Design and Analysis of Soft Switched Grid Connected Three Phase Inverter

In this paper a high frequency AC link three phase inverter is used for interface between input and the three phase grid is studied and analyzed in more detail. AC link converters are extension of buck boost converters and named as universal converters because of its variety of configurations and also used for different types of inputs and outputs. These converters are excellent choice for renewable energy sources over the other converter topologies. These converters have remarkable advantages like partial soft switching, isolation, compact size and elimination of DC link capacitor. In this paper, the complete switching scheme is developed in relation with the output reference currents and line to line grid voltages. The fundamental operation is explained and verified in the PSIM simulation environment.

The necessity of electrical energy escalating day by day. Since the restriction on non-renewable energy sources, its inadequacy, its prices and impact on ecology leads to significant research on alternative renewable energy sources like wind and solar power. Power electronic converters play a vital role integration of renewable energy sources to utility loads. On the other hand, these power converters have a problem in reliability aspect.

In photovoltaic systems the most failure incidents are taking place due to the inverter failures as per the report of Sandia National Laboratories [1]. The lifetime of the PV system is more in comparison with the life of the inverter, which leads to untrustworthy in renewable technology. So, there is a need for new power converters which can ensure higher reliability and long life of renewable energy systems. Formerly many converter topologies are proposed to integrate renewable energy sources and different loads. For solar applications the most commonly used topology is a centralized converter based PV system. In which a low frequency transformer is used for to step up the voltage and to provide galvanic isolation. Low frequency transformers are not appreciated because of their bulky size and low efficiencies. To overcome the above mentioned problems the multiple stage conversion systems are widely used for renewable energy systems.

These converters consists of DC-DC converter and DC to AC inverter. DC-DC converter consists of high frequency transformer which can minimize problems in previous topology. Even though it has advantages with high frequency transformer, this converter has multiple stage conversion which lowers the efficiency of overall system and it requires bulky electrolytic capacitor to maintain dc link. The electrolytic capacitor is one of the most unreliable component in the converter topology because they are very sensitive to the temperature variations and its lifetime will be reduced half, with the increase of temperature around 10oC.

Many topologies have been developed to partially overcome the aforementioned problems [6-8]. High-frequency ac-link inverter topologies [9-14] are outstanding solutions to overcome most of the problems associated with the existing inverter topologies. These partial resonant ac link converters are new class power converters called universal power converters because input and output can be dc or ac and single phase or multi-phase. In these topologies the ac link formed by parallel LC pair, here the main energy transfer element is inductor and the very small capacitor used for the resonant operation which can responsible for zero voltage turn on and soft turn off of the switches. The remarkable advantages with these topology are elimination large electrolytic capacitor improves reliability, inductor can be replaced with high frequency transformer in order to achieve galvanic isolation, low EMI and high frequency of operation leads to small size of filter components.

Ac-link universal power converter was first proposed in [9] , later authors carried studies on such converters [10-14]. But those works didn’t provide sufficient information related designated functional switches in relation with the comparison of output voltages and reference currents. In this paper, the complete switching control strategy is described in relation with the output voltages and reference currents for three phase ac link inverter. Furthermore, the unfiltered output current waveforms and the corresponding control signals of an analyzing case are discussed and shown in simulation section. The basic converter operation along switching control scheme is presented in section II. Section III will explains the design procedure and analysis of converter. Simulation and results analysis are presented in section IV. Conclusions are presented in section V.

Ac link converter operation

The partial resonant three phase ac link inverter is shown in Fig.1. This topology consists of two bridges along with parallel LC resonant pair. A single phase bridge is present between the input and LC link, here the reverse blocking MOSFET/IGBT is employed instead of normal MOSFET/IGBT in order to restrict the reverse current flowing into the source. The other bidirectional three phase bridge is connected between LC pair and grid/load.

Partial Resonant Ac-Link Inverters transfer the power indirectly from source to load through resonant LC pair. The link is charged from source and discharged in to the grid during charging and discharging modes alternatively and a resonant mode is present in between every charging or discharging mode to achieve the benefits from the soft switching. For the proper operation it is required to calculate the output reference currents. The output reference currents can be calculated simply from the below Eq.1. The remaining output reference currents can be calculated similarly but with the addition of phase shift. In order to have unity power factor reference current should be at same phase of the corresponding grid phase voltage.

Iar=?2*(Pin-Pcloss)/(?3 Vlo)*sin?(2?fo*t) (1)

Where Pin is the total input power depending on the source, PCloss is the probable power loss, VOL is the output line rms voltage, and grid frequency is represented with fo.

The operation of soft-switched ac link inverter consists of several modes in each link cycle, depending on the number of output phases and number of inputs. It has 12 modes of power transfer modes and six resonating modes. The part of switching strategy is can be explained by a flow chat for a mode 3 operation and total switching strategy and corresponding switches that are to be turn on are given in the Table 1 below. In charging mode the inductor charged up to the maximum value of the reference currents and then during discharging mode it will be discharged in to the corresponding phases depends on the conditions that are shown in the Fig.3. In order to select the corresponding phase firstly identify the maximum reference current and its sign , later check the voltage conditions as per the flow chat and then turn on the corresponding switches. Similarly the proper switches for remaining modes of operation can be identified.

A detailed description of modes of operation is as follows. Mode 1:

In this mode input supply energizes the link inductor as shown in Fig. 4. Switches S1 and S3 which are supposed to conduct in this mode are activated in previous mode, although the switches are activated but they do not conduct immediately, Because the link resonates in such a way that the voltage across the link keep the switches in reverse biased condition. Once the link voltage equals the input voltage (Vin), switches starts conducting and the link current starts rising linearly till it reaches to maximum reference current as shown in mode 1 of Fig. 2. Mode 2:

The switches S1 and S3 are turned off and the switches that to be conducted for proper discharge operation are turned on during capacitor reverse charging. For to know the switches to be conducted in discharging modes, identify the maximum reference currents (Iar,Ibr,Icr) and its sign. Based on that compare line to line voltages and decide the phase pair that shown in Table I . For example the instantaneous reference currents are Iar=20,Ibr=-15 and Icr=-5 then phase pairs ab and ac are chosen for power transfer from link to output. Now compare volatges Vab and Vac ,the phase pair which have smaller line to line voltage are connected in mode 3 operation. Suppose if Vab=300v and Vac =100v then ac phase pair will be connected in mode 3 and ab pair will be connected in mode 5. For the above case the switches to connect ac pair (S8 and S14) are turned on, but none of the switches will conduct. The LC link starts resonating as shown in Fig.5, during which voltage across the link starts reversing and facilitating the switch to turn on at zero voltage and soft turnoff of switches S1 and S3. Once the link voltage equals the phase pair voltage appropriate switches starts conducting and the mode 3 will start. Mode 3:

Once the switches are turned on, link starts discharging energy into the grid as shown in Fig.6. These switches should be turned off when the link current reaches to the reference current Ibr. So again it enters in to the resonating mode. Mode 4:

None of the switches will be conducted in this mode. The corresponding switches for the mode 5 are turned on in this mode, even though they will not conduct until the capacitor voltage swings from Vac to Vab. Mode 5:

In this mode the link voltage is established to Vab and the link discharges energy into ab phase. These switches should be turned off before there is some energy left in the link as shown in Fig.2, to alter the link current with the help of link capacitor voltage. All the switches are turned off at the end of this mode. Mode 6:

During this mode absolute link voltage will increases initially and then it reduces. The proper switches for the next mode is turned on in this mode but they are not turned on immediately as they are reverse bias in nature. When link voltage reaches to negative of input voltage the switches become positive bias and start next mode.

Modes 7 to 12 are similar to modes 1 to 6, except that the link charges and discharges in the reverse direction. For these modes the switching strategy is given in Table I.

Design procedure and analysis

A detailed design procedure is explained here. The resonating time, which is much shorter than the power transfer time at full power, will be neglected. Moreover, the assumption taken for discharging of link is in one equivalent mode instead of two different modes in each half of the link cycle. For this the equivalent outputs can be computed as follows:

A 100 KW ac link inverter system has been simulated using PSIM simulation software. In Table II the parameters for the ac link inverter are presented. The total control logic has been programmed in order to get the proper gate signals. Fig.8. represents the link Voltage and Link current it can be seen that they both are alternating.

The link current and all the unfiltered phase currents of are shown in Fig.9. from this we can differentiate the different modes of link cycle. The frequency of link currents or link voltages are 5 kHz based on the prior design calculations. The unfiltered currents 50Hz of all the phase are shown in Fig.11. LC filter used to filter out the output currents and the filter parameters are given in Table II. The three phase currents are injected in to grid are shown in Fig.12.

In this paper a soft switched ac link three phase inverter connected to grid is studied in detail. The link components inductor and capacitor operate with high frequency ac currents and voltage. Here there is no requirement of DC link capacitor and low frequency transformer. Isolation is achieved by using high frequency transformer instead of inductor. In this paper the complete switching scheme is evaluated through simulation and design procedure were studied.