Solar PV System for Electric Traction Application with Battery Backup

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Abstract – The growing interest in the use of energy storage systems to improve the performance of trains has prompted the development of control techniques and optimal storage devices, displacement, and sizing to obtain the maximum profit and reduce the total installation cost. Recently, the rapid diffusion of renewable energy generation from photovoltaic panels has also created a large interest in coupling renewable energy and storage units. A grid connected PV system with batteries as the energy storage element for application to electric train has been proposed in this paper. Battery packs and PV arrays are cascaded together to the utility through a bidirectional dc converter and boost converter. The PV module terminal voltage is regulated by a switched dc-dc step up boost converter, which uses the Incremental Conductance algorithm to track the MPPT. A bidirectional DC/DC converter efficiently regulates flow of power between battery and grid. Bidirectional Inverter provides supporting grid functions which enhances grid stability.

Index Terms – Electric traction, Grid integration, MPPT, Solar PV.

1. INTRODUCTION

The bi-directional DC-DC converter in the system plays a role of transmitting energy in both directions i.e. it can conduct when the battery is to be charged as well as when the battery is to be discharged. These systems have simple structures and control units, and have the advantage of storing the residual energy from the solar cell. It not only maintains the power flow balance in the circuit but it also helps in keeping the DC bus voltage constant. In remote or isolated regions where power grid cannot extend to stand-alone photovoltaic schemes have found a fairly wide application to meet the need for low but essential electric power consumption. A PWM Generator is used to provide the desired duty cycle to the buck as well as boost switches of the Bidirectional DC/DC Converter to keep the DC bus voltage constant by comparing the DC error voltage between the DC bus voltage and the reference voltage with a saw tooth pulse of desired frequency. A DC-DC boost converter is cascaded to the output terminal of PV array and duty cycle is maintained by MPPT to get the desired value of voltage so that the PV module can operate efficiently at maximum power point. The energy storage system employs a battery which provides safe, flexible, low cost and long duration energy storage.

The loads integrated at the DC bus are simple resistors for the sake of easy analysis although RL loads, which are most common, could also have been used. Five resistors of different ohmic values are switched at an interval of 1 second to represent variable load. Batteries and Ultra capacitors are some popular storage systems. Batteries have low output power density and can store large quantity of power but cannot provide large amounts of power within a short time. On the other hand, ultra capacitors have low storage potential but can provide large bursts of power within a short span of time. During the daytime, the PV array feeds active power to the grid through an inverter and provides charging current to the battery through the battery charger. The battery is in charged condition and the PV array cannot feed full power to the grid that is during partial cloudiness or during night time or when the solar irradiation is weak. In this mode of operation, PV array feeds the power to the grid based on maximum power point and the batteries also feed active power to the grid. The battery is in fully discharged state and the PV array cannot provide the charging current to the battery i.e. during night time. The grid provides the charging current to the batteries through the inverter and battery charger.

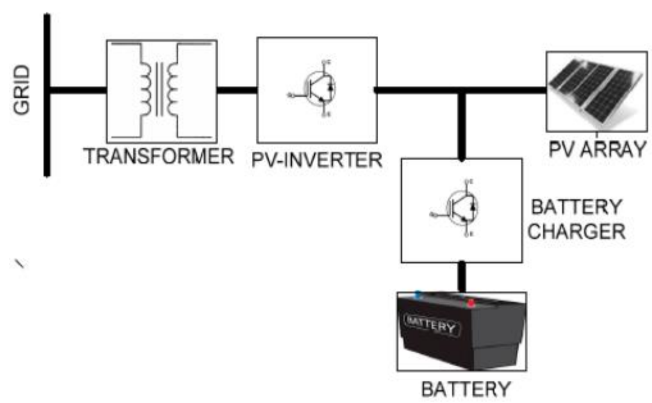

Fig. 1: Generalized Block Diagram of a Grid Energy Storage System in Photo Voltaic Applications

The different modes of operation of the above system are explained below:

i) Mode1

During the daytime, the PV array feeds active power to the grid through an inverter and provides charging current to the battery through the battery charger.

ii) Mode2

The battery is in charged condition and the PV array cannot feed full power to the grid i.e. during partial cloudiness or during nighttime or when the solar irradiation is weak. PV array feeds the power to the grid based on maximum power point and the batteries also feed active power to the grid.

iii) Mode3

The battery is in fully discharged state and the PV array cannot provide the charging current to the battery that is during night time. In this mode of operation, the grid provides the charging current to the batteries through the inverter and battery charger.

2. RELATED WORK

2.1 RENEWABLE ENERGY SOURCES

The worldwide demand for electricity continues to grow even as energy conservation measures and advances in power conversion efficiency reduce the consumption of individual loads. To feed the energy appetite of the world, renewable energy technologies are becoming feasible and offer alternative generation options that enable consideration of the impact on the environment and other social and economic factors. According to the U.S. energy information administration. Non-hydroelectric renewable energy is one of the fastest-growing energy sources; its contribution to total U.S. electrical generation is expected to reach 14% by 2035. While much of the current renewable generation is provided by wind, PV generation is enjoying tremendous growth worldwide. In the United States alone, grid-connected installations grew 102% to 878 MW of new PV generation in 2010, which brought cumulative installed capacity to 2.1 GW. Utility-installed PV represented only 28% of this growth, continuing a multiyear trend in which the growth in PV was led by nonutility installations.

2.1.1: Inverters

Since PV cells produce low-voltage, DC electricity, power electronics hardware is required to boost the voltage and convert the electricity from DC to grid-compatible AC. Wind power also requires power electronics to convert the output of the generator into grid-synchronized power and to provide voltage sag ride-through. Although inverter design is not a new concept, the performance and lifetime requirements of a renewable energy system are vastly different than those of other systems. As such, significant challenges remain in the areas of increasing the energy harvested from the sun, lowering the cost of components needed for the energy conversion, and improving reliability so as to eliminate replacement costs during the life of the system. A true turnkey PV system would have an inverter that carries a warranty of the same duration as its PV modules and other system components.

2.1.2: System Topology

In any PV system, numerous PV modules are interconnected to aggregate the power from each module. In a DC system topology, multiple PV modules are connected in series and a single inverter called a string inverter, provides the energy conversion and interconnection to the AC system. A newer option is an AC system in which smaller “micro-inverters” are located at each PV module and the power of each module is aggregated in the ac format. An inverter directly attached to a PV module is known as an AC PV module. Each system has advantages and disadvantages, including cost, reliability, energy harvesting effectiveness, and impact on balance-of-system requirements.

2.2: PHOTOVOLTAIC ENERGY MODULE

PV energy generating systems convert the sun’s energy directly into electricity using state-of-the-art semiconductor materials. PV systems produce clean, reliable energy without consuming fossil fuels and are used in a wide variety of applications. Some are called a “stand-alone or off-grid” system, which means they are the sole source of power to a home, water pump or other load. Stand-alone systems can be designed to run with or without battery backup. Remote water pumps are often designed to run without battery backup, since water pumped out of the ground during daylight hours can be stored in a holding tank for use anytime. In contrast, stand-alone home power systems often store energy generated during the day in a battery bank for use at night. Stand-alone systems are often cost-effective when compared to alternatives such as utility line extensions. Other PV systems are called “grid-connected” systems.

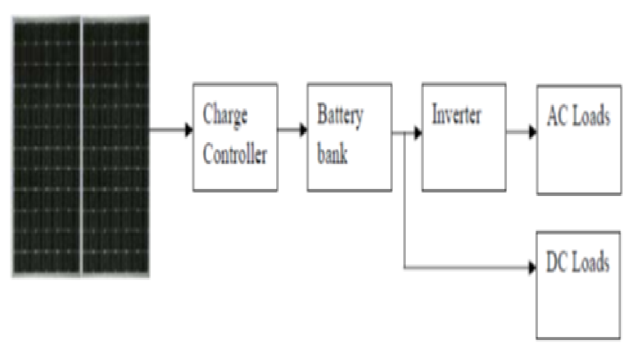

Fig. 2: Stand-Alone PV System

2.2.1: The Photovoltaic Effect

The basic unit of a photovoltaic system is the photovoltaic cell. It generates electricity because the cell’s materials give it an electric potential and are sensitive to sunlight. The photovoltaic cell consists of thin layers of semiconducting material, prepared as wafers or films, most commonly made from silicon cells which are one of the earth's most abundant elements. Silicon's natural properties as a semiconductor of electricity make it an ideal material for photovoltaic cells. Its electric properties are modified by two other elements, boron and phosphorus to create a permanent imbalance in the molecular charge of the material.

A solar cell is made up of two layers of semiconductor material. Two regions are created, a positively charged region and a negatively charged region. These layers create an electric potential within the cell. Light energy striking the cells free electrons from some of the atoms in the cell material. The cell's internal potential pushes these free electrons toward one of the layers. When one end of a wire is attached to this layer and the other end is attached to the second layer, the free electrons will flow through the wire, creating an electric current.

2.2.2: Photovoltaic Array

A photovoltaic array is a linked collection of photovoltaic modules, which are in turn made of multiple interconnected solar cells. The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can plug into the existing infrastructure to power lights, motors and other loads.

The modules in a PV array are usually first connected in series to obtain the desired voltage the individual strings are then connected in parallel to allow the system to produce more current. Solar arrays are typically measured by the electrical power they produce in watts, kilowatts, or even megawatts.

2.2.3: Electrical Characteristics of PV Modules

The industry standard against which all PV modules are rated and can be compared is called STC. STC is a defined set of laboratory test conditions which approximate conditions under which PV modules might be used. The same standard is also used to evaluate potential installation locations, since it is the basis for Insolation values. STC includes three factors:

i) Irradiance (sunlight intensity or power) in Watts per square meter falling on a flat surface. The measurement standard is 1 kW per sq. m. (1,000 Watts/m2)

ii) Air Mass refers to "thickness" and clarity of the air through which the sunlight passes to reach the modules (sun angle affects this value). The standard is 1.5.

iii) Cell temperature which will differ from ambient air temperature. STC defines cell testing temperature as 25 degrees C.

3. PORPOSED MODELLING

3.1: BLOCK DIAGRAM OF PROPOSED SYSTEM

Figure 3 shows the proposed topology consists of energy storage system in the form of batteries onboard the electric train combined with the DC/DC bidirectional chargers which integrates it to the PV system. DC/DC converter serves the purpose of controlling the terminal voltage of PV array for carrying out MPPT operation. Incremental Conductance algorithm is utilized as the MPPT method.

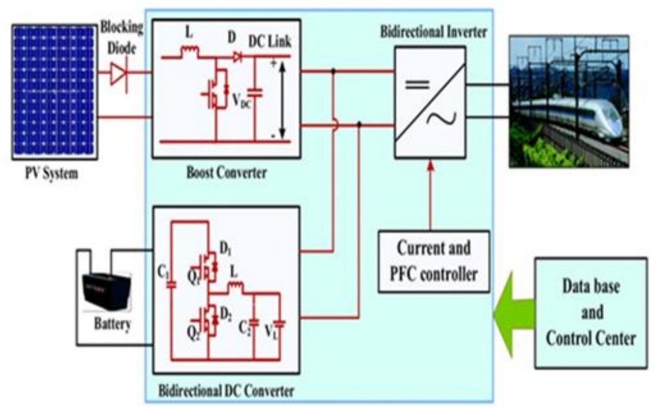

Fig. 3: Block Diagram of Proposed work

The DC/AC inverter and the DC/DC converter of boost type manage the power flow between PV array, battery, load and utility. In the case of enough solar insolation, the DC/DC converter charges the battery and PV arrays supply power to the load through DC/AC inverter. In the case of non-insolation or less insolation, the stored energy in battery should be delivered to load through Boost DC/DC converter and bidirectional DC/AC inverter. Therefore, the switch mode DC/DC Step Up converter must be able to conduct bi-directionally in order to charge and discharge the battery. A high voltage DC bus acts as a point for integration of bidirectional DC–DC train chargers, hence efficiently utilizing the already existing inverter setup for integration with the grid. The proposed architecture augments DC charging capability which becomes fast and highly efficient as it consumes power directly from the PV module or the power grid. Employing the same DC/AC bidirectional inverter for both charger and PV functions reduces hardware cost. Efficient delivery of real power to the grid at unity power factor is the primary function of the grid-tied PV inverters. The prime function of grid-tied PV DC-AC inverters is to deliver real power to the grid as efficiently as possible at unity power factor. As mentioned the extra remaining capacity of the bidirectional inverter can be utilized to provide additional grid supporting functions such as generation of reactive power and fast compensation of flicker.

3.2: PROPOSED CONTROL ALGORITHM

In order to maintain the DC bus voltage at a constant value, which is chosen as 500 V in this proposed topology and to ensure power flow balance in the circuit, the following algorithm has been proposed based on the different voltage level of the DC bus.

This method uses the incremental conductance dV/dI to compute the sign of dP/dV. When dV/dI is equal and opposite to the value of V/I the algorithm knows that maximum power point has reached and there it ends and returns the corresponding value of operating voltage for MPP. One problem is that it requires many sensors like voltage and current to operate. The proposed algorithm is shown in Fig. 4.

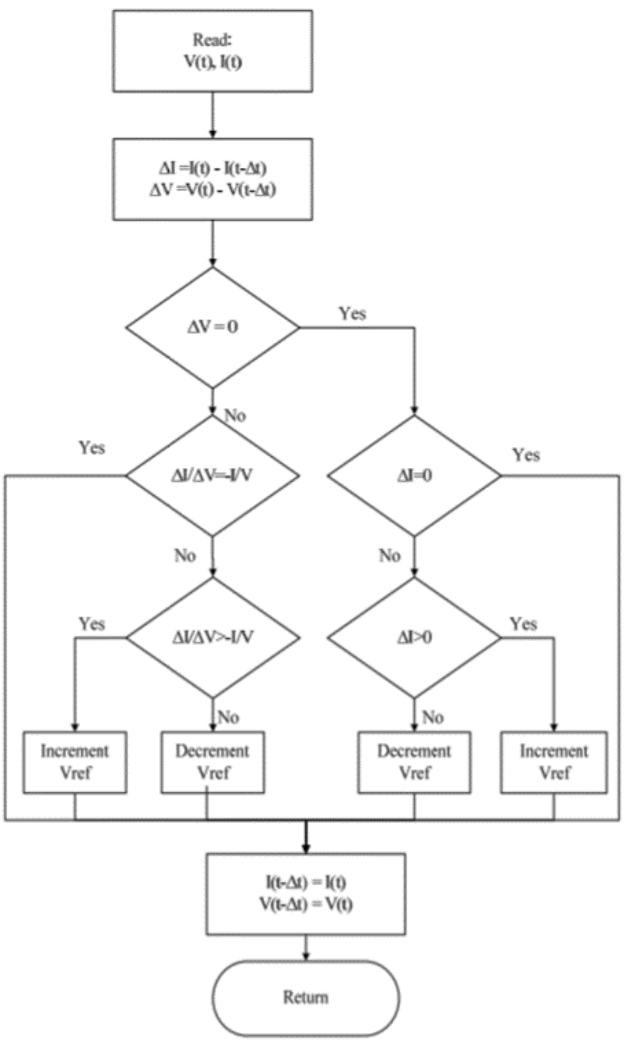

Fig. 4: Incremental Conductance Algorithm

4. CONCLUSION

The control circuit of Bidirectional DC/DC Converter with MPPT controller for photovoltaic system is develop to analyze its performance is explained. The simulation study is done on MATLAB/SIMULINK. The simulation results clearly show that the MPPT tracks the maximum power point effectively. The result shows that during charging, the power is effectively transferred to the battery and similarly during discharging, the power is transferred back to the supply. The result shows that the battery and PV system is meeting the load demand at all times. A grid connected PV system coupled with energy storing batteries with application to electric train is presented in this seminar. Hysteresis control is used as the current control technique which allows interfacing with the grid through the DC link. Easy implementation and reduction on the hardware costs are some of its benefits. Application to transportation network, especially the railways will lessen the power demands from the grid and is more economical in the long run.

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