Smart Controller Design for Solar Grid Integration and LVDC Distribution System

B. S. Sourab
Department of Electrical and Electronics Engineering, BNM Institute of Technology, Bangalore, India
Email: bssourab@gmail.com

***Abstract*—Nowadays Direct Current (DC) Distribution Systems have started to attract a lot of attention as they offer a natural interface to generation and consumption units such as renewable energy sources, energy storage systems and end-user electronic loads. However, a number of technical challenges related to integration of renewable energy sources and their control must be overcome. This paper presents a smart controller based design for efficient and cost effective operation of a LVDC Distribution System. This paper mainly focuses on solar energy as it is the most abundantly available renewable energy source. This paper basically presents a smart controller based design for cost effective operation of solar-grid tied LVDC system. The control strategy used in this system helps to achieve the maximum efficiency as utilization of dump power is also considered. This system is defined to fill the necessity of regions where solar power is used only as backup purposes to charge the battery and is actively dumped during the presence of active grid. The system has been tested for a solar panel with a battery backup storage and its effectiveness has been observed. The battery backup is made to operate during the Grid cutoff.**

***Index Terms*—LVDC system, hybrid system, smart controller, solar-grid hybrid system, full wave rectifier, discretization of energy, microcontroller based power controller, dump power utilization, automatic adjustable solar-grid integration**

I. Introduction

Alternative sources of energy are definitely the choice of future as the cost of conventional energy sources are increasing day by day. Although not many PV systems have been placed into the grid so far due to their relatively high cost compared to conventional energy sources, [1] this is gaining more and more visibility as the world's power demand is increasing [2]. To meet this increasing demand, one should either increase the number of energy sources or should increase the utilization of available energy sources. And since the second option is more economically viable, it is imperative to effectively utilize the available alternative energy sources. Solar energy is one such existing source which is not effectively utilized in the developing countries. This is because solar energy is used as a backup to the grid, as the grid is subjected to interruptions due to limited availability of energy sources. The current scenario of the grid in developing countries is as shown in Fig. 1.

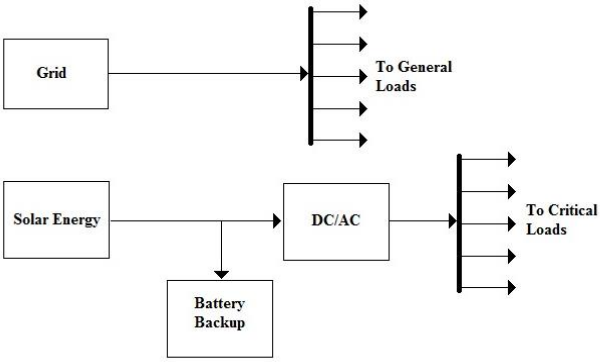

Figure 1. Current scenario of the grid

As seen in Fig. 1, it can be observed that the grid, which is extremely unreliable, is used as the main source of energy which feeds the general loads at household and the battery backup and the solar energy is used for the critical loads that have to be utilized during grid cut-off [3]. One of the major disadvantages of this approach is when the grid is active and the battery is fully charged. Since the grid is active and the battery is fully charged, the energy received from the solar panel is dumped. This introduces a waste of energy. Even if the amount of the energy dumped is small (In the range of few watts to few kW depending upon its location), if utilized properly, this dumped energy can add up to a huge amount. Hence, it is important to utilize the dump power as it will lead to reduction in the energy consumed by the user and will subsequently lead to reduction in the load on the grid.

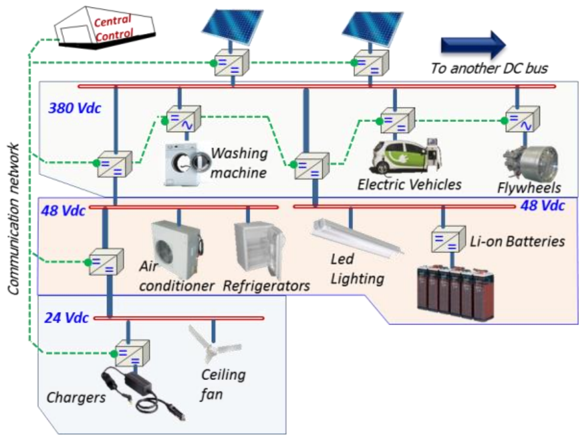

Figure 2. Typical LVDC distribution system

Manuscript received July 12, 2015; revised December 28, 2015.

doi: 10.18178/ijoee.4.1.79-83

The increase in the number of DC loads such as electric vehicles, distributed generation units and energy storages connected to the distribution network makes the LVDC distribution an interesting option [4]. One of the major advantages of a LVDC distribution system is the fact that the losses are less compared to a conventional LVAC distribution system. Moreover, since most of the loads are DC in nature, the need for converting AC supply to DC is eliminated in a LVDC distribution system. Fig. 2 shows a pictorial representation of LVDC distribution system.

The whole idea of LVDC distribution system is getting more and more popular as they offer a natural interface between generation and consumption units. The integration of small sized standalone solar systems to the grid is technically complicated which results in expensive operation which is not feasible at all. This paper here gives an overview of an alternative economical and technically feasible smart controller based discretized method for the utilization of the dumped power. It uses a novel approach by which the hybrid system is able to size the load and deploy appropriate operating strategy so as to get the maximum solar output. The system is designed in such a way that it fulfils the necessity of regions where solar power is used only for backup purposes and is dumped during the presence of an active grid. These regions include many parts of the world where grid cut off is common due to the shortage of energy.

II. Proposed Technology

One of the major disadvantages of the available technology is when the grid is active and the battery is fully charged. During this condition, the energy from the solar panel is dumped and this introduces a waste of energy. To avoid this, a simple method with discrete control algorithm is developed and implemented. Table I shows the various possible operating conditions in the algorithm.

TABLE I. Various Operating Conditions

Condition	Power Supply
Active Grid, Fully Charged Battery	Energy from PV cell is used to feed the load and excess load is fed by the grid
Active Grid, Partially Charged Battery	Energy from PV cell is used to charge the batteries and the loads are fed by the grid
Inactive Grid, Fully Charged Battery	Loads are fed by both the sources i.e. batteries and energy from the PV cell
Inactive Grid, Partially Charged Battery	Loads are fed by both the sources i.e. batteries and energy from the PV cell

A microcontroller based system is developed to govern the above requirement with a pre-defined algorithm. This is done so as to utilize the maximum energy from solar panel and add the remaining requirement from either grid or the battery. This reduces the consumption of grid supply which in turn reduces the load on the grid. As soon as the system is switched on, the system checks the output from the PV module and the charge level of the battery. If the battery is fully charged and an active grid is present, the system directs the PV output directly to the load. However, if the grid is inactive, the system directs the power from both PV and battery towards the load, irrespective of the charge level of the battery. To avoid over discharge of the battery, loads are prioritized based on the capacity of the PV module. In case of an active grid and insufficiently charged battery, the entire power to the load is fed from the grid and the PV output is used to charge the battery. The smart controller is made to check the condition of the system after every 10 minutes and the required changes are made automatically so as to maximize the use of PV module and reduce the load on the grid. Fig. 3 shows the controller algorithm.

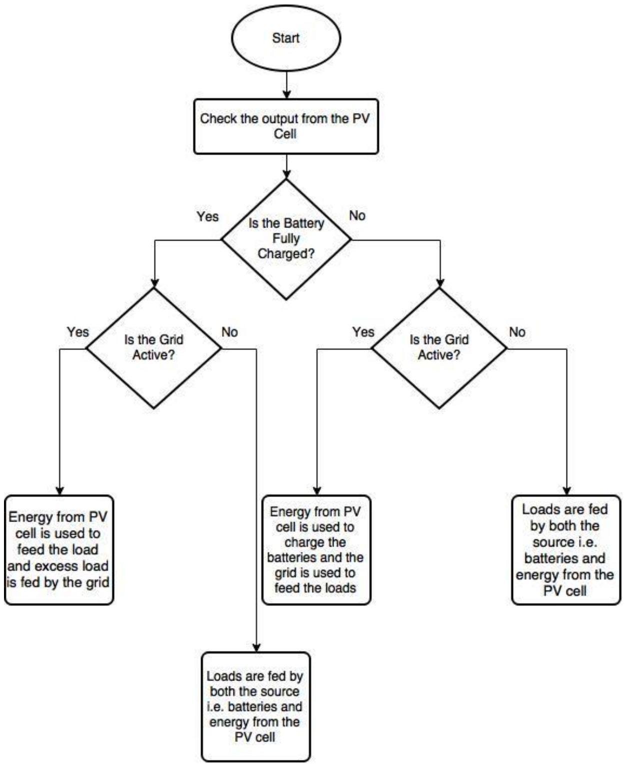

Figure 3. Controller algorithm

The block diagram of the system is as shown in Fig. 4. The system consists of a microcontroller which acts as an interface between the power supply and the load. Here the grid and the solar panel are the two power supply systems and the battery is used as a backup. Since all the loads are DC in nature, it is essential that the power supplied is also in DC. As the power output from the solar panel and the battery are DC in nature, there is no need for any conversion. However, the power supplied from the grid is alternating in nature and hence a rectifier must be used to convert that alternating power into DC. In this system a bridge rectifier is used to convert the AC power from the grid into DC. Sensors are used to monitor the real time output from the solar panel and depending upon the output and the amount of load switched on at that moment, appropriate power supply is chosen.

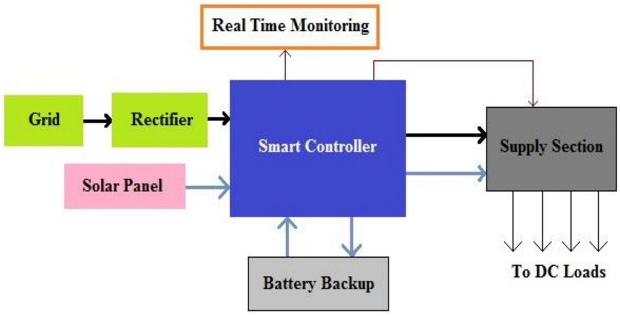

Figure 4. Block diagram of the system

III. DESCRIPTION OF TECHNOLOGY

A. Determination of PV Capacity

A PV module consists of a number of PV cells which are connected in series and parallel which results in high voltage and current [5]. The equivalent circuit of a PV cell is as shown in Fig. 5.

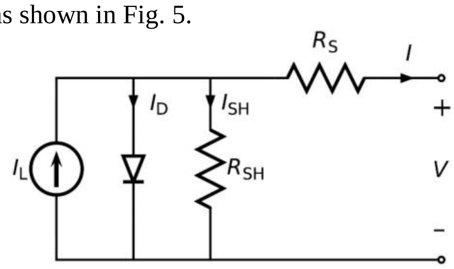

Figure 5. Equivalent circuit of a PV cell

The standard ratings found on a PV cell are calibrated for an irradiance of $1000W/m^2$ and a temperature of 25 ℃. However its actual performance in the field differs with changes in the above factors. The relationship between current and voltage is as given in (1).

$$I = I_{PV} - I_O \left\{ \exp\left(\frac{q(V + IR_S)}{\propto KT} \right) - 1 \right\} - \frac{V + IR_S}{R_{sh}} \quad (1)$$

Maximum Power Point Tracking (MPPT) samples the output from the solar cells. Fig. 6 shows a typical MPPT curve.

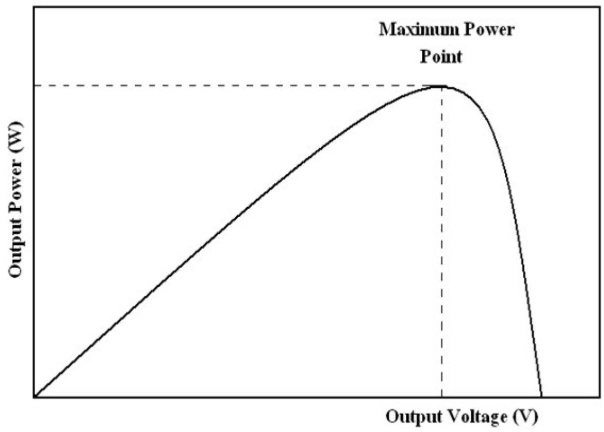

Figure 6. Typical MPPT output curve

The output of this sample is as given in (2).

$$P = FF * V_{OC} * I_{SC} \quad (2)$$

In (2), the factor FF is known as fill factor. The Fill Factor (FF) is essentially a measure of quality of the solar cell. It is calculated by comparing the maximum power to the theoretical power (P_T) that would be output at both the open circuit voltage and short circuit current together. This sample can be used to determine the entire DC capacity of the PV module at any given instant [6], [7].

B. Switching Load Feed between Grid and Solar PV/Battery

Unlike the conventional method of having separate loads for separate power supply, the same load can be supplied with different sources with an attempt to make the system highly efficient. The power loads are discretized into very small load units thus allowing almost all the available energy from the solar panel to be utilized. The microcontroller output signal is used for switching the load supply between Grid and Solar PV/Battery. High speed switching solid state relay rated 5V DC is used for switching the power supply. The microcontroller output signal with its current amplified is used for triggering the relay which results in change of power supply form one source to other. Normally the supply from the Grid feeds the load system with relay being in OFF state. However when sufficient power is detected from the solar PV, there will be a change of supply from Grid to PV/Battery source by making the relay in ON position. All the loads are classified according to their ratings. The circuit which is used for switching between different power supplies is shown in Fig. 7.

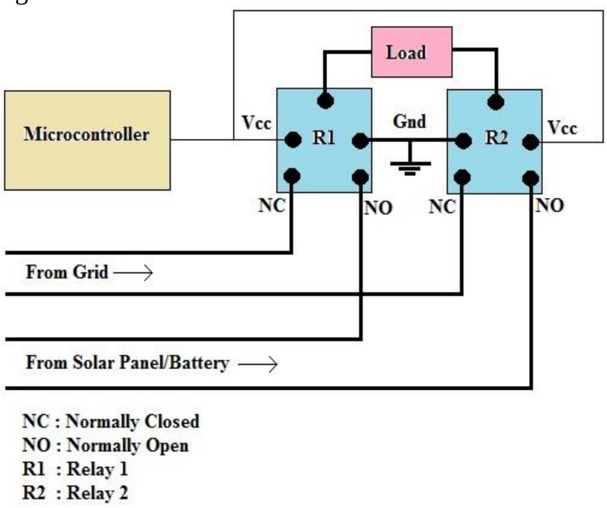

Figure 7. Circuit used for switching between different power supplies

IV. HARDWARE IMPLEMENTATION

When it comes to designing an electronic system, the same goal can be achieved by using different models of components which serve the same objective. This makes designing a very challenging part as the solution needs to be the most optimum solution. To achieve this, first the system is studied and then the most optimum components are chosen. One of the major components used is the control unit. Here Arduino Duemilanove microcontroller is used. It has a 16MHz, ATMEG328 processor with a SRAM of 2KB. It has 14 digital I/O pins and has 6 analog I/O pins which can be configured in the program. The internal ADC available in the microcontroller has the range of 0-5 V which gives the output current in the range of mA. Special techniques have been used to make sure that the power circuit is electrically isolated from the microcontroller. Diodes are also used to prevent the microcontroller from the back flow of current. Furthermore, pull up resistors are used in the circuit to limit the current entering the microcontroller. Fig. 8 shows the control unit of the system.

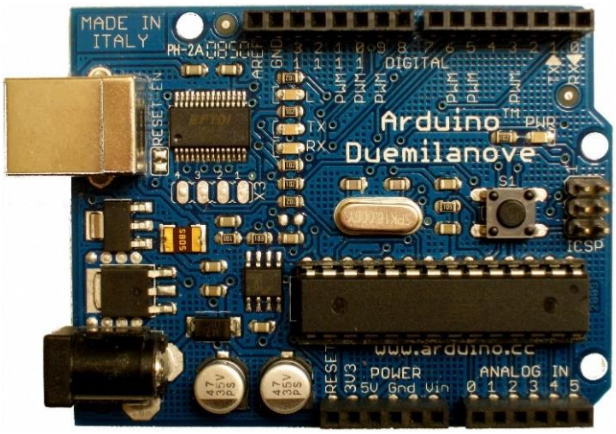

Figure 8. Control unit

To understand how the system is operating at any instant, a LCD module is installed with the system which shows the real time operation. The LCD module shows the amount of power fed from the Solar PV and it also shows the state of the battery and the grid. Here 4 data lines are sufficient to display the message. Fig. 9 shows a 16X2 LCD module.

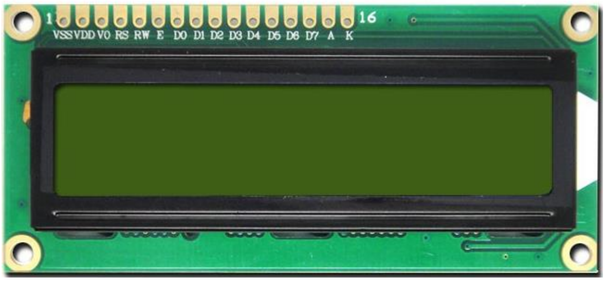

Figure 9. A 16X2 LCD module

The last part of the system is the rectifier unit. A bridge rectifier is used to convert AC supply into pulsating DC. This pulsating DC supply is then passed through a capacitive filter and then through a voltage regulator to get a constant DC supply.

V. Performance of the System

The operation of the system was tested in the laboratory with varying load conditions and the result was exactly in the manner expected. The changes in the load and the power supply systems were well detected by the smart controller and changes were applied accordingly with uninterrupted power supply. The changes in the load and the power supply system were displayed properly in the LCD module. With a working speed of 1 millisecond programmed in the microcontroller, the changes made in power supply unit were very reliable and stable. The microcontroller, LCD module and the relay systems co-operated very well and hence the performance was as per the expectations.

VI. Conclusion

The paper presents a design for smart controller which can be used to control the power supply in a LVDC distribution system. The method and algorithm presented in the paper is specifically for the utilization of dumped power from the Solar PV. All techniques rely on the ability to make effective co-operation between different units in the hybrid system (i.e. the programming algorithm and interface used with smart controller). The described algorithm is demonstrated with practical observation from the lab. Research along this direction will not only expand the scope of LVDC distribution system but will also increase its acceptability as the system is cost effective and is easy to implement. The proposed system will not only reduce the complications involved in distribution of power, but will also help to reduce the load on the grid which takes us a step closer in solving the current energy crisis.

Acknowledgment

The author wishes to thank his college faculty at BNM Institute of Technology for their continued support and feedback.

References

[1] S. B. Kjaer and J. K. Pedersen, "A review of single-phase grid-connected inverters for photovoltaic modules," *IEEE Transactions on Industry Applications*, vol. 41, no. 5, Sep./Oct. 2005.

[2] J. P. Benner and L. Kazmerski, "Photovoltaics gaining greater visibility," *IEEE Spectr.*, vol. 29, no. 9, pp. 34-42, Sep. 1999.

[3] U.S. Department of Energy, "Solar energy grid integration systems," *Program Concept Paper October 2007*, p. 17, 2007.

[4] T. Kaipia, P. Nuutinen, P. Peltoniemi, and J. Partanen. (January 2008). An LVDC distribution system concept. [Online]. Available: http://www.researchgate.net/publication/27516814_An_LVDC_Distribution_System_Concept

[5] Bonkoungou, Z. D. Bonkoungou, Z. Koalaga, and D. Njomo. (March 2013). Modelling and simulation of photovoltaic module considering single-diode equivalent circuit model in MATLAB. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.413.5543&re rep=rep1&type=pdf

[6] M. A. G. de Brito, L. Galotto, L. P. Sampaio, G. de Azevedo e Melo, and C. A. Canesin, "Evaluation of the main MPPT techniques for photovoltaic applications," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 3, pp. 1156-1167, March 2013.

[7] M. Balato and M. Vitelli, "A hybrid MPPT technique based on the fast estimate of the Maximum Power voltages in PV applications," in *Proc. 8th International Conference and Exhibition on Ecological Vehicles and Renewable Energies*, March 27-30, 2013. pp. 1-7,

B. S. Sourab was born on 4th September 1994 in Bangalore, India. He holds a Bachelor of Engineering (B.E) Degree in Electrical and Electronics Engineering from B N M Institute of Technology, Bangalore, India.

He has done his internship at Bharat Heavy Electricals Ltd. (BHEL) which is one of India's biggest heavy electrical equipment manufacturers and will be working in Robert Bosch Engineering and Business Solutions (RBEI) as an Associate Software Engineer. He will be working on designing of Active Safety System in passenger cars. He has two papers published in IEEE journal both of which are based on biomedical applications. The first paper deals with implementation of home automation using an eye blink. The system discussed in the paper was specially designed for paraplegic patients. The second paper deals with designing of an electronic mobility aid for blind. His research interests include embedded systems, renewable energy sources and biomedical engineering.