Volume 9, Issue 4
August 2020

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X



# A review of Single-Phase Inverter Topology for Grid Connected Small Distributed Renewable Energy Generation

[1]Mohammad Akram Syed, [2]Gunwant Ajabrao Dhomane and [3]Praful Vijay Nandankar

[1]Department of Electrical Engineering, GCoE, Chandrapur, M.S. INDIA

[2]Department of Electrical Engineering, GCoE, Chandrapur, M.S. INDIA

[3]Department of Electrical Engineering, GCoE, Chandrapur, M.S. INDIA

E-mail: [1]masyed705@gmail.com, [2]gadhomane@gmail.com, [3]pppful@gmail.com

## ABSTRACT

This paper focuses on inverter technologies for industrial and grid connected applications. The injection of photovoltaic power into the utility grid has gained attention in renewable energy generation and distribution. The development of modern and innovative inverter configurations have improved parameters like efficiency, size, weight, reliability etc. which in turn influences the cost of producing inverters. In this paper, various inverter topologies are presented depending upon the number of power processing stages, the type of power decoupling between the PV module and grid, whether they utilizes a transformer (either line or high frequency) or not and the type of grid-connected power stage. Single-stage inverters provides a simple structure and low cost but suffers from limited range of input voltage variations whereas multiple stage inverters provides a wide range of input voltage variations but suffers from high cost, complex structure and low efficiency. Some transformer-less topologies based on hybrid and multilevel techniques and some soft-switching inverter topologies are also discussed which are desirable for high efficiency, low cost and compact structure. The use of advanced semiconductor devices and de-coupling capacitor are also indicated for further increase of efficiency and lowering the cost.

**Keywords:** *Photovoltaic power, single-stage inverters, multiple stage inverter, soft-switching inverter, de-coupling, multilevel inverter.*

## 1. INTRODUCTION

Renewable energy, now a days is considered essential in order to meet present and future energy needs [1]. Photovoltaic power is clean and unlimited source of energy and is considered best amongst all renewable energy sources. For proper utilization of PV power, grid connection of PV systems is required. The injection of PV power to the utility grid is fastest growing areas and has drawn a lot of attention of policy makers [2]. Photovoltaic (PV) power supplied to the utility grid is becoming more popular due to increase in world's power demand. But cost of PV modules comprises 30%-50% of total cost of the grid connection of PV systems [3]. PV systems are relatively more costly as compared to other traditional energy sources such as oil, gas, coal, nuclear, hydro and wind. Solid-state inverter acts an interface between PV power and grid which enables the injection of PV power into the grid system. The price of PV modules contributes a major part in cost of these systems. But due to large scale production of PV modules, the price of PV modules is declining. A cost reduction per inverter watt makes interconnection of grid with PV modules more attractive [4]. The grid connected inverters have evolved in the last 2-3 decades and now it is considered as one of the fastest developing technologies in field of power electronics. The development of modern and innovative inverter configurations have improved efficiency, size, weight, reliability, installation costs etc. significantly which in turn influences the cost of grid connected PV systems. The further research in reduction of cost of these systems is still undergoing.

The inverter with high frequency transformer has less volume and weight as compared to inverter with line frequency transformer. Transformer-less inverters are produced now a days due to high efficiency and low cost [4-5]. If more than two-level output voltage is producer, the inverter cost is further reduced. Due to this reason, a lot of research has been done in the field of multilevel inverters [6]. The application of two-level voltage source inverters were restricted to low-voltage and medium power applications due to voltage and power ratings constraints on semiconductor devices. These types of inverters also suffer from high switching losses due to high switching frequency operation. These drawbacks give rise to concept of multilevel inverters. The MLI came in to existence in 1975.The proposed topology which comprises of series connection of full-bridge power cells and each cell is made of isolated DC source and four switches [7]. This topology produces a staircase AC voltage at then output side and it was named as cascaded inverter. Baker proposed a new three level voltage source invertor topology named as diode clamped or neutral point clamped (NPC) inverter in 1980. In this topology, diodes were used to clamp the voltage across the switch to mid-point DC link voltage or voltage across a DC link capacitor [8].

Related to reducing the number of components in CHB ML inverter and according to a binary or tertiary sequence manner the selection of unequal DC voltage sources was presented in [9-11], thus these topologies is further classified as an asymmetric topology [12]. Barbosa et al. in 2005 combined the attributes of NPC and FC MLIs and developed the active neutral point clamped (ANPC) converter topology [13]. Barbosa et al. in 2005 combined the attributes

Volume 9, Issue 4
August 2020

**ITEE Journal**
Information Technology & Electrical Engineering

ISSN: - 2306-708X



of NPC and FC MLIs and developed the active neutral point clamped (ANPC) converter topology [13]. A novel seven-level asymmetric hybrid MLI was presented by Manjrekar et al. in 2000 for high power applications by cascading high voltage (HV) and slow switching IGCTs based on H-bridge with the fast switching and low voltage IGBT based on H-bridge inverter [14]. A high frequency transformer based on 27-level asymmetrical inverter was implemented by Dixon et al. and they use a single DC source for traction drives and EVs of power rating up to 150 kW with regenerative braking capability [15]. A novel three phase hybrid MLI for MV application was proposed by Batschauer et al. in 2012. In this topology, a conventional three – phase VSI is in series with half-bridge inverter at each phase which reduces the requirement of DC sources significantly [16]. A seven-level inverter and a boost converter composed to solar power generation system is introduced by Wu and Chou in 2014 [17]. For medium voltage and high power applications, Ruiz-Caballero et al. introduced a novel symmetric hybrid MLI topology which was based on a three level switching cell with reduced dc sources [18]. Madhukar and Sivakumar in 2015 proposed a fault tolerant single-phase five-level inverter consisting of a half bridge inverter unit and three-level diode clamped inverter when PV generation system is considered. This topology have an advantage like reduction in switch count, fault tolerant capability, energy balancing, and capability [19]. The recent trends in MLIs are concentrated on reducing the switch count, DC supplies, and gate driver circuits. This helps in improvement of power quality and increases fault tolerant capability. It makes them economical for grid connected renewable energy applications [20]. This paper presents various MLI topologies and analyses their influence on grid connected applications. The performance of various inverter topologies have been evaluated and compared.

The efficiency of inverter is another important factor which can be improved further due to usage of soft-switching technologies in inverters. Soft switching reduces switching losses in power switching devices used in inverter circuit. The efficiency of inverter can be brought up to 98% but further 1% increase in efficiency is very challenging. For improvement in efficiency, different topologies incorporating soft switching technologies are also presented and discussed.

This paper starts with standards and specifications of grid connected PV inverter. It is followed by an overview of some existing power inverter topologies for interfacing PV modules to the grid. It considered some transformer-less inverter topologies based on- multilevel concept, half-bridge, full-bridge configuration and some soft-switching inverter topologies are mention which are desirable for grid connected single-phase PV inverters with the consideration of designing-structure, high efficiency and low cost. An organized and systematic approach has been taken to describe the overview of grid-connected single-phase inverters expanded till date. The historical overview of inverter technologies, standards and specification, summary of inverter topology, classifications of inverter topologies are presented one after the other.

## 2. STANDARDS AND SPECIFICATIONS OF GRID CONNECTED PV INVERTER

Table 1: Important standard dealing with interconnection of PV system and grid are IEC 61727, IEEE 1547–2003 and IEEE 929–2000.

| S. No. | Issues | IEC 61727[10] | IEEE 1547–2003[11] | IEEE 929–2000[8] |
|---|---|---|---|---|
| 1 | Introduction | Utility Interface Characteristics of PV | Standard for Interconnecting Distributed Resources with Electric Power Systems. | Standard containing guidance regarding equipment and its functions necessary to ensure compatible operation of PV systems that are connected in parallel with the electric utility. |
| 2 | Formation | UK | USA | USA. |
| 3 | Nominal Power | Up to 10 kW | Up to 10 MVA. | It provides sufficient requirements up to10 kW for PV systems and also contains reasonable guidelines up to 500 kW. |
| 4 | Guidance on | 1. PV systems connection to low voltage utility grid. | 1. Types of DR technologies and the issues associated in interconnection with grid.<br>2. Techniques and thumb rule for implementing DR project. | 1. Necessary equipment and their functions for its compatible operations.<br>2. Power quality, equipment protection and safety,.<br>3. Protection during Islanding. |
| 5 | Harmonic currents (Order-h) limits | 4.0% for (3–9)th<br>2.0% for (11–15)th<br>1.5% for (17–21)th<br>0.6% for (23–33)th<br>In these listed ranges the even harmonics shall be less than 25% of the odd harmonics limits. | < 4% for (2–10)th<br>< 2% for (11–16)th<br>< 1.5% for (17–22)th<br>< 0.6% for (23–34)th<br>< 0.3% above 35th | 4.0% for (3–9)th<br>2.0% for (11–15)th<br>1.5% for (17–21)th<br>0.6% for (23–33)th<br>– |
| 6 | Max. current THD | 5.0% | < 5% THD | 5% of the fundamental frequency current at rated inverter output |
| 7 | Voltage ranges to normal operation. | ± 10 -15% of rated voltage. | – | 88–110% of rated voltage.<br>Inverter should sense the abnormal voltage and respond.<br>Voltage at point of common coupling — Trip time.<br>V < 50% — 6 cycles<br>50% ≤V ≤ 88% — 120 cycles<br>88% ≤ V ≤ 110% — No operation<br>110%≤ V ≤ 137% — 120 cycles<br>Above 137% V — 2 cycles |
| 8 | Frequency range to normal operation. | 50 ± 1 Hz | – | 59.3 – 60.5 Hz |
| 9 | Power factor at 50% of rated power | 0.90 | – | – |
| 10 | DC current injection | Less than 1.0% of rated output current | Less than 0.5% of rated output current | Under any( either normal or abnormal) operating conditions the PV system should not inject DC current greater than 0.5% of the rated inverter output current into the AC interface. |
| 11 | Island | – | Shall detect and isolates within 2 seconds of the formation of island | An inverter that will cease to energize the utility line in ten cycles or less when subjected to a typical islanded load in which either of the following is true<br>(a) There is at least a 50% mismatch in real power load to inverter output. (b) The islanded load power factor is < 0.95 (lead or lag) |

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X



The Distribution sectors operators are responsible for providing reliable, safe and good quality electric power to their customers. The PV developing industry needs to be aware of the issues related to good quality and safety power and also assist in setting standards as this would ultimately lead to increase the acceptance of the grid-connected PV inverter technology by electric power users and the electricity utility industry. For the system to be operated in safely and reliable manner, the standards must be endorsed, which will serve to build electricity consumer's trust, reduce costs and further flourish grid-connected PV inverter development [21]. The standards in the market which deals with the interconnection of PV energy system with the utility grid are International Electro technical Commission (IEC), Institute of Electrical and Electronics Engineers (IEEE) and National Electrical Code (NEC). Amongst them the most popular standards are IEC 61727 [22], IEEE 1547–2003 [23], IEEE 929–2000 [24] etc. which are discussed in Table 1.

These standards fix the limits for its operating frequency changes, the inverter voltage change, power factor, and harmonics in the current injected into grid and injection of DC current into the grid to avoid distribution transformers saturation [25]. These also contain islanding information of PV systems when the utility grid is not connected to control voltage and frequency of the inverter, as well as techniques to avoid islanding of PV energy sources. In islanding state, the utility grid has been disconnected from the inverter, which then only supplies power to local loads. In addition to the above standards, there are also some more standard among which are- IEEE 1373 standard as it is recommends as a practice for procedures and field test methods for a grid-connected PV system, IEC 62116 standard recommends as a test procedure for islanding prevention for a grid-connected PV inverters, IEC 61173 standard provides guidance on overvoltage protection for a PV power generating system, IEC 61683 standard recommends for efficiency measurement procedure of the PV system.

## 3. SUMMARY OF GRID CONNECTED PV INVERTER TOPOLOGY

In the grid-connection of PV system, the DC output power of PV array is converted into AC power and then this AC power of proper voltage magnitude, frequency and phase sequence is fed to the utility grid. For this, an inverter is required which will convert the obtained DC output from PV array into AC power and therefore inverter consideration an important part in grid-connected PV systems [26-27].

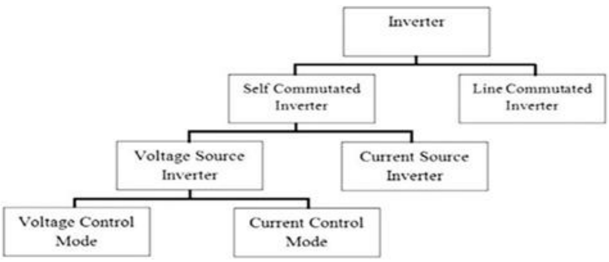


Figure 1. Classification of inverter type [26]

The classification of inverter types are shown through figure 1. There are mainly two types of inverters one is line-commutated inverter and other self-commutated inverter.

The line-commutated inverter uses commutating thyristors as power switching devices as its commutation process is dictated by utility grid. The gate terminal in this device is used for turn-on operation, but the same gate terminal cannot be used for turn-off operation. The turn-off of the device is carried out with the help of additional circuit. Whereas in the self-commutated inverter, with the help power switching device the current is transferred from one switching device to another switching device in a controlled manner. During this switching the potential at the gate terminal can manage both turn-on and turn-off operation. The switching devices used are MOSFET and IGBT. The use of Power MOSFETs are for low power less than 10 kW and for high-frequency (20–800 kHz) switching operation, whereas IGBTs are for medium and high power and also exceeding 100 kW, but not preferred for very high-frequency switching, its frequency limited to 20 kHz. But for a grid-connected inverter, high-frequency switching is needed in order to reduce an inverter's output-current harmonics, size of the filter and the weight of the inverter [1]. Now a day due to darwinism of advanced switching devices like Power MOSFETs and IGBTs, most inverters for distributed power generation systems such as PV systems is now adopting a self-commutated inverters rather than line-commutated inverters. As switching technique used in self-commutated inverter is Pulse Width Modulator (PWM), is used to generate sinusoidal waveform at the output i.e. AC output. The self-commutated inverters controls both the voltage and current waveforms of AC at the output side of inverter and adjust/correct the power factor and suppress the harmonics in the current waveform which is required for grid-connected PV system, and is highly resistant to utility grid disturbances.

The self-commutated inverters may be current source inverter (CSI) or voltage source inverter (VSI) depends on the current or voltage waveforms at the input DC side. In CSI, the input side comprises of DC current source holds the same polarity. The direction of the average power flow depends on the polarity of input voltage and output AC waveform. The constant amplitude and variable width of AC current waveform can be obtained using CSI. A relatively large inductor is connected in series with input DC side of CSI to maintain a continuous current flow. In VSI, the input port comprises of a DC voltage source and this input voltage holds the same polarity. The direction of the average power flow depends on the polarity of input DC current and output AC voltage waveform. The constant amplitude and variable width of an AC voltage waveform at the output side can be obtained. A tie- line inductor is used to prevent excessive current flow to the grid and it is connected between inverter and utility grid. A large capacitor is connected in parallel with input DC side of VSI. This large capacitor resembles like large voltage source. A VSI operates in voltage control mode and current control mode. VSI operated in current control mode is preferred for grid connected PV system. Figure 2 and

Volume 9, Issue 4
August 2020

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X



3 shows configurations of line-commutated CSI and self-commutated VSI respectively [27]. A voltage control mode is used for the stand alone PV system without any grid connection, but in case of grid connected PV system, both voltage control mode and current control mode is used. In order to obtained high power factor an inverter operated in current control mode is normally used for grid connected PV system. This arrangement is also prevent transient current flow when any grid disturbances occur in the utility grid.

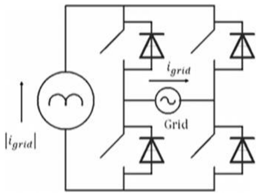

Figure 2. Line-commutated current source grid-connected inverter [27]

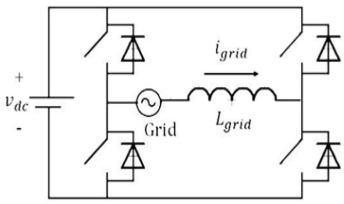

Figure 3. Self-commutated voltage source grid-connected inverter [27].

## 4. INVERTER TOPOLOGY CLSSIFICATION

The classification of inverter topologies are presented in this section, the classification is carried on the basis of different categories like number of power processing stages, location of power decoupling capacitor, whether they use transformer or not and if used, then whether it is a line-frequency transformer or high-frequency transformer etc.

### 4.1. NUMBER OF POWER PROCESSING STAGES

Classification of inverter topologies is according to the number of power processing stages, figure 4(a) is a single stage inverter which is used to perform MPPT, voltage amplification and then the inverter current is feed to the grid. The inverter is so designed that it should handle a peak power which is twice that of nominal power as in equation below.

$$P_{grid} = 2P_{grid} \sin 2(\omega_{grid} t)$$

Where $P_{grid}$ is the grid peak power, $\omega_{grid}$ is the grid frequency

Figure 4(b) shows an inverter with two power processing stages. The first power processing stage is dc-dc converter performs two tasks one is voltage amplification and other is MPPT. The output of a dc–dc converters is either a pure dc voltage (in this case the dc–dc converter is designed to handle the nominal power), or the output current of the dc–dc converter is modulated to follow a semi-sinusoidal wave (in this case the dc–dc converter is designed to handle a peak power of twice the nominal power) depending upon the control mode of the inverter.

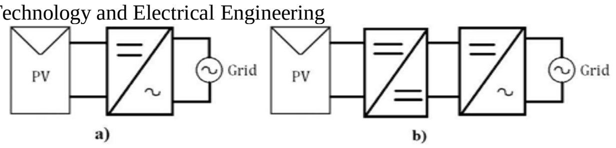

Figure 4. Two types of PV inverter (a) Single stage inverter, (b) Two stage inverter [27].

In the previous case, the current to be injected in to the utility grid by an inverter is controlled by means of pulse width modulation (PWM) or bang- bang operation. In the latter case, the semi-sinusoidal wave current is modified to a full-wave sinusoidal current in the inverter by switched it to line- frequency and in this case, the dc–dc converter controls the AC current to be injected in to the utility grid. If the nominal power is high, it is better to operate the inverter in PWM mode. On the other hand, if the nominal power is low latter case is employed to achieve high efficiency.

#### 4.1.1. SINGAL STAGE

A single-stage buck inverter topology with line-frequency transformer is shown in figure 5. As the line frequency transformer increases the size and weight of the inverter and is also responsible for losses of around 2% in peak efficiency [28]. The design of topology with high-frequency transformer or without transformer are more compact, cheaper, efficient, lighter and therefore line frequency transformer topologies are replaced by high frequency transformer and transformer-less designs. Several single-stage buck, boost or buck-boost inverter topologies were proposed in [29–36], which performs voltage amplification with MPPT and DC-AC conversion in a single power processing stage. The buck, boost and buck-boost inverters technology are DC-DC converters, they are use as DC inductors for energy storage and in most cases single stage inverters uses high-frequency transformers which performs both energy storage and electrical isolation. The electrical isolation in single power processing stage is required mostly for safety reasons.

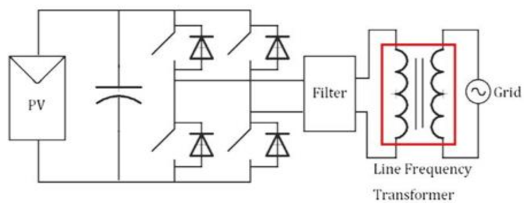

Figure 5. Self-commutated grid-connected full bridge PV inverters with line-frequency transformer [34].

Figure 6 shows buck-boost inverter topology with four power switching devices. In this topology the DC input voltage source is split in to two [37]. This spitted DC input voltage is feed to two buck-boost converters which operates for each half cycle of the grid voltage and share same output. This inverter can be suitable for residential purpose PV system with MPPT control.

Figure 7 shows another buck-boost inverter topology with six power switching devices. This topology energy storage inductor is use and which is charged from two

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X


different directions and due to which it generates AC output current [33]. This topology incorporates two additional switching devices along with four switching devices provides the grounding of both the grid and PV system.

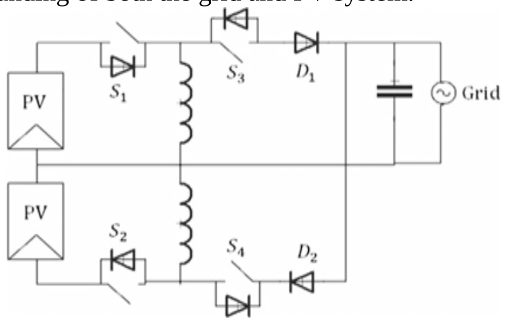

Figure 6. Single stage buck-boost inverter topology with four switching devices [37].

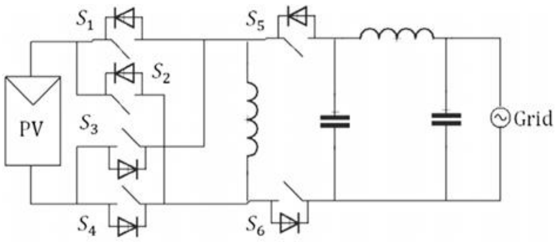

Figure 7. Single stage buck-boost inverter topology with six-switching devices [33].

Figure 8 shows a topology with two boost converters and each boost converters will work during each half cycle of the grid voltage. a non-isolated boost inverter by Cáceres and Barbi [29]. In non –isolated boost inverter, DC inputs of two identical boost DC-DC converters are connected in parallel. The load is connected across two outputs. Each converter is modulated to produce a unipolar DC-biased sinusoidal output, 180 out of phase with the other. Thus, a pure sinusoidal waveform is obtained across the load. Sliding mode control was employed to optimize inverter dynamics in [29]. But this topology suffered with a drawback of switching losses as all power switching devices are switched at high-frequency.

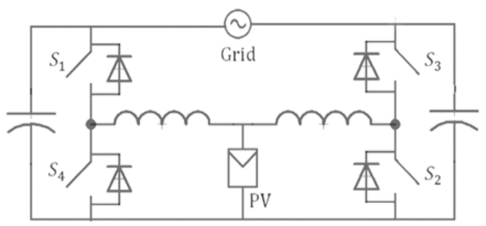

Figure 8. Single stage boosts inverter [29].

The another topology derived from Zeta and Cuk convertor is shown in figure 9, which eliminates the drawback of previous topologies [38] where in all power switching devices are switched at high frequency simultaneously. In the positive half cycle of the grid voltage, switch S1 is switched at high frequency while switches S2 and S4 are continuously kept on. During S1 switching or positive half cycle current is injected to the grid based on buck-boost principle. During negative half cycle of the grid voltage, switch S2 is switched at high frequency while switches S1 and S3 are kept continuously on. During S2 switching or negative half of grid voltage, the current injected into the grid based on boost principle. This topology suffers with this asymmetrical operation and hence dc current injection into the grid creates a problem in this topology. The dc current injection into the grid becomes a problem as it injects a current based on buck-boost operation during positive half and boost operation during negative half cycle of the grid voltage.

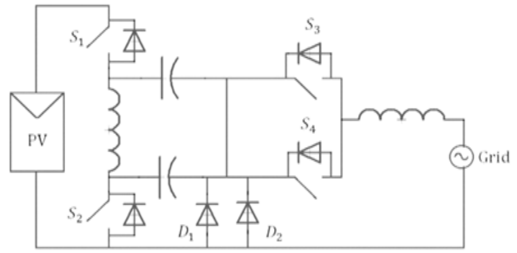

Figure 9. Single stage inverter derived from Zeta and Cuk converter [38].

Figure 10 shows a topology comprises of a high frequency transformer. This high frequency transformer provides isolation between PV modules and utility grid. This topology is suitable only for low power applications i.e. less than 500 W. This topology suffered from this drawback due to primary side inductance value of the transformer [39].

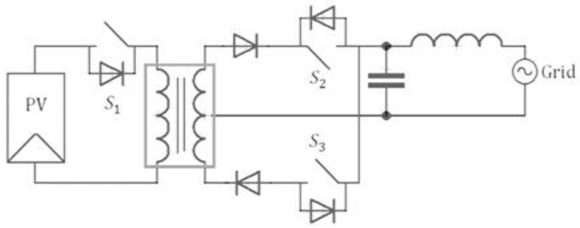

Figure 10. Single stage isolated flyback inverter [39].

Figure 11 shows another inverter topology based on buck-boost principle [40]. During the positive half cycle of the grid voltage, switch S1 switched at high-frequency while S2 is kept continuously on. During the negative half cycle, switch S3 is switched at high-frequency while switch S4 is kept continuously on. An optimum number of switching are carried at any given time in this topology. Two switches are operated during each half cycle of the grid voltage which drastically reduces switching loss and hence this topology has the advantage of low switching loss.

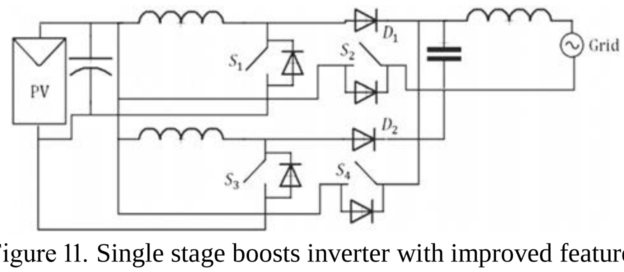

Figure 11. Single stage boosts inverter with improved features [40].

Figure 12 shows a similar buck-boost inverter which was proposed by Vázquez et al. [30]. This topology is

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X



connected in similar fashion as it is done in Fig. 8. This topology uses two buck-boost dc-dc converters and it generates an AC output voltage either lower or higher than the DC input voltage depending upon the buck-boost operation.

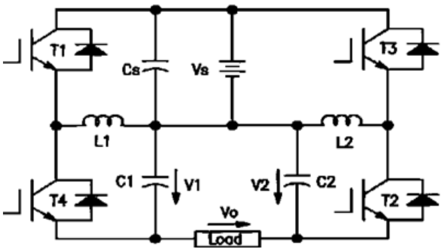


Figure 12. Four-switch buck-boost inverter by Vázquez et al. [30].

Figure 13 shows a dual fly-back inverter and it was proposed by Kjær and Blaabjerg [36]. The main circuit is formed by using two bidirectional fly-back converters and the load is differentially connected across their outputs. Both bidirectional fly-back converters share a common input source. The input to the converters is connected in parallel. The mode of operation is similar to that presented in [29] and [30]. In this topology, high frequency transformer provides galvanic isolation. But the use of two high frequency transformers increases the cost, weight and size of the system.

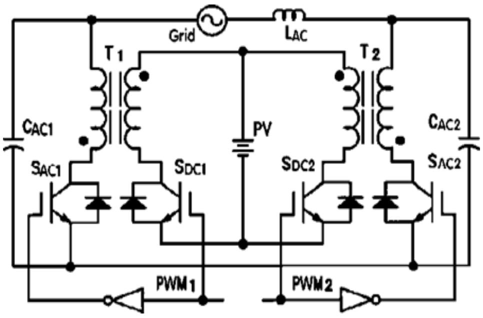


Figure 13. Four-switch isolated bidirectional buck-boost inverter by Kjær and Blaabjerg [36].

Figure 14 shows a zero-current-switching (ZCS) buck-boost inverter topology which was proposed by Wang [35]. During positive half cycle, switches S1, S3, and diode D2 operate and during negative half cycle, switches S2, S4, and diode D1 operate. Switches S3 and S4 can be turned on at ZCS by LC series resonant tank in order to achieve discontinuous conduction mode operation. Due to operation in discontinuous conduction mode, low switching power loss is obtained in this topology.

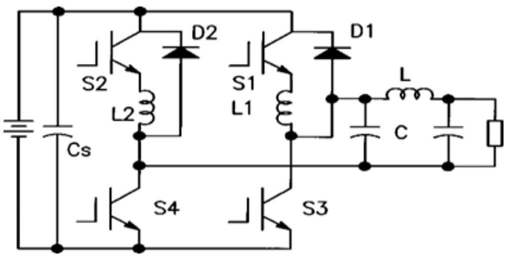


Figure 14. Four-switch resonant buck-boost inverter by Wang [35].

Figure 15 shows an isolated flyback buck-boost inverter by Nagao and Harada [32]. This topology combines two buck-boost converters in a four-switch bridge. This topology also uses additional two switches for synchronous commutation in each half cycle of ac output. The main advantage of this inverter incorporates a desired output power irrespective of the input voltage and the electrical isolation between the PV and utility grid.

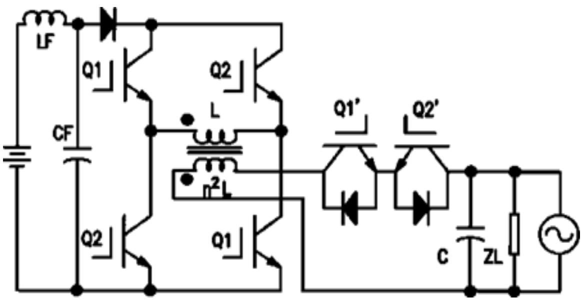


Figure 15. Six-switch isolated buck-boost inverter by Nagao and Harada [32].

A non-isolated six-switch buck-boost inverter topology by Kusakawa et al. is shown in figure 18. This topology consists of an energy storage inductor which gets charged from different directions in each half cycle of utility grid and hence produces an alternative output [33]. The grounding of two more additional switches as compared to four switch topologies provides grounding of both the PV modules and utility grid. This topology is transformer less which makes system more compact and appropriate for an AC module in PV systems.

In addition to above topologies, Myrzik had also derived single-stage boost or buck-boost non-isolated four-switch topologies and isolated five-switch topologies in [34]. These topologies are derived by connecting a pair of Zeta converters, Cuk converters, or D2 converters in parallel-parallel or parallel-series connections. These new inverters can be applied in grid-connected photovoltaic systems or stand-alone.

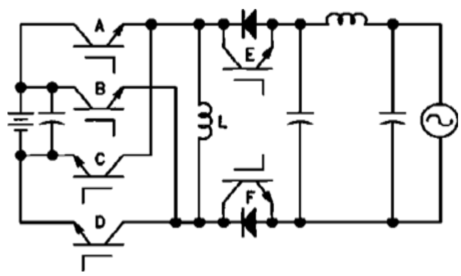


Figure 16. Six-switch buck-boost inverter by Kusakawa et al. [33]

Elimination of low frequency transformers is an important feature in single stage buck-boost inverters. The elimination of low frequency transformers makes single stage inverters more compact as compared to conventional buck inverters with line-frequency transformers. It is observed, in such an inverter, the currents through main switches are usually discontinuous triangular pulses, and the output current

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X


cannot be controlled directly by the current through power switches even in the continuous conduction mode (CCM) operation. Single stage inverters are generally efficient and low cost but these types of single stage inverters suffers from limited power capacity, compromised output quality, and limited operation range. Therefore, in applications requiring high power, high performance and wide input voltage range, multiple stage inverters are used.

#### 4.1.2. MULTIPLE STAGE

An inverter with more than one power processing stage and in which one or more stages accomplish voltage amplification, electrical isolation and the final stage performs DC–AC conversion task is defined as multiple-stage inverter. Let us considered a two stage inverter, in which each stage is controlled individually or synchronously. In two stage inverter the first stage provides necessary boosting and isolation while the second stage completes the inversion process. There are various multiple-stage topologies where buck-boost function of an inverter implemented. A DC-DC converter or DC-AC-DC converter is used in the first stage for the buck or boost function. The system can be configured with a dc-link followed by a PWM inverter or a pseudo-dc-link followed by a line-frequency operated inverter. The dc link can be chosen by either of two ways.

Figure 17 shows a two-stage boost inverter which is normally used in small wind systems [41]. This two stage boost inverter is formed by adding a boost dc-dc converter in front of a buck inverter. The first stage provides an increased dc voltage with tolerable ripple. The second stage is a high frequency buck inverter to produce desirable ac waveforms. The output power is controlled in second stage and no synchronization is required between two stages.

The same topology can be controlled in a different way. In the same topology, first stage is controlled in such a way that the dc link appears a rectified sine waveform. The second stage will then convert the rectified sine waveform into a line frequency ac output. This type of controlling improves the efficiency of two stage inverter and reduces the overall switching losses. This control approach was demonstrated by Yang and Sen [42], Kang et al. [43], and Chomsuwan et al. [44]. Line frequency inverters are used in the final stage and the entire system is then applied to grid connected PV system.

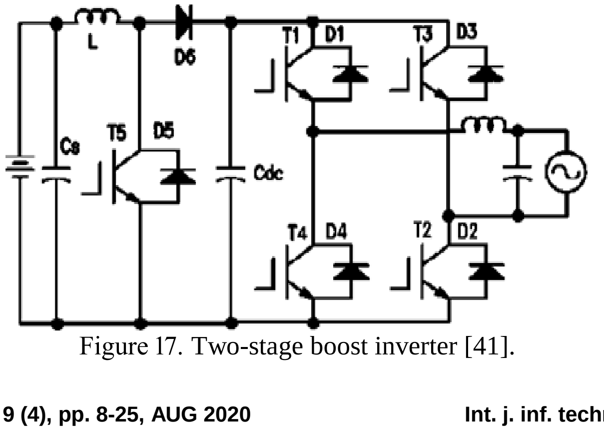

Figure 17. Two-stage boost inverter [41].

Figure 18 shows the two stage non-isolated buck-boost inverter by Saha and Sundarsingh in [45]. This non-isolated topology is designed for grid-connected PV systems. This structure is simple in nature and it has a limited dc voltage variation range and limited voltage conversion ratio. This is operated with a dc input voltage not more than 100V for the safety of system. Isolated topologies with a high frequency transformer can extract power from the renewable energy source even when the dc voltage is very low.

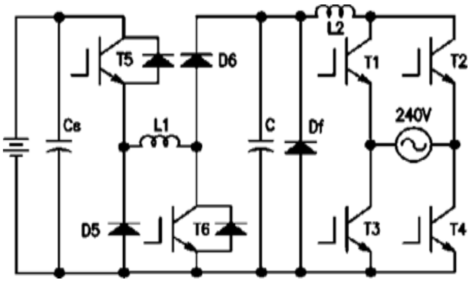

Figure 18. Two-stage non-isolated buck-boost inverter by Saha and Sundarsingh [45].

The two-stage isolated buck-boost inverter by Saha and Sundarsigh is shown in figure 19 where a fly-back transformer is used which provide electrically isolation of the utility grid from the input for safety and protection. The second stage is normally a current source inverter which operates in line frequency to implement half-wave inversion which is seen in figures 18 and 19[45].

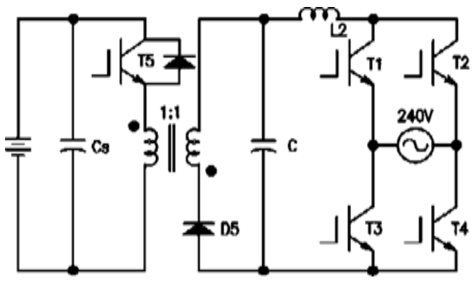

Figure 19. Two-stage isolated buck-boost inverter by Saha and Sundarsigh [45].

A capacitor is added to the charging loop of the energy storage device to form a buck-boost inverter by Funabiki et al. [46], as shown in figure 20. A capacitor is generally added to expand the dc input operation range without a high frequency transformer. Due to insertion of capacitor, this inverter can operate with a good response even if input dc source changes from zero to a level exceeding the output voltage. This is done at the cost of more complex operations and additional switching components.

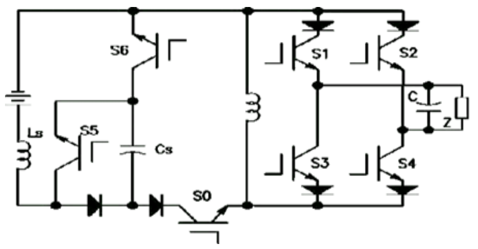

Figure 20. Buck-boost inverter by Funabiki et al. [46].

Figure 21 shows another isolated fly-back buck-boost inverter by Shimizu et al. [47] and Kjaer [48]. The MPPT control of PV modules provides a constant input power and this constant input power is processed in the first part of the switching cycle by the buck-boost converter. This processed energy is stored in the intermediate capacitor. The energy stored in the intermediate capacitor is processed by the fly-back converter in the second part of cycle. In the third stage the energy stored in the magnetizing inductance is transferred to the secondary side of the transformer and injected into the single-phase grid by the AC switches through an LC filter. Thus, the voltage across the intermediate capacitor comprises of DC component and AC component having frequency two times the frequency load that is 100Hz. The main advantage of this topology is small intermediate capacitors which can replace large electrolytic capacitors, which in turn increases the operating life of the invertor.

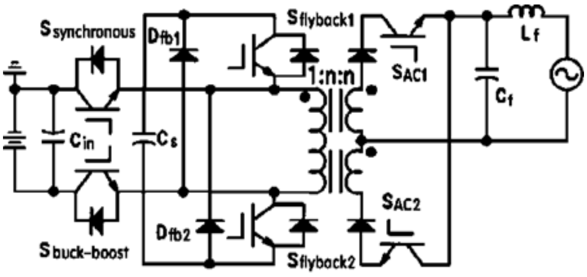

Figure 21. Fly-back inverter with enhanced power decoupling by Shimizu [47] and Kjær [48].

Multiple stage inverters generally consist of a high frequency dc-ac-dc converter and a high frequency or line-frequency inverter. A high frequency dc-ac-dc converter is used to realize a controlled dc voltage from a variable dc voltage and high frequency or line-frequency inverter used to realize the required ac output. Multiple stage inverters provide a high voltage boosting ratio. There are different types of topologies which is distinguished by two classes of intermediate dc link. A DC-link between two stages is shown in figure 22, where first stage is a inverter which takes care of boot and control of constant voltage DC-link. A high frequency step-up transformer, a rectifier, and a dc filter forms the second stage. These two stages operated at high swathing frequency which results in high switching losses and high cost.

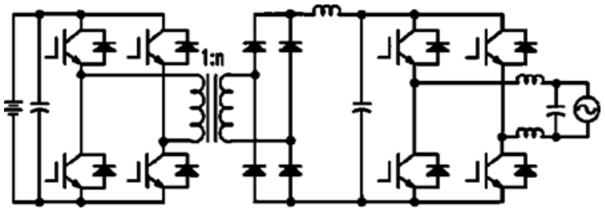

Figure 22. Multiple-stage inverter with a high frequency transformer.

Figure 23 shows a multiple-stage boost inverter promoted with a PWM dc pulse train is so-called “pseudo-dc-link.” The pulse train consists of multiple pluses whose widths distribute in semi-sinusoidal or sinusoidal way repeating in half of an AC output period. The inversion to ac from the high-frequency dc pulse train is carried in the last stage is a line-frequency switching inverter. The ac output of a low-pass filter is needed to ensure an acceptable THD of ac output.

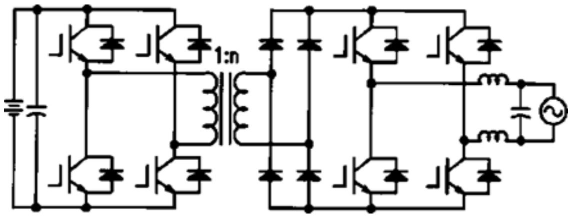

Figure 23. Multiple-stage boost inverter with pseudo-dc-link.

Figure 24 shows a multiple-stage boost inverter [49] and a current source inverter is placed in last stage. The two half sinusoidal current waves are obtained by controlling the power switches of first inverter. The line frequency inverter present in the last stage then converts half sinusoidal current waves into full sinusoidal current wave. This line frequency feeds AC current into the grid which is phase with line voltage. In this, configuration, an AC output filter is not used to deliver AC current in to the grid. Thus topology was commercially developed by General Electric Company (GE). This configuration is available for 10kW grid connected PV system [50].

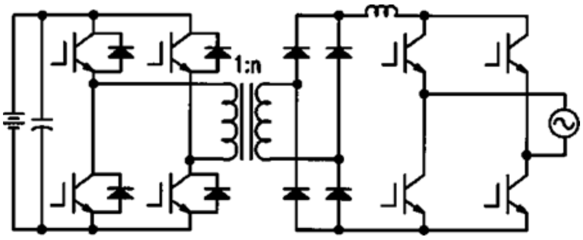

Figure 24. Multiple-stage boost inverter by GEC [49].

A bidirectional power flow is required in inverter control for stand-alone or autonomous systems. The provision is provided for the power to flow from the output side to the input side. This structure is proposed by Beristáin et al. [51] as shown in figure 25, where the second stage comprises of bidirectional ac-ac converter. This second stage eliminates an intermediate DC-link where bulky components are most prominent feature. This topology also incorporate high frequency transformer which is used for electrical isolation between two stages.

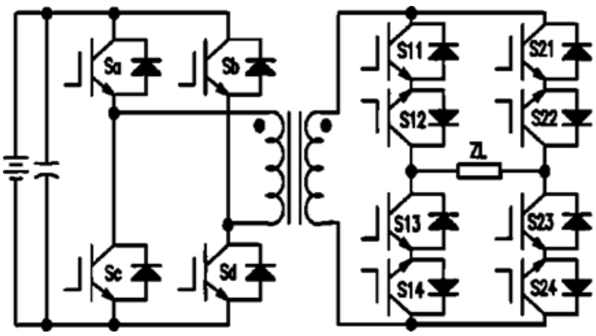

Figure 25. Bidirectional DC-AC-DC converter by Beristáin et al. [51].

**ITEE Journal**
Information Technology & Electrical Engineering

ISSN: - 2306-708X



Table: 2 Evaluation of different types of inverter according to their categories, topology's, components, parameter's, capability's and application's

| Sr. No. | Fig. No. | Technical Specification | | Components Used | | | | | | Electrical Parameters Range | | | Capability's and Application's | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Category | Topology | Capacitor | | Inductor | Transformer | Diode | Switches | Power Rating | Voltage Range | Frequency | Dual-Grounding & Isolation | Standalone / Grid Connected | Application |
| | | | | FC | EC | | | | | | | | | | |
| 1 | 5 | SS | Buck | 1 | 1 | 1 | LFT | 4 | 4 | >10kW | Wide range | 5-12kHz | Yes, Isolated | Both | Wind |
| 2 | 6 | SS | BB | 1 | 2 | 2 | - | 2 | 4 | 500W | 42V / 81V | 9.6kHz | Yes, Non-Isolated | Grid only | PV |
| 3 | 7 | SS | BB | 2 | - | 2 | - | 2 | 6 | 50W | Wide range | High frequency | Yes, Non-Isolated | Both | PV |
| 4 | 8 | SS | 2 x Boost | 2 | 1 | 2 | - | 4 | 4 | >3kW | 34V / 65V | 30Hz | NO, Non-Isolated | S_R & G_E | UPS |
| 5 | 9 | SS | Zeta-Cuk derive | - | 2 | 2 | - | 2 | 4 | 500W-3kW | 34V / 65V | High frequency | Yes, Non-Isolated | G_R & S_E | UPS |
| 6 | 10 | SS | Flyback | 1 | - | 1 | HFT | 2 | 3 | 500W | 42V / 81V | High frequency | Yes, Isolated | Standalone | PV |
| 7 | 11 | SS | BB | 1 | 1 | 3 | - | 2 | 4 | >3kW | Low range | High frequency | NO, Non-Isolated | S_R & G_E | UPS |
| 8 | 12 | SS | BB | 2 | 1 | 2 | - | 4 | 4 | 215W | 42V / 81V | 30kHz | NO, Non-Isolated | S_R & G_E | UPS |
| 9 | 13 | SS | 2 x Flyback | 2 | - | 1 | 2 x HFT | 4 | 4 | 160W | Wide range | 50kHz | Yes, Isolated | G_R & S_E | PV |
| 10 | 14 | SS | ZCS BB | 2 | 1 | 3 | - | 2 | 4 | 500W | 42V / 81V | 40kHz | NO, Non-Isolated | S_R & G_E | UPS |
| 11 | 15 | SS | Flyback BB | 1 | 1 | 1 | HFT | 2 | 6 | 140W | Wide range | 50kHz | Yes, Isolated | Both | PV |
| 12 | 16 | SS | BB | 2 | 1 | 2 | - | 2 | 6 | 50W | 42V / 81V | 70kHz | Yes, Non-Isolated | Both | PV |
| 13 | 17 | MS | BB | 1 | 2 | 2 | - | 6 | 5 | 1kW | 34V / 65V | - | NO, Non-Isolated | Both | Wind |
| 14 | 18 | MS | BB | 1 | 1 | 2 | - | 5 | 6 | 2kW | 42V / 81V | 36kHz | NO, Non-Isolated | Grid only | PV |
| 15 | 19 | MS | Flyback $X_{mer}$ | 1 | 1 | 1 | HFT | 2 | 5 | 2kW | Wide range | 36kHz | Yes, Isolated | Grid only | PV |
| 16 | 20 | MS | BB | 1 | 1 | 2 | - | 6 | 7 | 640W | 9V/16V | 5.3-17kHz | NO, Non-Isolated | S_R & G_E | PV, Wind |
| 17 | 21 | MS | Flyback BB | 3 | 0 | 1 | HFT | 8 | 6 | 160W | Wide range | - | Yes, Isolated | Grid only | PV |
| 18 | 22 | MS | BB | 1 | 2 | 3 | HFT | 12 | 8 | >10kW | Wide range | 5-12kHz | Yes, Isolated | Both | Wind |
| 19 | 23 | MS | Boost with Pseudo-dc-link, BB | 1 | 1 | 2 | HFT | 12 | 8 | - | Wide range | - | Yes, Isolated | Grid only | Wind |
| 20 | 24 | MS | Boost | 0 | 1 | 1 | HFT | 8 | 8 | 4kW | Wide range | 10-16kHz | Yes, Isolated | Grid only | PV |
| 21 | 25 | MS | Bidirectional-dc-ac-ac | 1 | 1 | 1 | HFT | 12 | 12 | 1kW | Wide range | 50Hz | Yes, Isolated | Both | PV |

SS – Single-Stage, MS – Multiple-Stage, BB – -Buck-Boost, FC – Film Capacitor, EC – Electrolytic Capacitor, LFT – Line Frequency Transformer, HFT – High Frequency Transformer
S_R & G_E – Standalone Reported & Grid connected Expected, G_R & S_E – Grid connected Reported & Standalone Expected. ZCS – Zero Current Switching

The review of multiple stage topologies provides the valuable information about a high frequency transformer and line frequency inverter. The multiple-stage topology review says that it is desirable to use high frequency transformer in the front stages to increase the voltage boosting ratio and to provide the necessary electrical isolation. Whereas it also says that line frequency inverter is to be used in the last stage to reduce switching losses. As the multiple stage inverter has more stages, so it is normally used to achieve a wide input voltage range and a large power capacity whereas it is not possible in single-stage inverter. This is possible only at the cost of additional power components and increased losses.

## 5. POWER DECOUPLING

In single stage inverter capacitor is either placed in parallel with the PV source whereas in multi-stage inverter capacitor is connected in parallel with PV module or in dc-link. Power decoupling is required to filter out voltage spikes and to pass only the DC component of the input source through it. Power decoupling is achieved by using electrolytic capacitor of large capacitance. The capacitor is either placed in parallel with the PV modules or in the dc link between the converter stages as shown in figure 26. High frequency

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X


switching is used to convert DC power to AC power in inverter circuits but it generates large transients at switching frequency. Capacitors used for power decoupling prevent transients from going back to input. These capacitors are normally large in size and costly. Their lifetime is shortened when used in a high temperature environment in comparison with other devices. Due to use of capacitors, some practical problems have appeared. These capacitors have low power conversion efficiency and low reliability. A significant effort has been made to eliminate these problems and it is done by using small film capacitors or by reducing the capacitance of electrolytic capacitor.

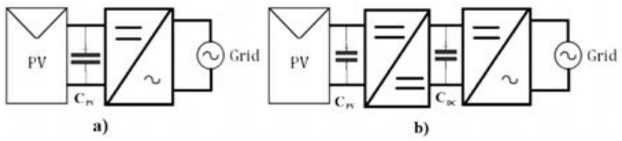


Figure 26. Different positions of power de-coupling capacitor. (a) Capacitor is placed in parallel with the PV modules, in the case of a single-stage inverter. (b) Capacitor is either placed in parallel with the PV modules or in the dc link, in the case of a multi-stage inverter.

## 6. SOFT SWITCHING INVERTERS

Now days, soft switching techniques have been applied in grid connected inverters in order to obtain better performance, higher efficiency and higher power density. The operation of PWM inverters at high switching frequency and sudden change in switch voltage and current waveforms causes high switching losses and electromagnetic interference problems [52-53]. High voltage and current spikes occurs in power switching devices due to parasitic capacitances and stray inductances around switches. These high voltage and current spikes occurred during switching transients. This is termed as hard switching of power switches. In soft switching topologies, a high frequency resonant network is incorporated in conventional hard switching circuits. A high frequency resonant network consists of passive components like inductors, capacitors or auxiliary diodes.

The conventional buck-boost PWM inverter topologies have certain drawbacks such as low efficiency, increased cost, large leakage current, EMI problems. The low efficiency occurred in PWM inverter topologies due to high switching frequency which results in higher switching losses. But, the operation at low switching frequency increases the weight and size of PWM invertor topology. PWM inverter also suffers from EMI problems if operated at high switching frequency. The high switching frequency induces high-frequency components in PWM inverter. To eliminate the above drawbacks, resonant soft-switching techniques have been used. The current through the switch and voltage across switch is made equal to zero by resonant soft-switching technique and due to which switching losses in the power switching devices are eliminated. Some soft-switching inverter topologies are illustrated.

Figure 27 is a voltage source inverter which is based on a 110-W series resonant dc-dc converter and grid connected inverter [54]. The inverter which is connected to the grid cannot be operated as a rectifier when it is viewed from the grid side. The addition of two diodes in this topology prevents the inverter to operate as a rectifier. The possibility of in-rush current is avoided when the inverter is attached to the grid first time due to this topology.

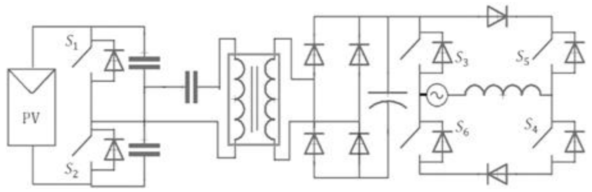


Figure 27. Series-resonant dc-dc converter with bang-bang dc-ac inverter [54].

Figure 28 shows a series resonant soft-switching inverter topology which consists of a full-bridge inverter, a series resonant circuit, an isolation high-frequency transformer. This high frequency transformer has centre tap winding on secondary side and switching devices are synchronized with utility grid. The output AC current is controlled by the discontinuous-resonant modulation using constant on-time gate signal synched with the resonant frequency to carry out soft-switching action. The inverter switching devices are operated under zero current switching (ZCS).

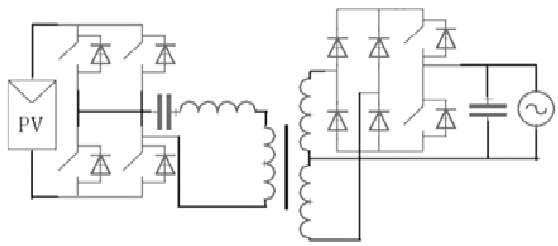


Figure 28. High-frequency link series resonant soft-switching inverter [55].

Figure 29 shows a topology consisting of a capacitive idling buck- boost converter on the input DC side which performs soft-switching operation of the inverter. It also comprises of a single-transistor fly-back inverter at the output AC side and it has a high-frequency center tap transformer.

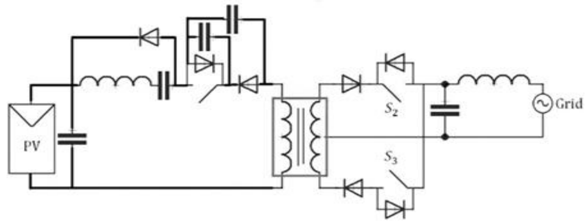


Figure 29. Soft-switching fly-back inverter based on capacitive idling [56].

Figure 30 shows a topology consisting of a ZVT-PWM boost DC-DC converter and a LLCC resonant inverter.

Volume 9, Issue 4
August 2020

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X



The switches used in ZVT-PWM boost converter are switched in soft-switching mode. Due to operation of active switching devices in soft-switching mode, voltage and current stresses have been reduced considerably. The LLCC resonant inverter incorporates series and parallel combinations of inductors and capacitor. This arranges is known as a series-resonant tank and a parallel-resonant tank which provide the AC output voltage with low THD value.

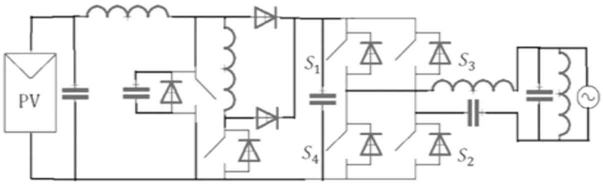


Figure 30. LLCC resonant inverter with ZVT-PWM boost converter [57].

Figure 31 shows a topology which is divided into three stages. The first stage is a ZVT-PWM boost converter. The second stage is a ZVS- ZCS-PWM buck converter which operates in ZVS and ZCS modes. It converts the DC current to semi-sinusoidal current. The third stage is a line-frequency full bridge inverter which inverts the semi-sinusoidal current to sinusoidal AC form.

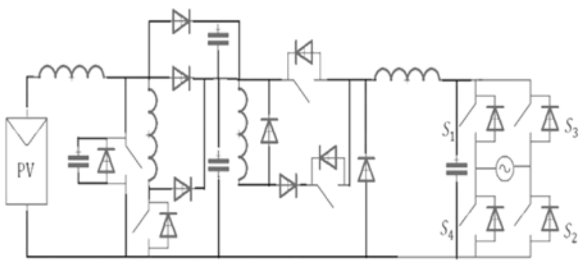


Figure 31. ZVS-ZCS-PWM inverter with ZVT-PWM boost converter [58].

The PWM convertors operated at hard switching faces a problem of higher switching losses. The resonant convertor utilizes the technique of soft-switching like ZVS and ZCS which help in reducing switching losses. But, the increased switching loss increases the high voltage or current stresses on power switching devices.

But switching losses are reduced only at the cost of increased voltage and current stresses of power switching devices. The parasitic reactive energy imposes transient high voltage, dv/dt, or di/dt stresses on semiconductor switches used in buck-boost inverters without reactive energy feedback paths. The parasitic reactive energy occurs due to leakage of inductors. Therefore, zero voltage transition (ZVT) and zero current transition (ZCT) is developed to eliminate switching losses and stresses which helps in increasing the efficiency of the convertors.

The figure 32 of inverter is based on a 110-W series-resonant DC–DC converter with an HF inverter toward the grid [59], and 250 W in [60]. The first converter present in figure 32 is series-resonant converter. The inverter close to the grid cannot be operated as rectifier when viewed from grid side. The two additional diodes serve the function of rectifier. The inrush current will not flow through the inverter when it is attached to the grid for the first time.

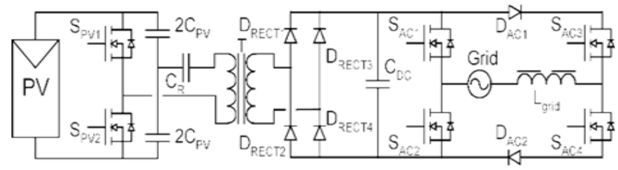


Figure 32. Series-resonant dc–dc converter with bang-bang DC–AC inverter [41, 61].

## 7. MULTILEVEL INVERTER

The reduction in cost of a grid connected PV system is related to improvement in grid connected inverters. Due to 98% efficiency of grid connected invertor thus the primary focus over the grid connected PV is shifted. The cost of grid connected PV inverter are determined by power modules, magnetic component etc. Multilevel inverters are more advantageous as compared to two-level inverters. Multilevel inverters produce staircase waveforms at the output terminal of the inverter and it is synthesized from several levels of voltages. The staircase output waveforms approaches towards a pure sinusoidal waveform and this staircase output waveform has low harmonic distortion and filter requirements are reduced. Multilevel inverter topologies are particularly suitable for PV systems due to the modular structure of PV arrays. The concept of multilevel converters has been introduced since 1975 [62]. The term multilevel originates with the three-level converter [63]. Subsequently, several multilevel converter topologies have been developed [59, 64-70].

Figure 33 shows a half-bridge diode clamped three-level inverter [71] as part of a single-phase transformer-less grid connected PV system as suggested in [60]. A positive voltage can be developed at the inverter output terminal due to simultaneously switching on the switches S1 and S2 and a negative voltage is obtained by switching on S3 and S4 respectively. When S2 and S3 are switched on a zero output voltage is obtained. The DC bus voltage is made higher than the grid voltage amplitude in order to allow power transfer into the grid. The major advantage of above said system is that its mid-point of PV array is grounded and because of this arrangement, it eliminates capacitive earth currents and their negative influence on the electromagnetic compatibility.

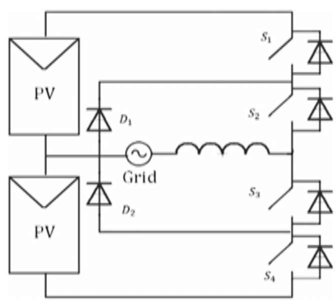


Figure 33. Half-bridge diode clamped three-level inverter [71].

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X


In [69] a full-bridge single leg switch clamped inverter is illustrated and applicable for residential PV systems. Figure 34 shows a full bridge single leg clamped inverter which comprises of conventional full-bridge switches S3, S4, S5 and S6. A bidirectional switches are realized with S1, D1, S2, D2 and added to control the current flow from the midpoint of the DC bus. The minimum size of the inverter with this topology is approximately 1.5 kW.

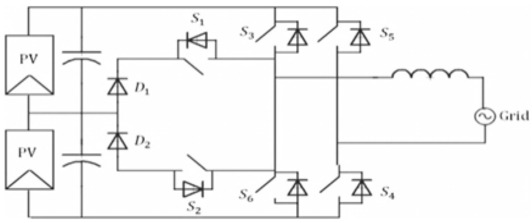

Figure 34. Full-bridge single leg switch clamped inverter [69].

Figure 35 shows a transformer-less grid connected PV system where a cascaded inverter [72] is used for DC to AC power conversion. The topology comprises of two full-bridge configurations and their outputs are connected in series. Each bridge configuration produces three different voltage levels at its AC output which helps in providing five-level AC output voltage. The advantage of this topology is the modular character. The concept of more than two full bridge configurations is suggested for transformer-less PV systems [59]. The small output voltages of two full-bridge are connected in series. High power applications using cascaded inverters are described in [68, 73].

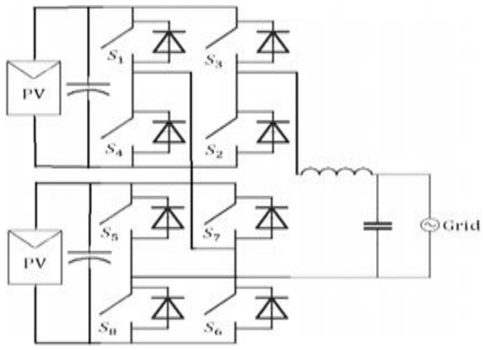

Figure 35. Cascaded inverter [72].

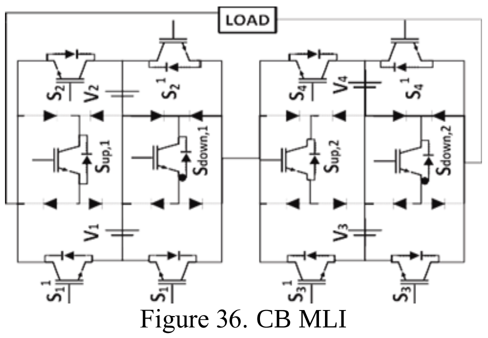

Figure 36. CB MLI

Figure 36 shows a novel topology which is cascaded basic multilevel inverter proposed by Mokhberdoran et al.[82] in which fundamental blocks were implemented in series pattern. Each basic block comprises of two dc sources, six switches and eight diodes are present in each basic block. This basic block produces five voltage level with symmetric sources and it generate seven-level output voltage with asymmetric sources (V1=V and V2=2V).

A cascaded multilevel inverter topology based on series connection of novel H-bridges units [74, 76] was proposed by Babaei et al. Figure 37 shows a new H-bridge unit which consists of six unidirectional switches (SL,1n, SL,2n, SR,1n, SR,2n, Sa,n and Sb,n) and two isolated dc sources (VL,n, and VR,n). Here, subscript n indicates the number of novel H-bridge cells in topology. This novel H-bridge cell generates five voltage levels for symmetric voltage sources (VR,n=VL,n=V), and it generates seven voltage levels for asymmetric voltage sources (VR,n=V, VL,n=2V),

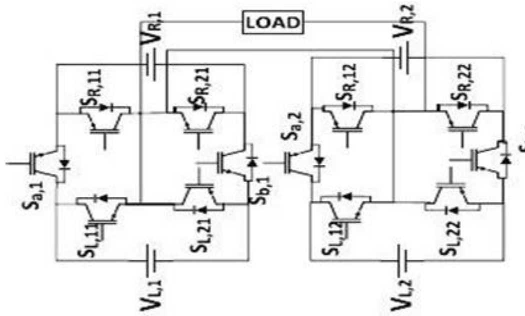

Figure 37. CMB MLI

CCMLI topology was initially in proposed in [81]. It has both the advantages of the chain cell converter and the static phase shifter. In [77], Lee et al. have proposed binary source selection scheme which produces high number of voltage level at the output. The binary source selection scheme is in the form of (1:2:4:8) and useful for selection of DC voltage sources. Figure 38 shows the 7-level configuration of CCMLI topology. This topology consists of series connection of three basic cells and each basic cell has one DC source and four unidirectional switches. The output voltage of each cell is different in phase and magnitude which is required to meet the load requirement.

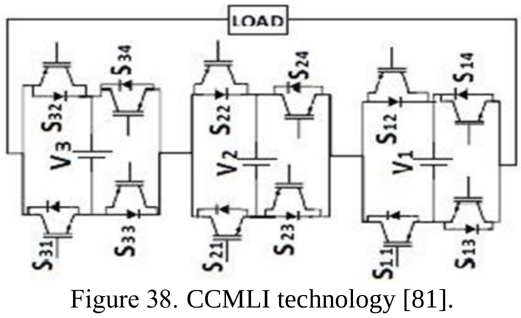

Figure 38. CCMLI technology [81].

Gupta and Jain presented a novel topology in [78-79] which comprises of alternate dc sources. These alternate dc sources are connected in opposite polarity manner through the switches. Due to cross connection of dc sources, this topology was named as cross-connected based MLI. A symmetrical structure of this topology is shown in figure 39 for seven-level voltage waveform. The modified CHB MLI topology with a self-voltage balancing level doubling network (LDN)

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X


was proposed by Chattopadhyay and Chakraborty [80] which is shown in figure 40. This topology utilizes a SCHB MLI and a series connected half-bridge inverter also called as LDN. The proposed topology comprising of LDN increases the number of output levels as compared to the number of voltage levels obtained from the SCHB MLI.

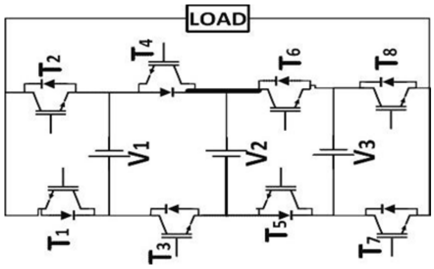

Figure 39. CCS MLI technology.

In figure 40, shows two cascade H-bridge cells and they are connected in series with the LDN. LDN pre-charged to voltage V/2 which gets supply by the capacitor. The LDN generates five-level voltage waveform at the output side. Two cascaded H-bridges generate five-level output voltage waveform. When LDN is introduced in the circuit, two additional levels (V/2, 3 V/2) are obtained in the positive half cycle (by adding V/2 with 0, and V respectively), while two voltage levels (−V/2, and -3 V/2) are obtained by adding half-bridge voltage V/2 with the negative voltage levels (-V, and −2 V respectively). One important advantage obtained due to LDN is that the capacitor get discharged when generated voltage level are positive and odd multiples of V/2 and capacitor get charged when generated voltage levels are negative and odd multiples of V/2. Therefore of the interesting features of LDN is that during the generation of the voltage levels that are positive and odd multiples of V/2, capacitor gets discharged whereas during the generation of voltage levels that are negative and odd multiples of V/2, capacitor gets charged. Hence, the voltage across the capacitor in half-bridge will remain unaltered.

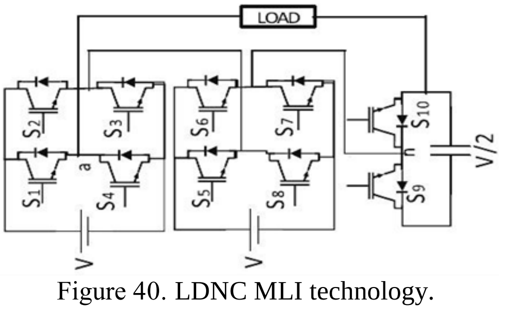

Figure 40. LDNC MLI technology.

A novel topology comprising of switched capacitor cells and H-bridges was proposed in [75] which is made of series connection of fundamental units. Each switched capacitor cell is made of two switches (S, P), a diode, and a capacitor. The capacitor C1 is charged to the voltage V1 when switch P1 is turned on and when the switch S1 is turned on the capacitor C1 is switched in series with the dc source. Both the switches S1 and P1 are complementary to each other. When the switch S is turned on diode D1 prevents the discharging of capacitor to the input dc source. As each switched capacitor cell produces positive voltage levels, therefor a bipolar voltage waveform is obtained at the output of each cell with the help of H-bridge as shown in figure 41.

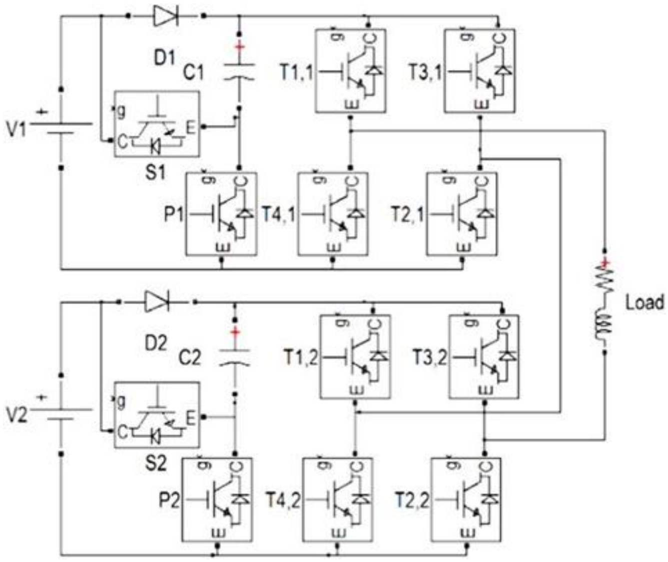

Figure 41. SCH MLI.

A multilevel inverter is used to improve system reliability and reduce maintenance cost. A multilevel inverter is normally used for a wide range of input voltage variations and a large power capacity. A conventional buck inverter along with line frequency voltage step-up transformers increases the size, weight and cost of topology. Multiple-stage inverters can reduce the system size and boost the dc-link voltage with dc–dc converters or high-frequency transformers. Single stage boost or buck boost inverters are more compact and efficient due to low component count but for achieving high power and voltage range, additional power conversion stages are incorporated.

## 8. CONCLUSION

The grid connected PV inverters is becoming popular now a days. The cost and efficiency are two important issues for usage of grid connected PV inverter. The rated power of the inverter is not only the only factor that determines the cost of system. The technology to produce grid connected inverter varies from manufacturer to manufacturer which causes a difference in efficiency, size, weight, reliability etc. These factors influence the cost of inverters. The development has been witnessed in grid connected PV inverter by reducing the component count. The reduction in component count increases the power density of grid connected PV inverter. The innovative topologies have been emerged which provides reduced number of power switching devices and effective energy storing and harmonic filtering devices. Due to emergence of innovative topologies, the cost of grid connected PV systems reduces which in turn improves the overall power conversion efficiency. This review work covers the overview of single-phase grid- connected inverters including the standards and specifications of inverters, classification of inverter types, classifications of inverter topologies etc.

The standards are presented in the first section of review which deals with interconnection of PV energy with the utility grid. The most important standard for interconnection of distributed resource in USA and many countries is IEEE 1547.

The classifications of various inverters are discussed in the next section of review. The inverters are broadly classified into line-commutated and self-commutated inverters, voltage- source and current-source inverters, voltage controlled and current controlled inverter.

The various switching devices used in inverter circuit are also discussed in this section of review. Grid-connected inverter comes under the category of current source inverter. But, a numerous times the voltage source inverter operated in the current control mode is best suited for grid connected PV inverter. As this arrangement provides high power factor with a simple control circuit therefore the voltage source inverter is more advantageous as compared to current source inverter. This topology also suppresses the transient current when any disturbances occur in the utility grid. The self-commutated inverter employs power MOSFETs and IGBTs and this are more popular now a days. Power MOSFETs are used for low power and high-frequency switching operation whereas IGBTs are used for high power and low frequency switching operation as IGBTs are not suitable for high frequency operation. The high frequency operation using IGBTs is not possible due to reverse recovery current flowing through a switch. To eliminate this problem, advanced semiconductor devices have been fabricated.

High switching losses occur when hard-switching PWM converters employed in system. The switching losses can be reduced effectively when resonant converters are used in place of hard-switching PWM converters. But, resonant converters increases the voltage and current stresses across switches. The efficiency of the inverter is improved when soft-switching technologies are used.

In soft-switching inverters, switching losses are reduced effectively but at the cost of increasing conduction losses. The conduction losses increases due to increased voltage/ current stresses of the power switching devices. The ZVT-PWM inverter reduces current stress. The active and passive switching devices are operated with ZVS and both switching devices are subjected to minimum voltage and current stresses. The voltage and current stresses are reduced as compared to PWM converters.

The multilevel topologies are designed in such a way that a three or more discrete DC voltage levels are obtained at the power converter output. The multilevel topologies are widely used in high power applications and provide an alternative to the standard topologies used in small-power transformer-less inverters. The multilevel topology offers a wide range of input voltage variations but these multilevel topologies are costly due to additional cost of power diodes and transistors.

## REFERENCES

[1] T. Ishikawa, “Grid-connected photovoltaic power systems: survey of inverter and related protection equipments”, Report IEA (International Energy Agency) PVPS T5-05; Dec-2002. www.scribd.com/document/132798934/rep5-05-pdf.

[2] Trends in Photovoltaic Applications. Survey report of selected IEA countries between 1992 and 2003, Photovoltaic Power Systems Program, Report IEA-PVPS T1-13; 2004; 2004.

[3] N. A. Rahim, R. Saidur, K. H. Solangi, M. Othman, N. Amin, “Survey of Grid-connected photovoltaic inverters and related systems”, Clean Technologies and Environmental Policy 2012, Vol. 14, pp. 521–533

[4] V. Salas, E.Olías, “Overview of the state of technique for PV inverters used in low voltage grid-connected PV systems: inverters below 10 kW”, Renewable and Sustainable Energy Reviews 2009, Vol. 13, no. 6-7, pp. 1541–1550.

[5] H. A. Sher, K. E. Addoweesh, “Micro-inverters—Promising solutions in solar photovoltaics”, Renew Sustain Energy Rev Renewable and Sustainable Energy Reviews 2012, Vol. 16, no. 4, pp. 389–400.

[6] Patrao Iván, Figueres Emilio, González-Espín Fran, Garcerá Gabriel, “Transformerless topologies for grid-connected single-phase photovoltaic inverters”, Renewable and Sustainable Energy Reviews 2011, Vol. 15, pp. 3423-3431.

[7] R. H. Baker and L. H. Bannister, “Electric Power Converter,” U.S. Patent 3 867 643, Feb. 1975.

[8] R. H. Baker, “Switching Circuit", U.S. Patent 4 210 826, July 1980.

[9] M. Malinowski, K. Gopakumar, J. Rodriguez, M. Perez, “A survey on cascaded multilevel inverters”, IEEE Trans. Industrial Electronics 2010, Vol. 57, no.7, pp. 2197–206.

[10] X. Kou, K. A. Corzine, Y. L. Familiant, “Full binary combination schema for floating voltage source multilevel inverters”, IEEE Trans. on Power Electronics 2002, Vol. 17, no. 6, pp. 891- 897.

[11] S. Lu, S. Mariethoz, K. A. Corzine, “Asymmetrical cascade multilevel converters with noninteger or dynamically changing DC voltage ratios concepts and modulation techniques”, IEEE Trans. on Industrial Electronics 2010, Vol. 57, no.7, pp. 2411–2418.

[12] S. Mekhilef, M. N. A. Kadir, “Voltage control of three-stage hybrid multilevel inverter using vector

transformation”, IEEE Trans. on Power Electron 2010, Vol. 25, no. 10, pp. 2599–2606.

[13] P. Barbosa, P. Steimer, J. Steinke, L. Meysenc, M. Winkelnkemper, N. Celanovic, “Active neutral-point-clamped multilevel converters”, IEEE 36th, Power Electronics Specialists Conference”, PESC '05, 2005, pp. 2296–2301.

[14] M. D. Manjrekar, P. K. Steimer, T. A. Lipo, “Hybrid multilevel power conversion system: a competitive solution for high-power applications”, IEEE Trans. Industry Applications 2000, Vol. 36, no. 3, pp. 834–41.

[15] J. Dixon, J. Pereda, C. Castillo, S. Bosch, “Asymmetrical multilevel inverter for traction drives using only one DC supply”, IEEE Trans. on Vehicular Technology 2010, Vol. 59, no.8, pp. 3736–3743.

[16] A. L. Batschauer, S. A. Mussa, M. L. Heldwein, “Three-phase hybrid multilevel inverter based on half-bridge modules”, IEEE Trans. on Industrial Electronic 2012, Vol. 59, no. 2, pp. 668–678.

[17] J. C. Wu, C. W. Chou, “A solar power generation system with a seven-level inverter”, IEEE Trans. on Power Electron 2014, Vol. 29, no. 7, pp. 3454–3462.

[18] D. A. Ruiz-Caballero, R. M. Ramos-Astudillo, S. A. Mussa, M. L. Heldwein, “Symmetrical hybrid multilevel DCAC converters with reduced number of insulated DC supplies”, IEEE Trans. on Industrial Electronics 2010, Vol. 57, no. 7, pp. 2307–2314.

[19] A. Madhukar Rao, K. Sivakumar, “A fault-tolerant single-phase five-level inverter for grid-independent PV systems”, IEEE Trans. on Industrial Electronics 2015, Vol. 62, no. 12, pp. 7569–7577.

[20] K. Gupta, A. Ranjan, P. Bhatnagar, L. K. Sahu, S. Jain, “Multilevel inverter topologies with reduced device count: a review”, IEEE Trans on Power Electronics 2015, Vol. 31, no. 1, pp. 135–151.

[21] E. D. Spooner, G. Harbidge, “Review of international standards of grid connected photovoltaic systems”, Renewable Energy 2001, Vol. 22, no. 1-3, pp. 235–239.

[22] IEC61727, “Photovoltaic (PV) systems– characteristics of the utility interface”, IEC 61727 ED. 2.0 B, 2004.

[23] IEEE- 1547, IEEE Application Guide for IEEE Std. 1547(TM), “IEEE Standard for Interconnecting Distributed Resources”, IEEE-1547.2-2008

[24] IEEE Standard 929-2000 (Revision of IEEE Std. 929-1988), “IEEE Recommended Practice for utility Interface of Photovoltaic (PV) systems”, IEEE Standards Coordinating Committee 21, Photovoltaics, 2000.

[25] B. Verhoeven, “Utility Aspects of Grid Connected Photovoltaic Power Systems. International Energy Agency Photovoltaic Power Systems”, IEA PVPS T5-01: 1998. www.iea-pvps.org et al. 1998.

[26] IEA International Energy Agency, Grid-Connected photovoltaic power system: survey of inverter and related protection equipments, Task V, Report IEA-PVPS T5- 05; 2002.

[27] S. B. Kjaer, J. K. Pedersen, F. Blaabjerg, “A review of single-phase grid-connected inverters for photovoltaic modules”, IEEE Trans on Industrial Applications 2005, Vol. 41, no. 5, pp. 1292-1306.

[28] R. Attanasio, M. Cacciato, F. Gennaro, G. Scarcella, “Review on single-phase PV inverters for grid-connected applications”, In: Proceedings of the 4th IASME/WSEAS international conference on energy, environment, ecosystems and sustainable development (EEESD'08) 2008, pp. 23-238

[29] R. O. Cáceres, I. Barbi, “A boost dc-ac converter: analysis, design, and experimentation”, IEEE Trans. on Power Electronics 1999, Vol. 14, no. 1, pp.134–141.

[30] N. Vázquez, J. Almazan, J. Álvarez, C. Aguilar, J. Arau, “Analysis and experimental study of the buck, boost and buck-boost inverters”, In: Proceedings of 30th Annual IEEE Power Electronics Specialists Conference (PESC’99) 1999, Vol. 2, pp. 801-806.

[31] N. Kasa, T. Iida, H. Iwamoto, “An inverter using buck-boost type chopper circuits for popular small-scale photovoltaic power system”, In: Proceedings of 25th Annual Conference of the IEEE Industrial Electronics Society (IECON’99) 1999, Vol. 3, pp. 185-190.

[32] M. Nagao and K. Harada, “Power flow of photovoltaic system using buck-boost PWM power inverter,” In: Proceedings of Second International Conference on Power Electronics and Drive Systems (PEDS’97) 1997, Vol. 1, pp. 144–149.

[33] M. Kusakawa, H. Nagayoshi, K. Kamisako, K. Kurokawa, “Further improvement of a transformerless, voltage-boosting inverter for AC modules”, Solar Energy Materials and Solar Cells 2001, Vol. 67 no. 1, pp. 379–387.

[34] J. M. A. Myrzik, “Novel inverter topologies for single-phase stand-alone or grid- connected photovoltaic systems” In: Proceedings of 4th IEEE International Conference on Power Electronics and Drive Systems, (PEDS’01) 2001, Vol. 1, pp. 103–108.

[35] C-M. Wang, "A novel single-stage full-bridge buck-boost inverter", In: Proceedings 8th Annual IEEE Applied Power Electronics Conference and Exposition (APEC'03), 2003, Vol. 1, pp. 51–57.

[36] S. B. Kjaer, F. Blaabjerg, "A novel single-stage inverter for the ac-module with reduced low-frequency ripple penetration", In: Proceedings of 10th EPE European Conference Power Electronics and Applications 2003, Vol. 1, pp. 1-10.

[37] N. Kasa, T. Iida, H. Iwamoto, "An inverter using buck-boost type chopper circuits for popular small-scale photovoltaic power system", In: Proceedings 25th Annual Conference of the IEEE Industrial Electronics (IECON'99) 1999, Vol. 3, pp. 185–190.

[38] D. Schekulin, "Grid-Connected Photovoltaic System", Germany patent DE197 32 218 Cl, Mar. 1999.

[39] R. Henk, "Practical design of power supplies", New York: McGraw Hill; 1998. p. 95–96.

[40] S. Jainn, V. Agarwal, "A single-stage grid connected inverter topology for solar PV systems with maximum power point tracking", IEEE Trans. on Power Electronics 2007, Vol. 22, no. 5, pp. 1928-1940.

[41] T. Boutot, L. Chang, "Development of a single-phase inverter for small wind turbines," In: Proceedings of IEEE Canadian Conference on Electrical and Computer Engineering (CCECE'98) 1998, Vol. 1, pp. 305–308.

[42] Z. Yang, P. C. Sen, "A novel switch-mode dc-to-ac inverter with non- linear robust control," IEEE Trans. on Industrial Electronics 1998, vol. 45, pp. 602–608.

[43] F-S. Kang, C-U. Kim, S.-J. Park, and H.-W. Park, "Interface circuit for photovoltaic system based on buck-boost current source PWM inverter", In: Proceedings of 28th Annual Conference of the IEEE Industrial Electronics Society (IECON'02) 2002, Vol. 4, pp. 3257–3261.

[44] K. Chomsuwan, P. Prisuwanna, V. Monyakul, "Photovoltaic grid-connected inverter using two-switch buck-boost converter," In: Proceedings of 29th Annual IEEE Power Electronics Specialists Conference (PESC'02) 2002, 5P1.5, pp. 1527–1530.

[45] S Saha, V.P Sundarsingh, "Novel Grid-Connected Photovoltaic Inverter", In: Proceedings of IEEE Trans. on Generation, Transmission and Distribution 1996, Vol. 143, no. 2, pp. 219–224.

[46] S. Funabiki, T. Tanaka, and T. Nishi, "A new buck-boost-operation- based sinusoidal inverter circuit," In: Proceedings of 33th Annual IEEE Power Electronics Specialists Conference (PESC'02) 2002, Vol. 4, pp. 1624–1629.

[47] T. Shimizu, K. Wada, and N. Nakamura, "A flyback-type single phase utility interactive inverter with low-frequency ripple current reduction on the DC input for an AC photovoltaic module system," In: Proceedings of 33th Annual IEEE Power Electronics Specialists Conference (PESC'02) 2002, Vol. 3, pp. 1483–1488.

[48] S. B. Kjær, F. Blaabjerg, "Design optimization of a single phase inverter for photovoltaic applications," In: Proceedings of 34th Annual IEEE Power Electronics Specialists Conference (PESC'03) 2003, Vol. 3, pp. 1183–1190.

[49] B. K. Bose, P. M. Szczesny, R. L. Steigerwald, "Microcomputer control of a residential photovoltaic power conditioning system", IEEE Trans. on Industrial Application 1985, vol. IA-21, pp. 1182-1191.

[50] S. Saha, V. P. Sundarsingh, "Grid connected photovoltaic inverter as an industrial product," Eur. Polymer Eed. (EPE'96) 1996, pp. 46–51.

[51] J. Beristáin, J. Bordonau, A. Gilabert, G. Velasco, "Synthesis and modulation of a single phase DC/AC converter with high frequency isolation in photovoltaic energy applications," In: Proceedings of 34th Annual IEEE Power Electronics Specialists Conference (PESC'03) 2003, Vol. 3, pp. 1191-1196.

[52] J. Mahdavi, J. Roudet, R. Scheich, J. P. Rognon, "Conducted RFI emission from an AC/ DC converter with sinusoidal line current", In: Proceedings of 28th Conference Rec. IEEE- Industry Applications Conference IAS Annual Meeting 1993, Vol. 2, pp. 1048–1053.

[53] J. Mahdavi, M. Tabandeh, A. K. Shahriari, "Comparison of conducted RFI emission from different unity power factor AC/DC converters", In: Proceedings of 27th Annual IEEE Power Electronics Specialists Conference (PESC'96) 1996, Vol. 2, pp. 1979-1985.

[54] P. K. Hinga, T. Ohnishi, T. Suzuki, "A new PWM inverter for photovoltaic power generation system", In: Proceedings of lEEE Power Electronics Specialist Conference (PESC'94) 1994, Vol. 1, pp. 391–395.

[55] Y-F. Huang, Y. Konishi, W-J. Ho, "Series resonant type soft- switching grid-connected single-phase inverter employing discontinuous-resonant control applied to photovoltaic AC module", In: Proceedings of 26th Annual IEEE Applied Power Electronics Conference and Exposition (APEC'11)2011, pp. 989–994

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X

[56] G. Tan, Y. Tang, B. Gao, F. U. Xinghe, J. I. Yanchao, "Soft-switching AC module inverter with flyback transformer for photovoltaic power system", Przeglad Elektrotechniczny (Electrical Review) 2012, R. 88, nr 10a pp. 180-184. (ISSN 0033-2097)

[57] D. Amorndechaphon, S. Premrudeepreechacharn, K. Higuchi, "An improved soft-switching single-phase inverter for small grid-connected system", In: Proceedings of 34th Annual Conference of IEEE Industrial Electronics Society (IECON'08), 2008, Vol. 3, pp. 185-190.

[58] M. Chen, X. Lee, Y. Tsutomu, "A novel soft-switching grid-connected PV inverter and its application", In: Proceedings of 9th IEEE International Conference on Power Electronics and Drive Systems (PEDS'11) 2011, pp. 373-378.

[59] B. B. Gru, W. Kleinkauf, U. Krengel, J.Myzrik, "Loss-reduced energy conversion in PV systems by means of transformerless inverters (Verlustarme nergiewandlung in PV-systemen durch transformatorlose Wechselrichter, in German), in Tagungsband des Symposiums Photovoltaische Solarenergie 1997, pp. 324–25.

[60] H. Hinz, P. Mutschler, "Single phase voltage source inverters without transformer in photovoltaic applications", In: Proceedings of Power Electronics and Motion Control (PEMC'96) 1996, Vol. 3, pp. 161–165.

[61] A. Lohner, T. Meyer, A. Nagel, "A new panel-integratable inverter concept for grid-connected photovoltaic systems," In: Proceedings of IEEE International Symposium on Industrial Electronics (ISIE'96) 1996, Vol. 2, pp. 827–831.

[62] J. Schmid, W. Kleinkauf, "New trends in photovoltaic systems technology". In: Proceedings of 14th European Photovoltaic Solar Energy Conference 1997, pp. 1337–1339.

[63] G. Keller, W. Kleinkauf, U. Krengel, J. Myrzik, P. Zacharias, Developments in PV- inverter technology, overview, state of the art, trends in development (Entwicklungslinien der PVWechselrichtertechnik, Ruckblick, Stand der Technik, Entwicklungstendenzen, in German), in Tagungsbund des Symposiums Photovoltaische Solurenergie, 1997, pp. 163-168.

[64] M. Meinhardt, P. Mutschler, "Inverters without transformer in grid connected photovoltaic applications", In: Proceedings of Eropean Conference on Power Electronics Applications (PEA'95) 1995, pp. 3. 086-3.091.

[65] H. Shinohara, K. Kimoto, T. Itami, T. Ambou, C. Okado, K. Nakajima, S. Hojo, K. Owada, M. Kuniyoshi and Y. Sato, "Development of a residential use, utility interactive PV inverter with isolation transformer-less circuit - development aspects", In: Proceedings of the 24th IEEE Photovoltaic Specialists Conference, Hawai, 1994, Vol. I, no. 5P4, pp. 1216–1218.

[66] P. M. Bhagwat, C. V. Stefanovic, "Generalized structure of a multilevel PWM inverter", IEEE Trans. on Industrial Application 1983, Vol. 19, no. 6, pp. 1057–1069.

[67] J-S. Lai, F. Z. Peng, "Multilevel converters – a new breed of power converters", IEEE Trans.on Industrial Applications 1996, Vol. 32, no. 3, pp. 509–517.

[68] F. Z. Peng, J-S. Lai, J. W. McKeever, J. VanCoevering , "A multilevel voltage-source inverter with separate DC sources for static VAr generation", IEEE Trans on Industrial Applications 1996, Vol. 32, no. 5, pp. 1130–1138.

[69] V. G. Agelidis, D. M. Baker, W. B. Lawrence, C. V. Nayar, "A multilevel PWM inverter topology for photovoltaic applications", In: Proceedings of IEEE International symposium on Industrial Electronics (ISIE '97) 1997, pp. 589–594.

[70] M. Marchesoni, "High-performance current control techniques for applications to multilevel high-power voltage source inverters" IEEE Trans. on Power Electronics 1992, Vol. 7, no. 1, pp. 189–204.

[71] B. Burger, D. Kranzer, "Extreme high efficiency PV power converters", In: Proceedings 13th European Conference on Power Electronics and Applications 2009, pp. 1–13.

[72] M. Marchesoni, M. Mazzucchelli, S. Tenconi, "A non-conventional power converter for plasma stabilization", In: Proceedings of 19th Annual IEEE Power Electronic Specialists Conference (PESC'88) 1988.

[73] G. Joos, X. Huang, B. T. Ooi, "Direct-coupled multilevel cascaded series VAr compensators" In: Proceedings of 32 Annual Meeting IEEE Industry Application Society Conference (IAS'97) 1997, Vol. 2, pp. 1608–1615. and IEEE Trans. on Industry Applications 1998, Vol. 34, no. 5, pp. 1156 – 1163.

[74] E. Babaei, S. Laali, S. Alilu, "Cascaded multilevel inverter with series connection of novel H-bridge basic units" IEEE Trans. on Industrial Electronics 2014, Vol. 61, no. 12, pp. 6664–6671.

[75] E. Babaei, S. S. Gowgani, " Hybrid multilevel inverter using switched capacitor units", IEEE Trans. on Industrial Electronics 2014, Vol. 61, no.9, pp. 4614–4621.

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X


[76] E. Babaei, S.H. Hosseini, G. B. Gharehpetian, M.T. Haque, M. Sabahi, "Reduction of dc voltage sources and switches in asymmetrical multilevel converters using a novel topology", Electr Power Syst Res 2007, Vol. 77, no. 8, pp. 1073–1085.

[77] C. K. Lee, S. Y. R. Hui, H.S. H. Chung, "A 31-level cascade inverter for power applications", IEEE Trans. on Industrial Electronics 2002, Vol. 49, no. 3, pp. 613–617.

[78] K. K. Gupta, S. Jain, "A novel multilevel inverter based on switched dc sources", IEEE Trans. on Industrial Electronics 2014, Vol. 61, no. 7, pp. 3269–278.

[79] K. K. Gupta, S. Jain, "Comprehensive review of a recently proposed multilevel inverter", IET Power Electronics 2014, Vol. 7, no. 3, pp. 467–479.

[80] S. K. Chattopadhyay, C. Chakraborty, "A new multilevel inverter topology with self- balancing level doubling network", IEEE Trans. on Industrial Electronics 2014, Vol. 61, no. 9, pp. 4622–4631.

[81] D. W. Sandells, T. C. Green, "The Chain cell PFC", In: Proceedings of 31th Annual IEEE Power Electronics Specialists Conference (PESC'00) 2000, Vol. 2, pp. 955–960

[82] A. Mokhberdoran, A. Ali, "Symmetric and asymmetric design and implementation of new cascaded multilevel inverter topology", IEEE Trans. on Power Electronics 2014, vol. 29, no. 12. pp.6712-6724.

## AUTHOR PROFILES

**1. Mohammad Akram Syed** did his Electrical Engineering

degree from R.C.E.R.T. Chandrapur, under R.T.M.N. University, Nagpur in 2006. PG degree in Energy Management System from R.C.E.R.T. Chandrapur, under R.T.M.N. University, Nagpur in 2010. Presently he is research scholar in Government College of Engineering, Chandrapur, under Gondwana Univeraity, Gadchiroli.

**2. Gunwant Ajabrao Dhomane** did his degree from

Walchand College of Engineering Sangli, India in 1986. He received PG from Government College of Engineering Amravati. He obtained his Ph. D degree from VNIT, Nagpur, India in 2010. Presently he is Professor and Head of Electrical Engineering Department, Government College of Engineering Amravati. He is also Dean R&D. He has published around 50 papers in refereed National/International/Journal/Conference. His field of interest includes power electronics converters, renewable energy systems, smart grids, power system protection etc.

**3. Praful Vijay Nandankar** did his degree from St. Vincent

Pallotti College, Nagpur in 2010. He received PG from VNIT, Nagpur in 2013. He is working as an Assistant Professor in Government College of Engineering, Chandrapur. He has published around 12 papers in refereed National/International/Journal/ Conference. His field of interests include power electronics, renewable energy systems, FACTS devices etc.