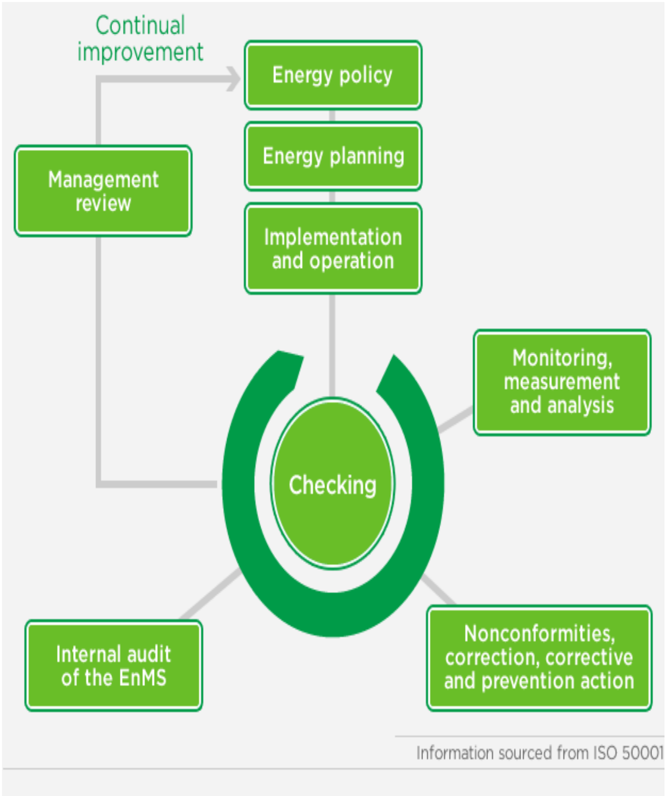

Fig.1: Basic Block Diagram of an Energy Management System

The increased penetration of renewable generation on the power grid imposes great challenges to the current energy management system scheme as renewable resources largely differ from conventional generation because of their uncertainty and variability. To thrive in this situation, energy management system technologies need to evolve into a proactive, look-ahead paradigm. Advanced energy management system technology is also sorely needed at the distribution system level. The traditional distribution energy management system is much less integrated than the transmission energy management system. Operational challenges arise from the significantly increased complexity of modern distribution systems, especially from distributed renewable resources, electric vehicles, and demand-side management. A fully integrated and intelligent distributed energy management system is a key to meet these challenges.This is based on an international standard for Energy Management. The ISO 50001 Energy Management Systems Standard was released in August 2011. This International Standard establishes a framework for industrial plants; commercial; institutional and government facilities and entire organizations to manage their energy. The Standard is based on the classic business planning cycle "Plan-Do-Check-Act" and provides guidance for organizations in establishing energy policies, programs and action plans to improve their energy use.

Description of Proposed system

The EMS presented in this paper includes batteries and a three leg power module controlled by a field programmable gate array (FPGA).

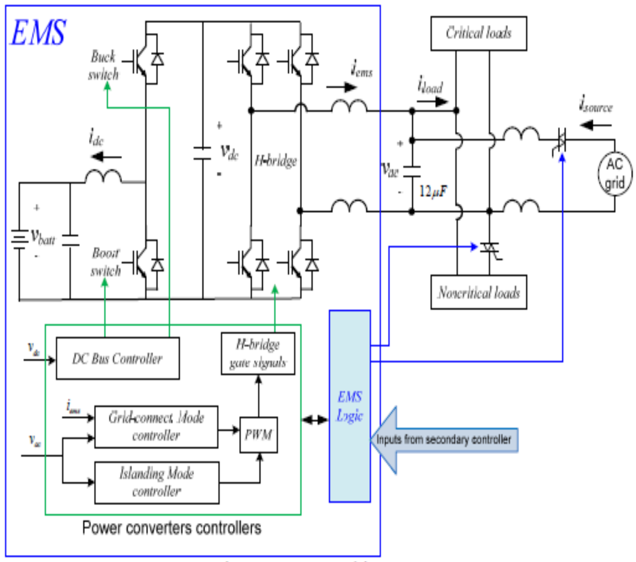

Fig.2 EMS architecture [1]

The schematic in Figure-2 depicts the EMS architecture. A three phase IGBT power module is controlled to achieve buck and boost power flow from one leg of the module and single phase voltage source operation (H-bridge inverter) from the other two legs of the module. The H-bridge inverter thus formed is connected to an output LC filter to produce the sinusoidal voltage for the AC loads. There are two voltage sensors to monitor the voltages *vdc*and *vac*. There are two current sensors to monitor *iems*and *iload*.A battery pack is connected to the buck-boost leg to accomplish bidirectional power flow to/from the battery. The battery consists of six, 12V battery cells in series, forming a 72V battery pack. Note that a 300V battery pack would eliminate the need for the buck/boost stage of the EMS, thus forming the DC bus for the H-bridge inverter. Critical loads are connected directly to the AC voltage created by the EMS which is labeled *Vac*in Figure.2.

Critical loads are those loads that must be powered at all times because they are critical to the mission. Noncritical 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.The EMS functionality is demonstrated in this paper are:-

1) Peak shaving by tapping the energy storage system during high power demand.
2) Islanding or standalone mode of operation when the main AC grid is no longer available.
3) Battery charging mode.

By accomplishing these goals the EMS can be very useful in grid connected systems where there is a limit on the user’s power consumption. This limit maybe enforced by circuit breakers controlled by a power meter. If the EMS keeps the

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source current below a set threshold at all times by load management and shedding, then the user can operate loads beyond the steady state power limits of the AC grid for short times without worrying about the circuit breaker interrupting service.

EMS Control System

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. This paper focuses on the primary control system. The basic functions of the primary controller are included in Figure -2 and will be examined in details in this section.

Figure-3 shows the EMS primary controller logic flowchart, which is a detailed visualization of the "EMS Logic" block in Figure-2. The operator or the secondary controller inputs four distinct logical commands; Run, Charge, Source Connect (SC) and Current Threshold (CT). CT is the load current level when the EMS will begin peak shaving. If Run is low then the EMS does nothing. When Run is high the EMS will operate in islanding mode. If SC is also high then the EMS will connect *vac*to the AC source if the AC source RMS voltage is above 100 Vrms (VRMS OK is high). If the load current exceeds the peak shaving limit (CT) then the EMS will continue to inject current otherwise the EMS will turn off after connecting to the AC source. If Charge is set high then the EMS will charge the batteries when the AC source is present and peak shaving is not demanded.

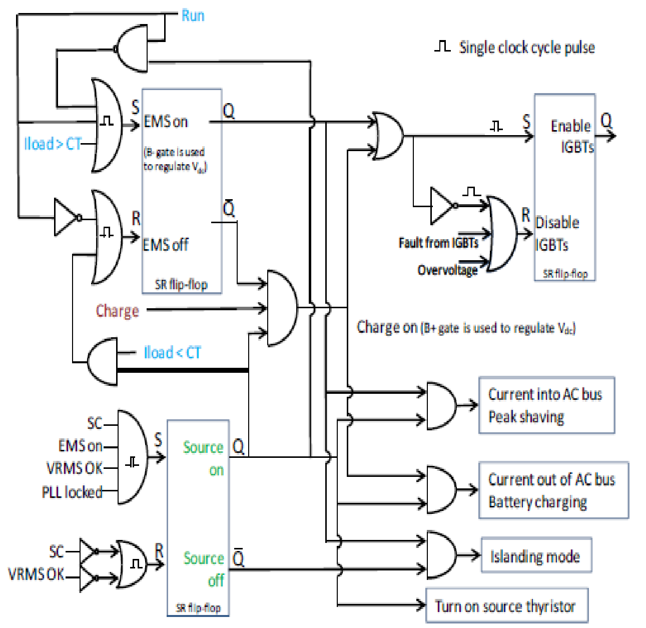

Figure-3. EMS logic flowchart. Run, Charge, SC and CT are inputs from the operator or secondary controller

There are two other internal variables: phase locked loop (PLL) locked and voltage root mean square (VRMS) OK. When the signal VRMS OK is high, the AC grid RMS voltage is above a set threshold. When this signal is low, the EMS switches from grid connect to islanding mode of operation. These four commands coming from the secondary controller can be set based on several factors. The secondary control system will set the charging command and the peak shaving thresholds in order to achieve the best performance. The information that will be used by the higher level controller will include state-of-charge, time of day, cost of electricity and other factors. The different components of the EMS primary control system for the different modes of operation are presented in the following subsections.

IV. SIMULATION AND RESULT DISCUSSION

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.

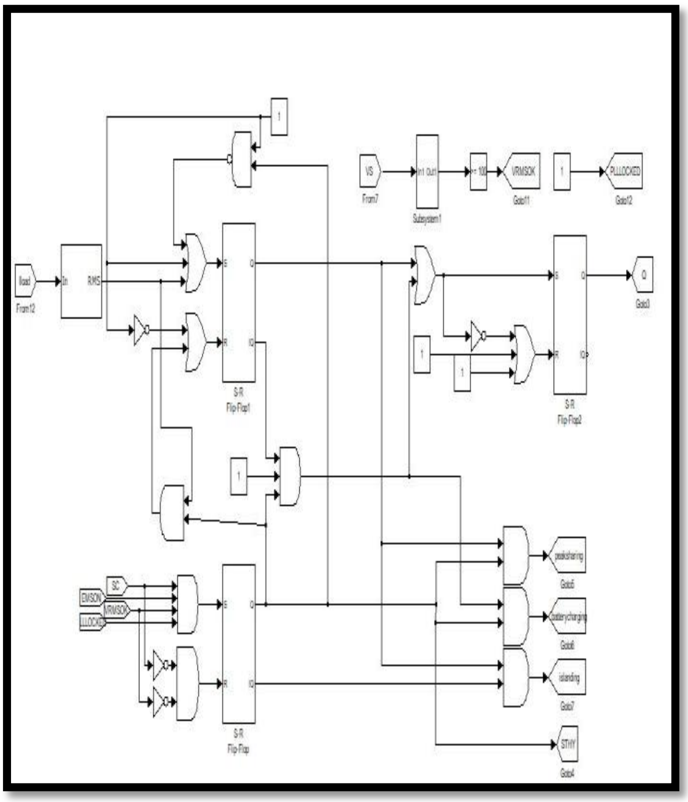

Fig 4- EMS Controlling subsystem

Peak shaving is achieved by controlling the RMS current in the load, which is related to the source current. A threshold is set for the load current such that when the load RMS current exceeds this threshold the EMS supplies some of the load current. This keeps the peak current drawn from the AC grid below a set limit. In the simulation results here, the threshold for the load current is such that the peak shaving feature turns on when the load current is greater than 2.2 Arms and turns off when the load current is below 2.1 Arms. When peak shaving turns on the EMS behaves as a current source supplying to the load a sinusoidal current with unity power factor. The threshold value can be changed by modifying the EMS reference current by the secondary controller. The EMS can be programmed to provide reactive power as well as current harmonics as needed by the user or the secondary controller.

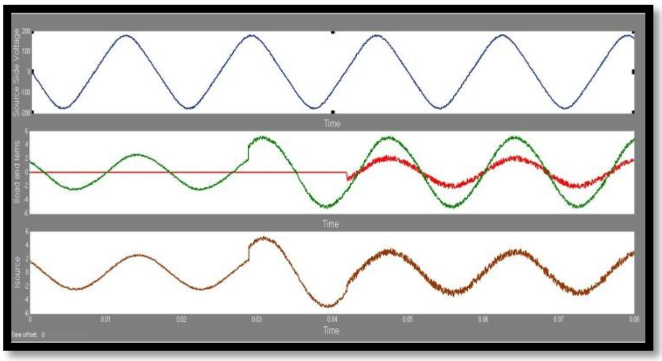

Fig 5- Peak shaving with the EMS providing some of the load current from the battery pack when the load increases. Load 2 steps from 600Ω to 80 Ω and then the EMS turns on (B). All the loads are linear.

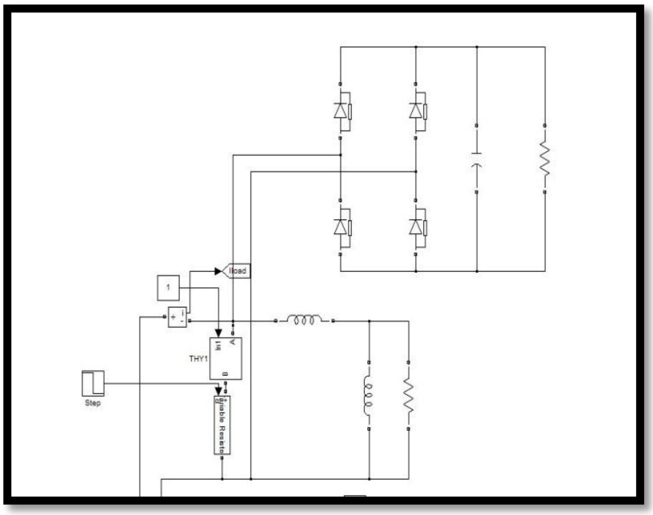

Fig 6- Variable load condition

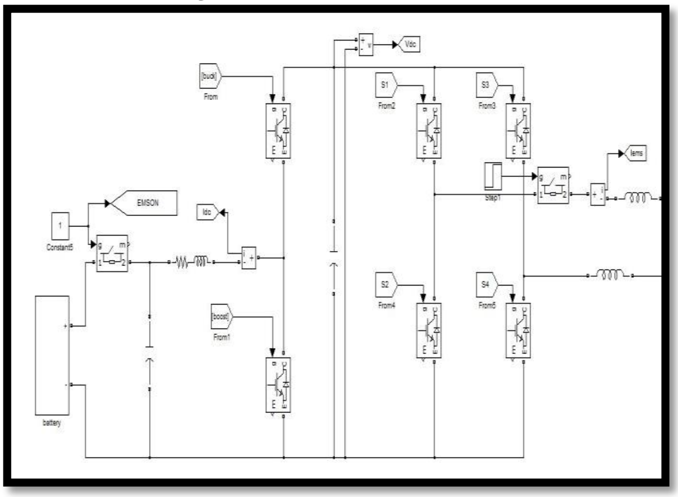

Fig 7- EMS controlling system

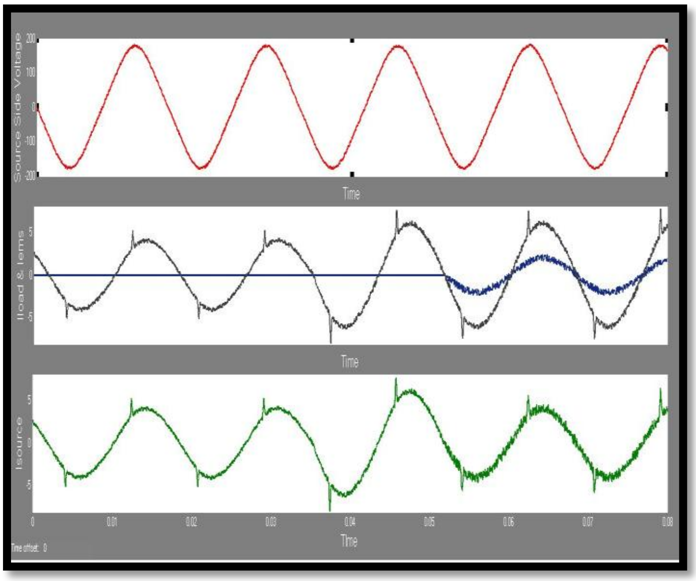

Fig 8- Peak shaving with the EMS providing some of the load current from the battery pack when the load increases. Load 2 steps from 1200 Ω to 85.7 Ω and then the EMS turns on (B). The load includes a diode rectifier

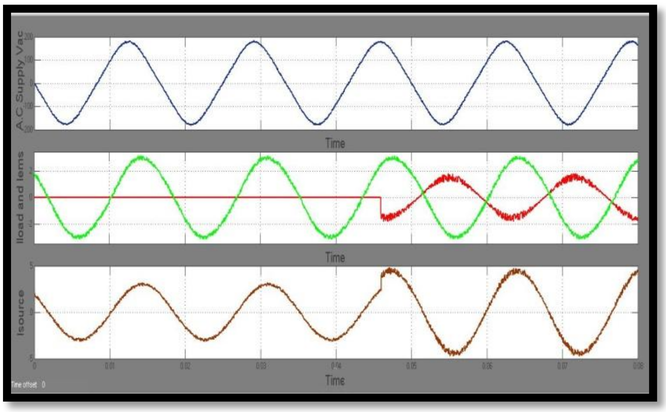

Figure 9 EMS turning on at *t=0* to charge the battery pack

There is a delay between the load increase and the EMS turning on due to the RMS current computation algorithm, which is described in the next section.

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 non critical 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. Non critical load shedding is easily accomplished by the EMS by opening the thyristor switch connected to the non-critical loads (shown in Figure 10). When the AC grid is available again, 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.

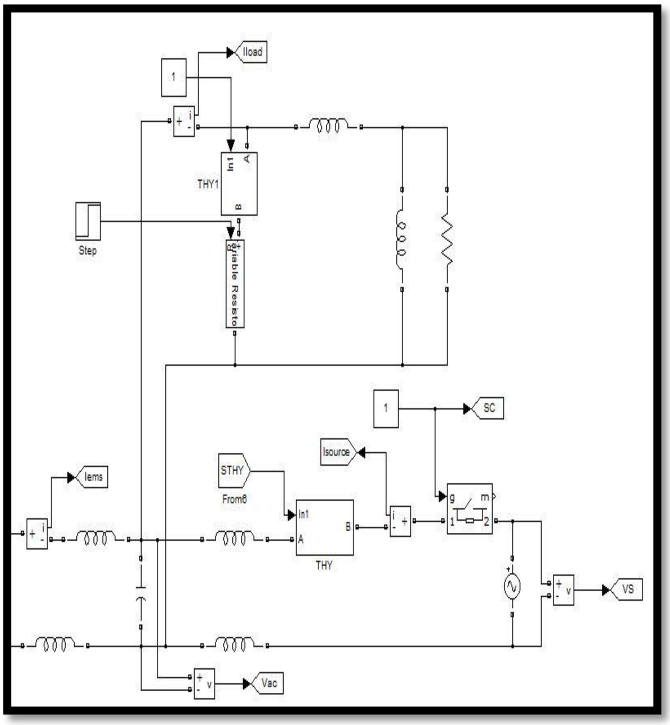

Fig 10- EMS Powering Critical Loads when the AC Grid Fails – Islanding Mode of Operation

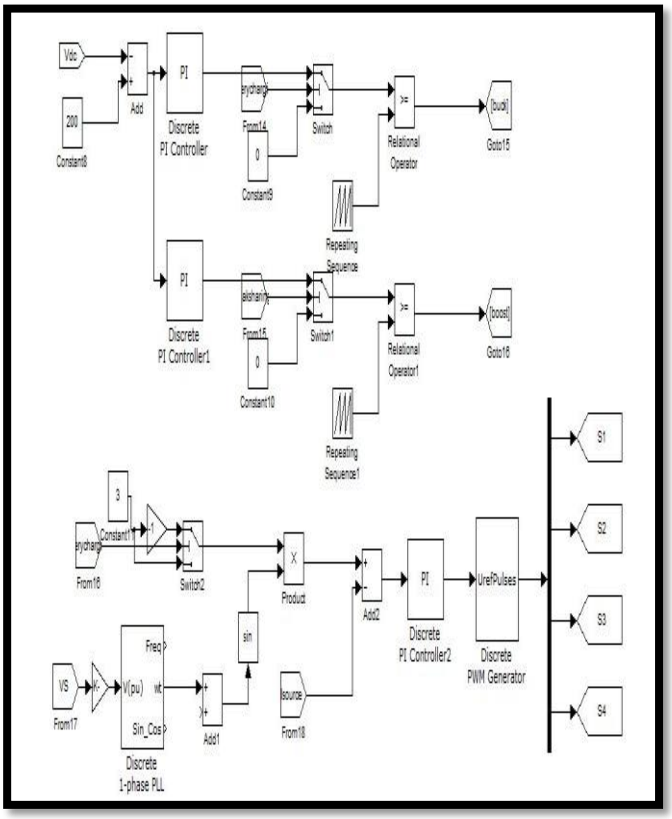

Fig 11- Controlling subsystem for EMS switching control

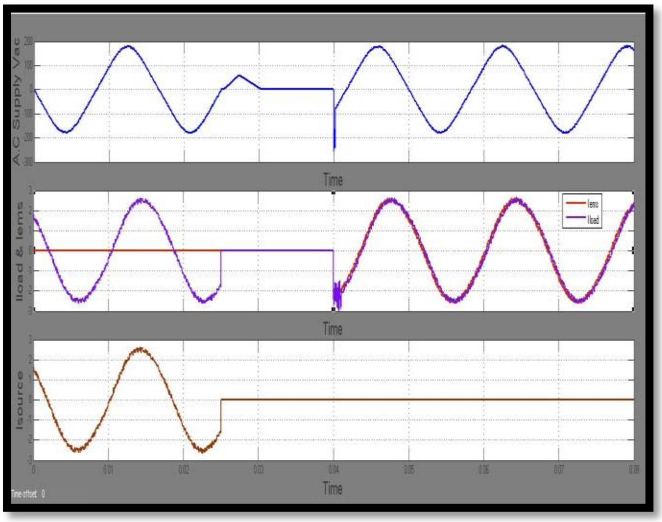

Figure 12.Simulation waveforms showing AC grid failure and the EMS taking the loads into islanding mode

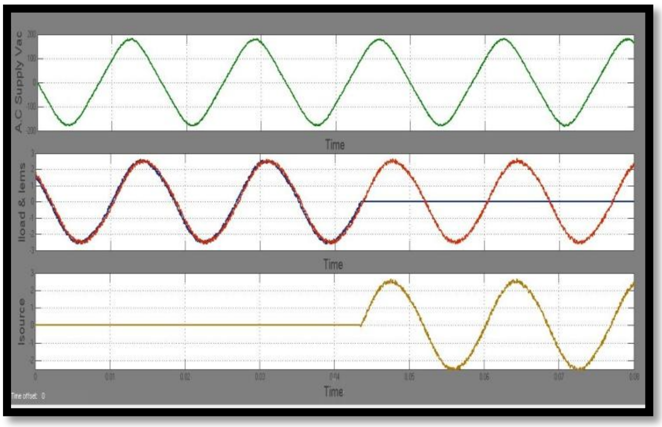

Figure.13 Simulation waveforms showing the AC grid being restored at *t=0*.

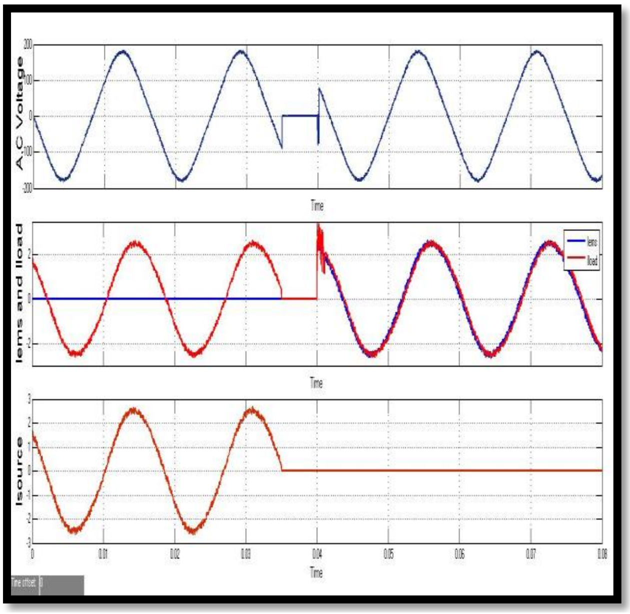

Figure.14 Simulation waveforms showing AC grid failure (A) and the EMS taking the loads into islanding mode (B). α= 60 Л.

V. CONCLUSION

In this paper 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. Simulation data is 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 non-linear 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. The Matlab simulation is successfully done for different case analysis as shown in the simulation results for Energy Management System in Matlab-Simulink.

REFERENCES

[1] Giovanna Oriti, Alexander L. Julian, Nathan J. Peck, "Power Electronics Based Energy Management System with Storage", IEEE Transactions on Power Electronics, 2018 IEEE.

[2] Giovanna Oriti, Alexander L. Julian, Nathan J. Peck, "Power Electronics Enabled Energy Management Systems", Office of Naval Research and the Naval Postgraduate School, U.S. Government work not protected by U.S. copyright, IEEE 2016.

[3] Joan Rocabert, Alvaro Luna, FredeBlaabjerg and Pedro Rodr´ıguez, "Control of Power Converters in AC Micro grids", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 27, NO. 11, NOVEMBER 2012.

[4] SoerenBaekhoejKjaer, John K. Pedersen, and FredeBlaabjerg, "A Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules", IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 41, NO. 5, SEPTEMBER/OCTOBER 2005.

[5] Murat Yilmaz, and Philip T. Krein, "Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 28, NO. 5, MAY 2013.

[6] Sergio Vazquez, Srdjan M. Lukic, Eduardo Galvan, Leopoldo G. Franquelo, and Juan M. Carrasco, "Energy Storage Systems for Transport and Grid Applications", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 57, NO. 12, DECEMBER 2010.

[7] Zahra Amjadi, and Sheldon S. Williamson, "Power-Electronics-Based Solutions for Plug-in Hybrid Electric Vehicle Energy Storage and Management Systems", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 57, NO. 2, FEBRUARY 2010.

[8] SirirojSirisukprasert, "Power Electronics-based Energy Storages: A Key Component for Smart Grid Technology", Proceedings of the International Electrical Engineering Congress 2014, 978-1-4799-3174-3114/ ©2014lEEE.

[9] S. Chakraborty, M. D. Weiss, M. G. Simões, "Distributed Intelligent Energy Management System for a Single-Phase High-Frequency AC Microgrid", IEEE Trans. Ind. Electronics, vol. 54, no.1, Feb 2007.

[10] Y. Chen, Y. Wu, C. Song, Y. Chen, "Design and Implementation of Energy Management System with Fuzzy Control for DC Microgrid Systems", IEEE Trans. Power Electron. Vol. 28, No.4, April 2013.

[11] B. I. Rani, G. S. Ilango, C.Nagamani, "Control Strategy for Power Flow Management in a PV System Supplying DC Loads", IEEE Trans. Ind. Electron., vol. 60, no. 8, Aug 2013, pp. 3185-3194.

[12] J.M. Carrasco, L.G. Franquelo, J.T. Bialasiewicz, E. Galvan, R.C.P. Guisado, M. A.M. Prats, J.I. Leon, N. Moreno-Alfonso, "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey", IEEE Trans. Ind. Electronics, vol. 53, no. 4, Aug 2006, pp. 1002-1016.

[13] P. Sun, C. Liu, J. Lai, C. Chen, "Grid-Tie Control of Cascade Dual-Buck Inverter with Wide-Range Power Flow Capability for Renewable Energy Applications", IEEE Trans. Power Electronics,vol.27 no.4, April 2012.

[14] C. Cecati, C. Citro, A. Piccolo, P. Siano, "Smart Operation of Wind Turbines and Diesel Generators According to Economic Criteria", IEEE Trans. Ind. Electronics, vol. 58, no.10, Oct 2011, pp. 4514-4525.

[15] H. Kanchev, D. Lu, F. Colas, V. Lazarov, and B. Francois, "Energy Management and Operational Planning of a Microgrid With a PV-Based Active Generator for Smart Grid Applications", IEEE Trans. Ind. Electronics, vol. 58, no.10, Oct. 2011, pp 4583-4592.

