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Grid-Connected Photovoltaic Systems And Active Power Filtering Function, A Review

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Abstract- The inverter is an essential element in a photovoltaic system. It exists as different topologies. This review-paper focuses on different technologies for connecting photovoltaic (PV) modules to a three-phase- grid. The inverters are categorized into some classifications: the number of power processing stages; the use of decoupling capacitors and their locations; the use or no of the transformers; the type of three phase inverter; whether they are preceded by a DC/DC converter or not .Some of three-phase topologies are presented, compared according to the type of control (i.e. the PWM method; the bang-bang method or the fuzzy logic method or numerical control and a comparison with single-phase inverters is given.

Keyword- PV system, centralized inverter, three-phase, grid-connected, control method.

I. INTRODUCTION

Grid connected PV systems consist of a PV generator for conversion of solar irradiation into DC electricity, and an inverter for converting direct current into alternating current. PV power supplied to the utility grid has made big step, while the world's power demand is increasing. Not many PV systems have been placed into the grid due to the relatively high cost, compared to more traditional energy sources such as oil, gas, nuclear, hydro, and win [1].Solid-state inverters have been shown to be the enabling technology for putting PV systems into the grid. Due to the massive production capacity of PV modules, they are becoming increasingly cheaper during these last years. The price of grid-connected inverter is, therefore, becoming more visible in the total system price. But, from 1998 to 2022 the general price level of inverters fell by about 40%. Now, focus has been placed on new, cheap and innovative inverter solutions and new system configurations. This paper starts with a categorization of inverters classification in different classifications and how they are controlled. Next follows a comparison between single and three phase inverters. Finally all the topologies are discussed and a conclusion is given.

II. CLASSIFICATION OF INVERTERS TOPOLOGIES

Whether single or three phase inverters are categorized as follows:

1. Number of power processing stages

There are three cases of single and multiple stage inverters:

- Firstly, the single stage inverter, which must handle all tasks, itself, i.e., MPPT, grid current control and perhaps, voltage amplification: This is the typical configuration for a centralized inverter with all its drawbacks.
- Secondly, the dual stage inverter where we have the addition of a DC/DC converter must ensure that the MPPT function. The inverter is controlling the grid current by means of PWM or bang- bang operation. But voltage amplification can be included in both stages.
- Thirdly, The dual stage for AC- module technology, where each module is connected to its own DC/DC converter and all converters are connected to the same inverter, which takes care of the grid current control.

2. Use of decoupling capacitors

The capacitor is the main component which limits the lifetime. Thus, it should be kept as small as possible; therefore, it is preferable to substitute the electrolytic capacitor with film capacitor , and If we use the three-phase inverter the capacitor is 10 times smaller[4],then, frequency transformer and the transformer- less inverter constitute the majority (see fig.1).

C = 1 VL.Iout_inv_1 10 2.VDC.ΔVDC.ω (1)

Where: VL is the rms value of the line voltage(average value of the three phases), Iout_inv_1 is the inverter fundamental output current, VDC is the DC voltage, ΔVDC is the variation of voltage in the capacitor and m is the utility frequency. Equation (1) is based on the fact that the current from the PV modules is a pure DC, and that the current draw from the grid-connected inverter follows a sin2 ($m$grid.t) waveform, assuming that VDC is constant. In addition, the capacitor is either placed in parallel with the PV modules or in the DC link between the inverter stages.

3. Use of transformers: Isolation between AC side and Dc side

To isolate the DC circuit and the AC circuit, a simple method is to install an isolating transformer at the output

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side of the inverter. However, in this case, a transformer of a commercial frequency is required, raising the problem that the volume and the weight of the entire inverter system are increased. Accordingly, a system is employed in which a high frequency AC circuit is provided for the inverter between the direct current and the commercial AC system, and a transformer is installed at this high-frequency part to isolate the DC circuit and the commercial AC circuit. In this case, although a high-frequency circuit is required, the higher the frequency is the smaller the capacity and the weight of the transformer are, so the size and the weight of the transformer are reduced. In addition, an inverter of a transformer-less system can be provided in which no isolating transformer is used. In this case, a circuit for detecting the DC component superposed on the AC circuit, and a grounding detection circuit in the DC circuit is required. However, capacity and weight can be minimized because the transformer is omitted. The results of this survey include the inverter system using a commercial transformer or high-frequency transformer, as well as a transformer-less inverter system. The high-

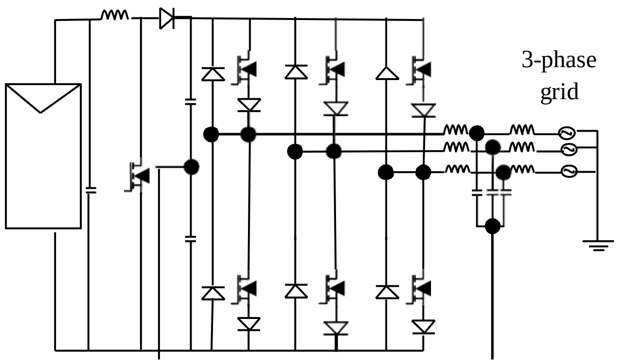


Fig.1 Typical circuit diagram of a MOS-equipped VSI with Boost-**C**onverter for a PV module generation system

4. Types of three phase inverters

In this paper we try to give an overview on the three-phase inverters , the types of theirs control ,if they use DC/DC converters or no
,and a comparison with single-phase inverters will also be given. Inverter topologies can be basically divided into two main types:

- Voltage source inverters (VSI) and
- Current source inverters (CSI).

To some extend, the recently introduced Z- Source Inverter represents a combination of both [4], [5].

1. MOS-equipped VSI with Boost-Converter Fig.1 depicts the typical circuit diagram of a MOS-equipped voltage source inverter (VSI) .for a PV module generation system. The VSI with neutral-point connection needs at least a dc-link voltage of 650V to feed into a three-phase 400V grid as each dc-link capacitor needs to have a voltage higher than the amplitude of the phase voltage. In the practical design, the dc-link voltage actually needs to be 700-750V due to a 10% grid voltage tolerance and some control reserve. The reason why the neutral point should be connected to the dc-link is to minimize common-mode voltages at the PV module. A VSI directly connected to the PV module would even need a higher MPP voltage because of a module manufacturing tolerance. An additionaldc-dc boost converter (BC) would be required which can Works with lower MPP voltages.

1. 2. The current source inverter (CSI) (Fig.2)

2. This inverter is a viable alternative to a VSI+BC due to its voltage step-up characteristic [2], [3]. The CSI directly connected to the PV module features a single- stage power conversion system for feed-in and MPPT. With regard to the CSI at unity power factor, the MPP voltage has an upper limit of about 440Vwhich is derived from the minimum of the rectified phase to phase voltage minus a grid voltage tolerance. A comparison between these basic concepts presented in [4] revealed that an IGBT- equipped VSI with boost converter tends to have a better performance in medium power fuel cell applications.

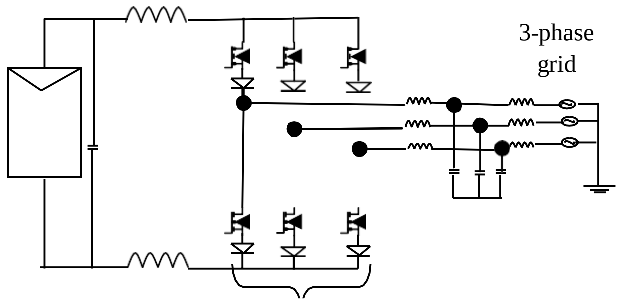


Fig.3 Circuit diagram of a 3-phase three wire BJT equipped inverter topology [15].

3.Three -phase four-wire inverter with splitDc-link

The topology shown in fig.4 is a three phase four-wire BJT-equipped inverter with split DC-link. It was a simple topology and the advantage is that a three-phase split-link inverter essentially becomes three single-phase half-bridge inverters and permits each of the three legs to be controlled independently, making its current tracking control simpler than the four-leg inverter[6]. Several problems are introduced by choosing the split-link topology. One of them is ensuring equal voltage sharing between the split capacitors and the need to attenuate voltage ripple. This results in the need for large and expensive dc-link capacitors or even extra balancing structures. Another disadvantage is caused by the fact that the split-link topology requires that the phase- voltage peak is less than or equal to half the total dc-link voltage, whereas the four-leg inverter can follow a line-voltage peak equal to half the total dc-link voltage. This gives an approximately 15% advantage in dc voltage utilization in favor of the four-leg inverter. In [7], a split voltage controller is developed to obtain maximum dc voltage utilization

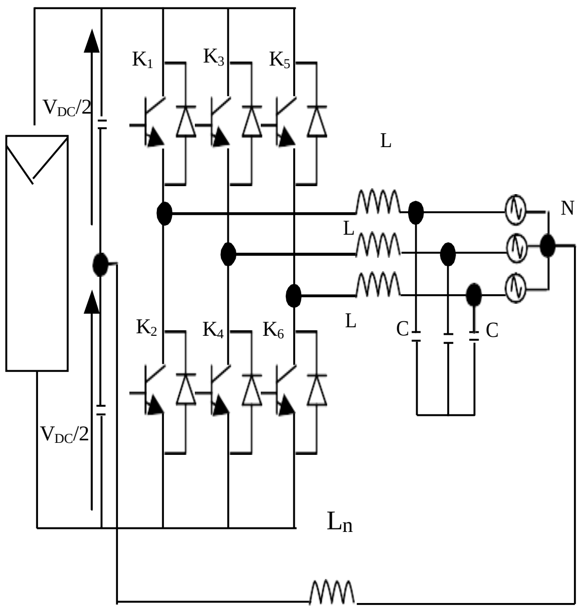


Fig.4 Topology of the three phase four-wire inverter with split dc-link [6].

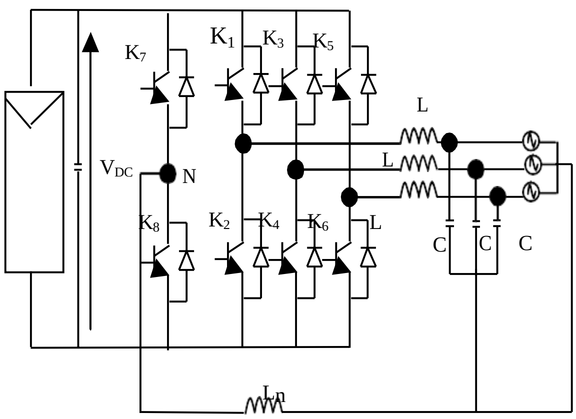
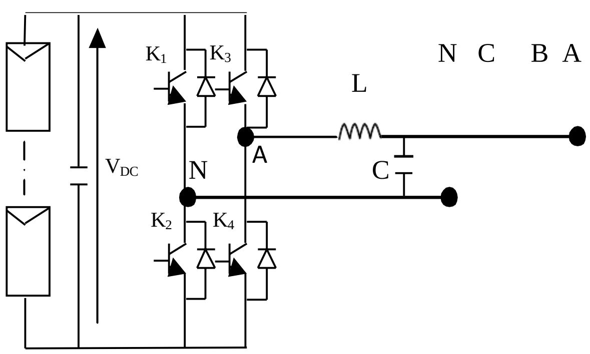


Fig.5 Circuit diagram of three- phase four leg Inverter.



3. Topology of the three phase four-leg Inverter

In this topology (Fig.5), there is the addition of two switches to form a fourth leg which his point medium is regarded as neutral point. The extra two switches result in a complicated control which makes the topology less interesting. Fig.3 Circuit diagram of a 3-phase three wire BJT equipped inverter topology [15]

4. Three -phase four-wire inverter with split Dc-link

The topology shown in fig.4 is a three phase four-wire BJT-equipped inverter with split DC-link. It was a simple topology and the

6. Multi-string inverter

PV systems as an alternative energy resource or an energy-resource complementary in hybrid systems have been becoming feasible due to the increase of research and development work in this area [8] In order to maximize the success of the PV systems a high reliability, a reasonable cost, and a user-friendly design must be achieved in the inverter topology. Fig.9 depicts the multi-string topology is commonly used in PV applications. It permits the integration of PV strings of different technologies and orientations (north, south, east and west) [9]. This topology can be seen as three single-phase inverter which makes it uninteresting in view of voltage unbalance. This can be avoided by using three-phase multi-string inverters [9].

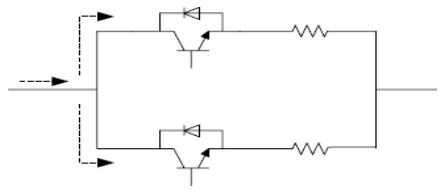


Fig.6Topology of the three phase four-wire Multi-string inverter.

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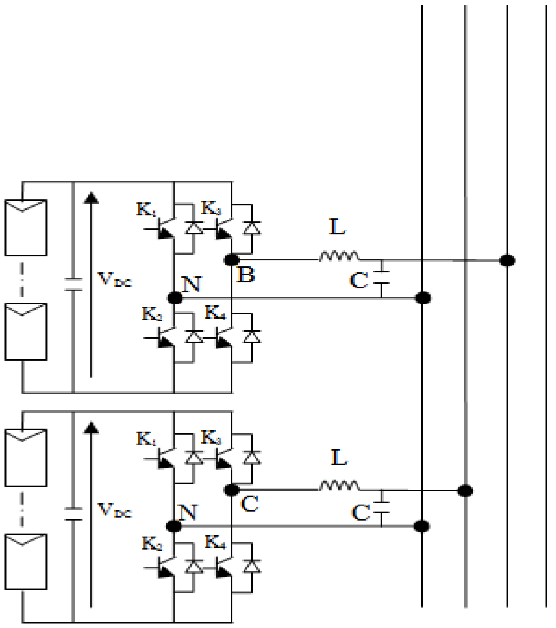

Fig.6Topology of the three phase four-wire Multi-string inverter.

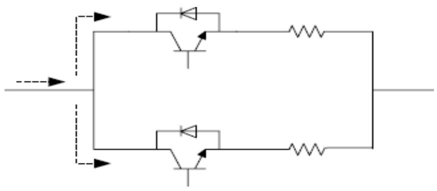

Fig.7 Parallel Connection of Two Three-Phase Inverters

6.Three-Phase Parallel Inverter

In parallel operation, two or more inverters are tied together to share the load. A system of two units was discussed in [10]. Fig.7shows two inverters which are directly connected at input and output ends. The parallel connection done for the two bridges such that the dc side filters and the ac side filter are common for the two parallel inverters. Inverters with different ratings some times encountered toincrease the power capability of the system; it is desirable to share the currents according to the rated power of each module. To study the current sharing and circulating current one mode of operation is to be considered. Fig.8shows the mode of operation when the current I_{DA} flowing through K1A and KB, however the current I_{DA} flowing back to the source through K6A and K6b. the Figure shows the current sharing between K_{1A} and K_{1B} with two series resistors included.

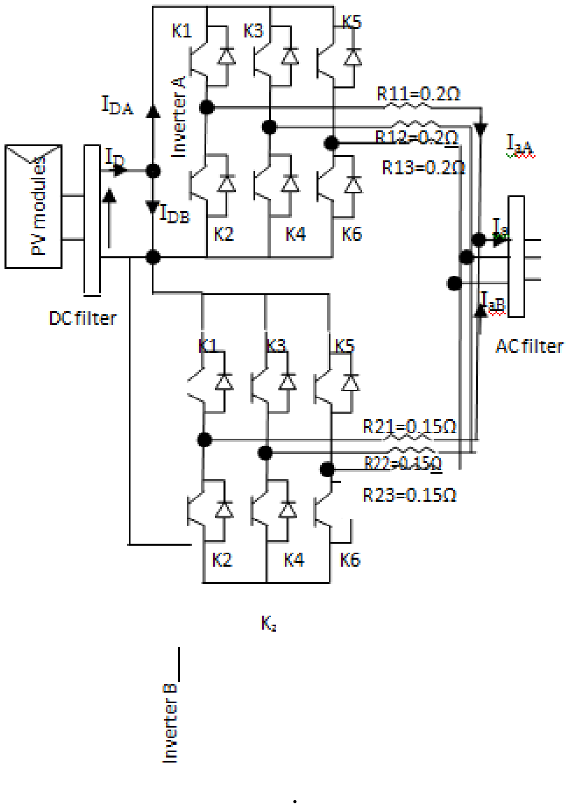

Fig.8 Circulating Current during One Switching Cycle

8. Three-phase inverter with stabilizer and transformer

Fig.9 depicts a three-phase inverter with stabilizer and transformer [11]. The basic components of this are a stabilizer, a 6 IGBTs 3 arm bridge, a Filter LC and a 10KW load. The stabilizer is consisted of four IGBTs bridge and 2 switches for the logical operation. The switches compare the output voltage to the desirable value of 650V and consequently turn on or off the IGBTs through the synchronization signal. The output of the stabilizer is connected to a low pass filter (LC) and is the input for inverter. The inverter is composed of 6 IGBTs and the control unit. The last generates control pulses to drive the IGBTs. The pulse generator gives a digital signal to the IGBTs.The Filter which is an LC low pass filter reducing the harmonic distortion by cutting off the high frequency harmonics The control unit in which a PLL ynchronizes the output phase of the inverter with the phase of the grid and the PWM synchronizes the IGBTs.This topology is very influenced by variations in the load. When the Load is getting bigger the variation follows up and the sinusoidal characteristicsare becoming worse off. Where as if each part of the system was considered separately the behavior would seem to be ideal.

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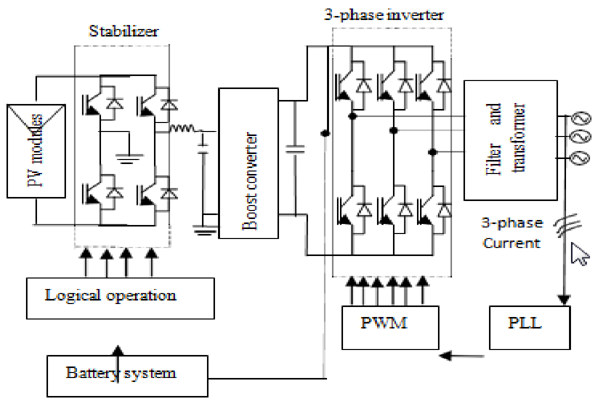

Fig.9 Topology of three-phase inverter with stabilizer and transformer.

IV. COMPARISON WITH SINGLE-PHASE INVERTERS

A one phase AC grid connection with sinusoidal current of cos(φ) = 1 accepts power proportional to sin2(*mt*), which oscillates every 10 ms between zero and 2•PL[12] :P (t)=2.VL.IL.sin2(*mt*)=2.PL. sin2(*mt*) (2)Where: VL is the rms value of the line voltage (average value of the three phases) and IL is the rms value of the generated line current (inverter output current) But, In a symmetrical three phase grid connection operated with sinusoidal currents at cos(φ) =1, the three phase powers add up to a constant value. A three phase power flow then is [12]:
P(t) = ∑ [Pi(t)] i=1,2,3 , with :
P(t) =∑[2/3.VL . IL . sin2 (*mt*+φi)]i=1,2,.3 = PL (3)
Due to continuous power flow (= PL) an electrolyte capacitor as buffering storage can be avoided, and the sizing of components can be considerably reduced (peak load on input stage semiconductors, inductance and transformer reduced by 50%, and on output stage semiconductors by 67%).
The following principal differences between one- phase and three-phase inverter design can be stated (see table 1).

Table .1: Differences between single-phase and three-phase inverters

Single –phase inverter	Three-phase inverter
Power Delivery	
Oscillating and equal to : $2 \cdot P_L \sin^2(wt)$	Constant and equal to : P_L
Buffering Storage	
needed	not needed
Output Stage Switches	
(low-frequency zero-voltage switched)	(PWM controlled)
Input Stage Switch P_{MAX}	
$2 \cdot P_L$	P_L
Output Stage Switch P_{MAX}	
$2 \cdot P_L$	**2/3·PL**

Single –phase inverter Three-phase inverter
Power Delivery
Oscillating and equal to :
2•PL sin2(wt) Constant and equal to :
PL
Buffering Storage
needed not needed
Output Stage Switches
(low-frequency
zero-voltage switched)
(PWM controlled)
Input Stage Switch PMAX
2•PLPL
Output Stage Switch PMAX
2•PL2/3•PL

V. DISCUSSION &CONCLUSION

In this paper an overview of some three-phase inverter topologies for connecting photovoltaic (PV) to the 3-phase grid is given. The most interesting topologies are the split DC-link and the four-leg inverter due to their simple topology. These topologies provide a three-dimensional control which is interesting in active filtering applications.The current-controlled scheme inverter is extensively used (81%) for the inverter of a grid interconnection photovoltaic power system because a high power factor can be obtained by a simple control circuit, and transient current suppression is possible when any disturbances such as voltage changes occur in the utility power system. However, some inverters employ the voltage control scheme (19%).
- Parallel Connection of Two Three-Phase Inverters is given and by comparing the THD and efficiency in single unit and parallel connected unit the THD improve and the efficiency as well. The THD reduced to be less than 1.5% for the current and the voltage. And if we want to increase the power level at the output of the inverter, several three-phase inverters can be paralleled.
-According to table1. The three-phase inverter appears more significant than the single-phase inverter because expected achievements are higher lifetime, improved efficiency, smaller size and lower costs through absence of an electrolyte capacitor and reduced stress and sizing of the semiconductors and magnetic components.

Regarding differences in characteristics between IGBT and MOSFET, the switching frequency of IGBT is around 20 kHz; IGBT can be used even for large power capacity inverters of exceeding 100 kW, while the switching frequency of MOSFET is possible up to 800 kHz, but the power capacity is reduced at higher frequencies. In the output power range between 1 kW to 10 kW, the switching frequency is 20 kHz, thus, both IGBT and MOSFET can be used.

Finally, in this paper we do not present multilevel inverters because these can be treated in another paper. Multilevel inverters posses the advantage of generating output voltages with extremely low distortion, generating smaller common-mode voltage and drawing current with very low distortion but a complex topology, a large number of components and a complicated control strategy have to be overcome. Nevertheless, the multilevel inverter will play an important role in the future.

Three-phase inverters are forecast to see fastest growth over the next five years and shipments are predicted to exceed 15 GW by 2014.

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