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Modelling and Simulation of High Gain Hybrid Boost Converter

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Abstract – The Power electronic converters are needed to interface renewable energy sources with the load along with energy storage in stand-alone commercial applications. Recently, the converters have attracted attention for such applications since the port connected to the energy storage to allow bidirectional power flow. The former systematic method of two coupled inductor which used to step up the voltage from input load. In this a complex procedure is needed to step up the voltage, the more number of switches are required to step up the voltage with alone with the coupled inductors. Due to the increasing number of switches influences a higher level of switch loss. The system efficiency was improved by using two sets of active-clamp circuits. Also the former converter is open loop circuit. A High step up three port DC-DC H-bridge converter for standalone PV/battery systems is the proposed system in which the step up can be done with single step up transformer alone and also improved efficiency. In addition to that less number of power switches needed for the system compared to the existing system. The proposed system is the closed loop circuit is the added benefit to the proposed system.

Index Terms – Maximum Power Point Tracking - MPPT, Photovoltaic - PV, Pulse Width Modulation - PWM, Three Port Converter - TPC.

1. INTRODUCTION

There are many types of renewable energy such as solar, wind, tidal and geothermal etc. Among these natural resources power generation by using photovoltaic (PV) become more popular because of its clean and pollution free operation. In an environment with electrical power generation causes so many pollutions, the solar power generation is a perfect solution. The main reason for pollution free operation is that, the conventional energy sources like fossil fuels, coal, petrol, diesel etc. is not using in solar power generation. So that the greenhouse gases like CO, SF_6, CFC, PF_6, are not produced during the solar power generation. Hence, Global warming can be reduced by using such a pollution free power generation. Moreover the solar power generation is quiet and abundant in nature. So the cost of the fuel and transportation cost can be reduced. The most important attraction is that the maximum power can be obtained by using various maximum power points tracking method. The solar power generation can be said to a long term substitute for the electricity crisis [1].

The photovoltaic energy is currently considered to be one of the most useful natural energy sources because it is free, abundant, pollution free, and distributed throughout the Earth. The PV array normally uses a maximum power point tracking (MPPT) technique to continuously deliver the highest power to the load when there are variations in irradiation and temperature. The disadvantage of PV energy is that the PV output power depends on weather conditions and cell temperature, making it an uncontrollable source. Furthermore, it is not available during the night. However, the present energy conversion efficiency of the PV array is still low. Therefore, in order to achieve maximum utilization efficiency, which extracts the maximum possible power from the PV array, is essential in systems powered by the PV array [2].

The Integrated multiport converters for interfacing several power sources and storage devices are widely used in recent years. Instead of using individual power electronic converters for each of the energy sources, multiport converters have the advantages including less components, lower cost, compact in size, and better dynamic performance. In many cases, at least one energy storage device should be incorporated. A boost converter with coupled inductor and active clamp circuit are present in the circuit [3]. This boost converter can yield a high step-up voltage gain, reduce the voltage stress on switches, and recycle the energy in the leakage inductor. The integrated three-port converters derived from a half-bridge converter are presented to interface PV and battery power. The transformer provides full isolation among all ports and wide input voltage range. The switching losses are reduced due to soft-switching operation. A family of three-port half-bridge converters is described and the primary circuit can function as a synchronous rectification buck converter. Therefore, the converters are also suitable for stand-alone step-down applications [4].

The Photovoltaic (PV) power generation has an important role to play due to the fact that it is a green source. The only emissions associated with PV power generation are those from the production of its components. After the installation it can generate electricity from the solar irradiation without emitting greenhouse gases. In the 25 years of lifetime, PV panels produce more energy than that for their manufacturing. Also they can be installed in places with no other use, such as roofs and deserts, or they can produce electricity for remote locations, where there is no electricity network [5].

The latter type of installations is known as off-grid facilities and sometimes it is the most economical alternative to provide electricity in isolated areas. However, most of the PV power generation comes from grid connected installations, where the power is fed in the electricity network. In fact, it is a growing business in developed countries such as Germany, which in 2010, is by far the leading in PV power generation followed by Spain, Japan, USA and Italy. On the other hand, due to the equipment required [6], PV power generation is more expensive than other resources. Government are promoting it with subsidies or feed-in tariffs, expecting the development of the technology so that in the near future it will become competitive. Increasing the efficiency in PV plants so the power generated increases is a key aspect, as it will increase the incomes, reducing consequently the cost of the power generated so it will approach the cost of the power produced from other sources [7], [8].

The efficiency of a PV plant is affected mainly by three factors: the efficiency of the PV panel, the efficiency of the inverter (95-98 %) and the efficiency of the maximum power point tracking algorithm (which is over 98%). Improving the efficiency of the PV panel and the inverter is not easy as it depends on the technology available, it may require better components, which can increase drastically the cost of the installation. The MPPT algorithm has also certain limitations in increasing the efficiency of the solar power generation [9]. The fast improving technologies motivates every researcher to take bold steps towards power optimization and hence innovative efforts in each field have started budding and one such is in the area of hybridization of renewable energy sources. The power quality aspects, controller design, development of dynamic model, optimum power retrieval are comparatively analyzed in view of obtaining a beneficial record over the past years and to acquire better future in power management [10], [11].

The three input DC–DC boost converter interfaces two unidirectional input power ports and a bidirectional port for a storage element in a unified structure. This converter is interesting for hybridizing alternative energy sources such as photovoltaic source, fuel cell source and battery. Supplying the output load, charging or discharging the battery can be made by the PV and the FC power sources individually or simultaneously. This converter structure utilizes only four power switches that are independently controlled with four different duty ratios. Utilizing these duty ratios, tracking the maximum power of the PV source, setting the FC power, controlling the battery power, and regulating the output voltage are provided. Depending on utilization state of the battery, three different power operation modes are defined for the converter. In order to design the converter control system, small signal model is obtained in each operation mode. Due to interactions of the converter control loops, decoupling network is used to design separate closed loop controllers [12].

2. PHOTOVOLTAIC CELL

Solar cells are the basic components of photovoltaic panels. Most are made from silicon even though other materials are also used. Solar cells works on the principle called as photoelectric effect. The ability of semiconductor to convert electromagnetic radiation directly into electrical current is called as photoelectric effect. The charged particles generated by the incident radiation are separated conveniently to create an electrical current by an appropriate design of the structure of the solar cell; a solar cell is basically a p-n junction which is made from two different layers of silicon doped with a small quantity of impurity atoms. In the case of the n-layer, atoms with one more valence electron, called donors, and in the case of the p-layer, with one less valence electron, known as acceptors. When the two layers are joined together, near the interface the free are joined together, near the interface the free electrons of the n-layer are diffused in the p-side, leaving behind an area positively charged by the donors [13], [14].

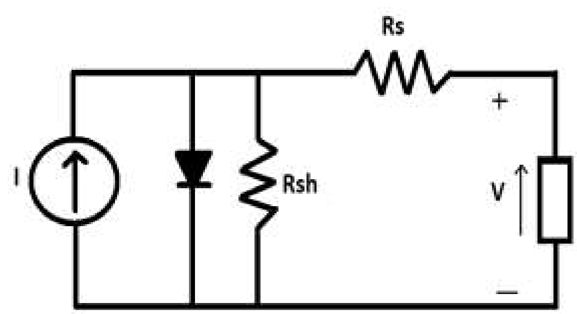

Figure 1 Equivalent circuit of PV cell

Similarly, the free holes in the p-layer are diffused in the n-side, leaving behind a region negatively charged by the acceptors. This creates an electrical field between the two sides that is a potential barrier to further flow. The equilibrium is reached in the junction when the electrons and holes cannot surpass that potential barrier and consequently they cannot move. This electric field pulls the electrons and holes in opposite directions so the current can flow in one way only electrons can move from the p-side to the n-side and the holes in the opposite direction. Metallic contacts are added at both sides to collect the electrons and holes so the current can flow. In the case of the n-layer, which is facing the solar irradiance, the contacts are several metallic strips, as they must allow the light to pass to the solar cell [15], [16]. The Figure 1 shows the equivalent circuit of photovoltaic cell.

3. THREE-PORT CONVERTER

The primary side of the converter consists of two switching legs, composed of S_{A1}, S_{A2} and S_{B1}, S_{B2} in parallel, connected to a common input source V_s. For the primary side of the converter, the constraint of the operation of converter is the voltage second balance principle of the magnetizing inductor L_m. This means that, from a topological point of view, the two switching legs of the converter can also be split into two symmetrical parts, cells A and B, if only L_m satisfies the voltage-second balance principle, The two cells can be connected to different sources V_{sa} and V_{sb} respectively, as shown in Figure 2.

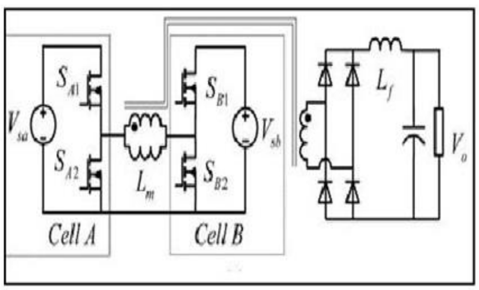

Figure 2 Three Port Converter

The voltage of the two sources of the three port converter (TPC) can be arbitrary. Specially, if V_{sa} always equals V_{sb}, the two cells can be paralleled directly and then the conventional converter is derived. Close observation indicates that the TPC has a symmetrical structure and both V_{sa} and V_{sb} can supply power to the load V_o.

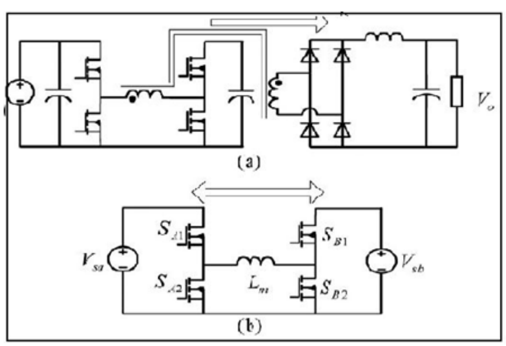

Figure 3 Equivalent circuits. (a) Between source and load,

(b) Between the two sources

The equivalent circuit from one of the source ports to the load port is shown in Figure 3 (a). In addition, a bidirectional buck-boost converter is also integrated in the primary side of the TPC by employing the magnetizing inductor of the transformer L_m as a filter inductor. With the bidirectional buck-boost converter, the power flow paths between the two sources, V_{sa} and V_{sb}, can be configured and the power can be transferred between V_{sa} and V_{sb} freely. The equivalent circuit between the two sources is illustrated in Figure 3 (b). It can be seen that the power flow paths between any two of the three ports, V_{sa}, V_{sb} and V_o have been built. Ignoring the power loss in the conversion:

$$P_{pv} = P_b + P_o \qquad (1)$$

where P_{pv}, P_b and P_o are the power flows through the PV, battery, and load port, respectively. The FB-TPC has three possible operation modes: 1) dual-output (DO) mode, with $P_{pv} \geq P_o$, the battery absorbs the surplus solar power and both the load and battery take the power from PV; (2) dual-input (DI) mode, with $P_{pv} \leq P_o$ and $P_{pv} > 0$, the battery discharges to feed the load along with the PV; and (3) single-input single-output (SISO) mode, with $P_{pv} = 0$, the battery supplies the load power alone. When $P_{pv} = P_o$ exactly, the solar supplies the load power alone and the converter operates in a boundary state of DI and DO modes. This state can either be treated as DI or DO mode. Since the TPC has a symmetrical structure, the operation of the converter in this state is the same as that of SISO mode, where the battery feeds the load alone. The switching states in different operation modes are the same and the difference between these modes are the value and direction of iL_m, which is dependent on the power of P_{pv} and P_o . In the DO mode, iL_m is positive, in the SISO mode, iL_m is negative, and in the DI mode, iL_m can either be positive or negative [17], [18].

4. PWM TECHNIQUES

Mainly the power electronic converters are operated in the "switched mode". Which means the switches within the converter are always in either one of the two states; turned off (no current flows), or turned on (saturated with only a small voltage drop across the switch). Any operation in the linear region, other than for the unavoidable transition from conducting to non-conducting, incurs an undesirable loss of efficiency and an unbearable rise in switch power dissipation [19]. To control the flow of power in the converter, the switches alternate between these two states (i.e. on and off). This happens rapidly enough that the inductors and capacitors at the input and output nodes of the converter average or filter the switched signal. The switched component is attenuated and the desired DC or low frequency AC component is retained. This process is called Pulse Width Modulation (PWM), since the desired average value is controlled by modulating the width of the pulses [20], [21].

For maximum attenuation of the switching component, the switch frequency f_c should be high, many times the frequency of the desired fundamental AC component f_1 seen at the input or output terminals. In large converters, this is in conflict with an upper limit placed on switch frequency by switching losses [22], [23]. For GTO converters, the ratio of switch frequency to fundamental frequency f_c/f_1 (= N, the pulse number) may be as low as unity, which is known as square wave switching. Another application where the pulse number may be low is in converters which are better described as amplifiers whose upper output fundamental frequency may be relatively high. These high power switch mode amplifiers find application in active power filtering test signal generation servo and audio amplifiers. These low pulse numbers place the greatest demands on effective modulation to reduce the distortion as much as possible [24], [25].

The low pulse numbers place the greatest demands on effective modulation to reduce the distortion as much as possible. In these circumstances, multilevel converters can reduce the distortion substantially, by staggering the switching instants of the multiple switches and increasing the apparent pulse number of the overall converter [26]. The PWM schemes of different converters are usually different from each other and mainly determined by the topology [27]. For better analysis of the PWM scheme of the TPC, the control circuit diagram for the three-port converter is shown in Figure 4.

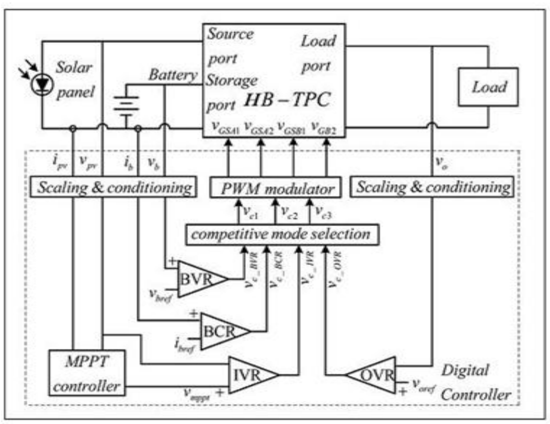

Figure 4 Control diagram for three-port converter

The four regulators having the following application such as: PV voltage regulator (VR) for MPPT, battery voltage regulator (BVR) for maximum voltage charging control, battery current regulator (BCR) for maximum current charging control, and output voltage regulator (OVR) for output voltage control, are used to implement the power management of the system. With the control diagram shown in Figure 4, the TPC can work in the DO, DI, or SISO mode, depending on the relationship between the PV power and load power However, iL_m can be decreased by increasing D_{A1} and D_{B1}. To decrease the magnetizing inductor current of the transformer, D_{A1} and D_{B1} should be as large as possible. According to the switching state analysis, it can be seen that, as shown in Figure 4. The smaller the D_1, the larger the D_{B1} Therefore, The maximum value of D_{B1} is D_{B1} max = $D_{A1} + D_3$.

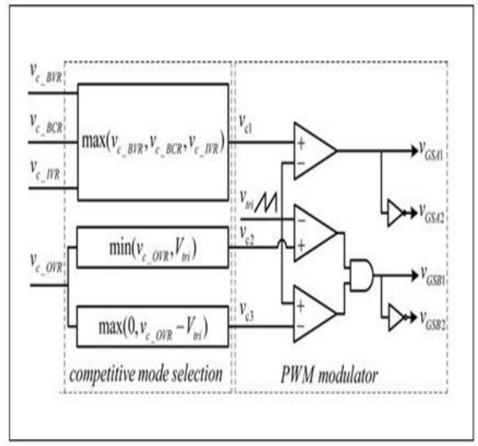

Figure 5 PWM Generation

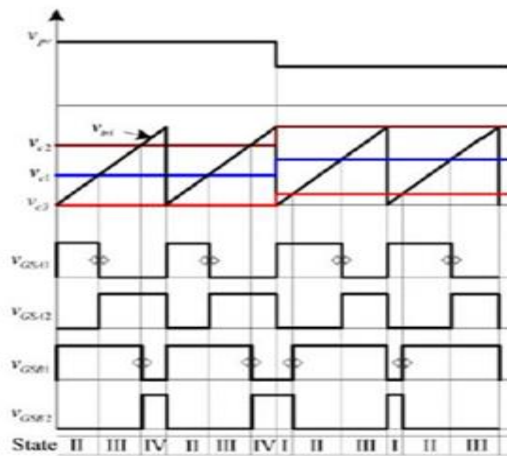

Figure 6 PWM scheme for the TPC

Based on the analysis, the proposed PWM scheme and its generation are illustrated in Figure 5, where V_{tri} is the peak-to-peak value of the carrier voltage V_{tri} , and V_{c1} , V_{c2} and V_{c3} are control voltages generated by using a competitive method. With the proposed PWM scheme, when V_{pv} is much higher than V_b, $V_{c2} < V_{tri}$, and V_{c3} stays at zero, D_{B1} will reach its maximum value, as shown in Figure 6. There are only three switching states, states II–IV, in one switching cycle. This means that by regulating the turned OFF time of S_{A1} with V_{c1}, the PV power can be controlled to achieve the MPPT, or battery charging control and output voltage V_o is further controlled with V_{c2} regulating D_3 by adjusting the turned OFF time of S_{B1} .When V_{pv} decreases and $V_{c2} \le V_{tri}$, D_{A1} will reach its maximum value $V_{c2} = V_{tri}$ and $V_{c3} \ge 0$, then V_o is controlled with V_{c2} by regulating the turned ON time of S_{B1} , as shown in Figure 6, and there are three switching states, states I–III, in one switching cycle. With the proposed PWM scheme, the converter can adapt to different input voltages while minimizing the magnetizing inductor's current of the transformer [28] - [31].

5. SIMULATION RESULTS

In Figure 7 shows the simulation model of three port converter. In that model the MOSFET is used as a switch for the best performance of voltage control, fast switching and low losses. When the MOSFET switch is closed supply voltage is connected to inductor and the inductor current starts to increase and store the energy. When the MOSFET switch is opened the inductor current starts to decrease. The Figure 8 (a) and 8 (b) show the simulation results of inductor current L_1, L_{1K}, L_2 and L_{2k} of the three port converter.

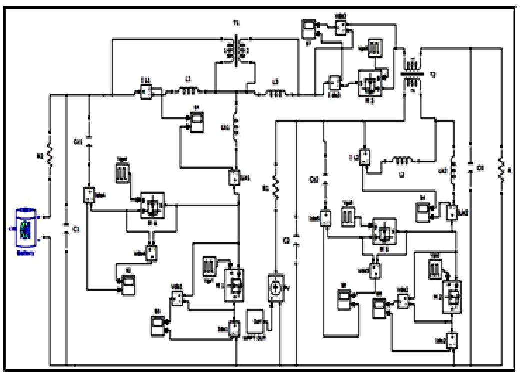

Figure 7 Simulation diagram

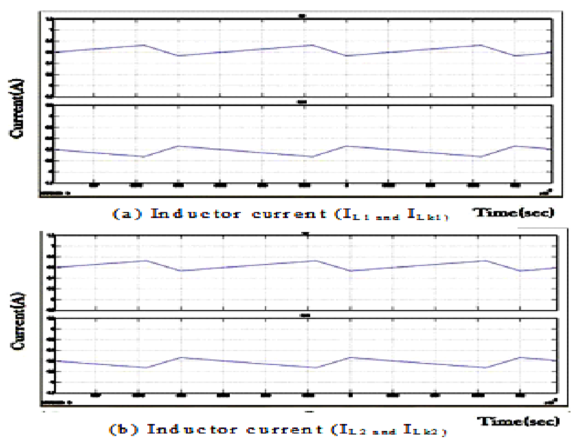

Figure 8 Inductors current (a) I_{L1}, I_{Lk1}, and (b) I_{L2}, I_{Lk2}

6. CONCLUSION

This paper presented with the integrated operation of two switching cells, connecting the two cells to different sources and utilizing the magnetizing inductance of the transformer. Which is aimed to handle a wide range of source voltage and utilizing the energy stored in the leakage inductance of the transformer, this result in high conversion efficiency, The proposed converters offer the advantages of simple topologies and control, reduced number of devices, and a single-stage power conversion between any two of the three ports. They are suitable for renewable power systems that are sourced by solar, thermoelectric generator, etc., with voltages varying over a wide range. The analysis of operating principles and the signal waveforms and load waveforms are also done by using the simulation results. MATLAB/SIMULINK is used for the simulation of the proposed system.

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