ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An UGC Approved Journal)

Website: www.ijareeie.com

Vol. 6, Issue 8, August 2017

A Review of Grid Connected Inverters for Photovoltaic System

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ABSTRACT: Photovoltaic inverter is an essential element of grid connected Photovoltaic power system consisting of solar panels, inverters, grid connection equipment and power conditioning equipment units. Solar photovoltaic system being weather dependent, maximum power storage can be achieved using MPPT (Maximum Power Point Tracking), plant monitoring, anti-islanding techniques. These techniques enable stable operation at very low irradiation levels. Transformer less inverters based on H Bridge and NPC are highly efficient up to 98%. The use of more number of switches has reduced losses and increased efficiency by 1%. The problem with the photovoltaic inverters is that there are so many topologies and it is difficult to find the standard modules for the implementation.The choice of topology for each inverter should be based on what is the usage of the inverter. As energy demands are rapidly increasing and in view of the reliability and pollution concern the Photovoltaic inverters structures are evolving at a high rate

KEYWORDS: Maximum Power Point Tracking, Neutral Point Clamped, Ministry of New and Renewable Energy, Direct current, Alternating current, Photovoltaic, Metal oxide semiconductor field effect transistor, Insulated gate bipolar transistor, Highly efficient and reliable inverter concept, Forward biased, Electromagnetic induction, Compound annual growth rate.

I.INTRODUCTION

In the recent years there has been a tremendous growth in the grid connected renewable electricity. The major power developed by the renewable energy resources is by the solar power and wind power. In India Ministry of New and Renewable Energy (MNRE) is established to look after the power developed by the renewable energy sources. As of March 2017 the Grid connected renewable electricity is 57244.33MW in which 18.65% is produced by solar power. Solar power will take over the wind by 2040 and by 2050 it will be the world's largest source of electricity. Gallium Arsenide based photovoltaic cells with multijunction device can give a maximum efficiency of 30% and the carbon Nano tube based photovoltaic cells can give a maximum efficiency up to 50%. The power developed by the photovoltaic system is DC and the grid is AC. So in order to connect to the grid the DC has to be converted into AC. This is done by the grid connected inverters. With the development in the solar power has led to a tremendous increase in the inverter industry which connects the photovoltaic system to the grid that is grid connected inverters. Section II explains detailed PV system. This paper gives overview of the available inverter topologieswith advantages, disadvantages, applications, and their efficiencies

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II.PHOTOVOLTAIC POWER SYSTEM

A grid interactive solar photovoltaic system is as shown in Figure 1.

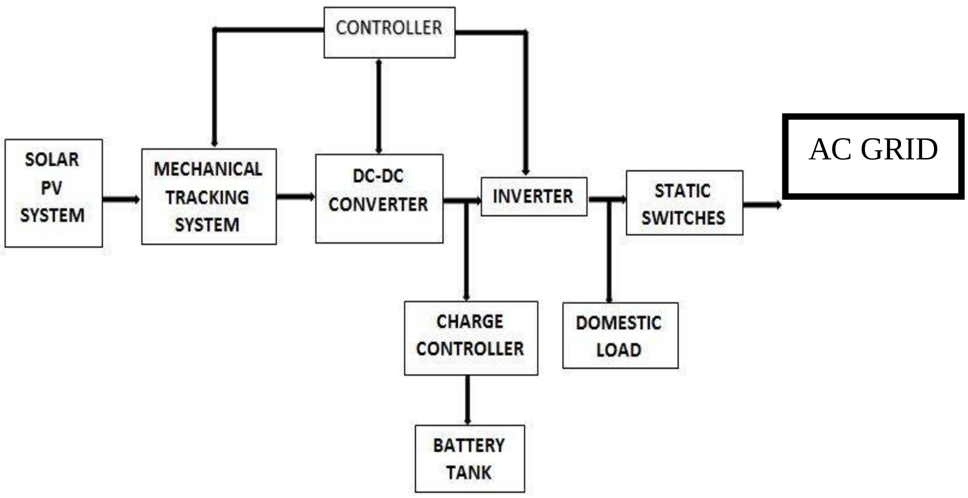

Fig. 1 Grid Interactive Solar Photovoltaic System

The photovoltaic cells produce DC output power but the grid is AC and the domestic loads are working on single phase AC. So it requires inverters in between photovoltaic cells and the grid in order to interface the photovoltaic system to the grid. A mechanical tracking system is used to increase the efficiency of the photovoltaic cells .The photovoltaic DC output is not suitable for grid directly, so DC-DC high frequency chopper is used to raise the DC voltage using inductors which is followedby the inverters. A battery via converter inverter feeds the domestic load at night or at cloudy day or when the grid fails. The process of power conversion DC –DC-AC via solid state devices that is inverters is known as power conditioning. Section III gives information on types of inverters with advantages and disadvantages.

III.INVERTERS

DC power generated by the photovoltaic cells is converted to the AC power by the inverters. Solar photovoltaic cells behave like batteries powered by the sun, inverters have to manipulate the dc to ac power. The grid connected inverters are the ones which enable to connect the PV cells to the grid. These are the most commonly used. These inverters have a decent demand in the inverter market.

One of the basic classifications of the inverters associated with the photovoltaic system is based on the mode of the operation.

1. Stand-alone inverters 2. Grid-connected inverters
3. Bimodal inverters

The grid-connected inverters are also classified according configuration topology. There are four different categories under this classification.

1. Central inverters: which are usually around several kW to 100 MW range.
2. String inverters: typically rated around a few hundred Watts to a few kW.
3. Multi-string inverters: typically rated around 1 kW to 10 kW range.

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4. Module Inverters or Micro Inverters: typically rated around 50 to 500 W.

A. CENTRAL INVERTER

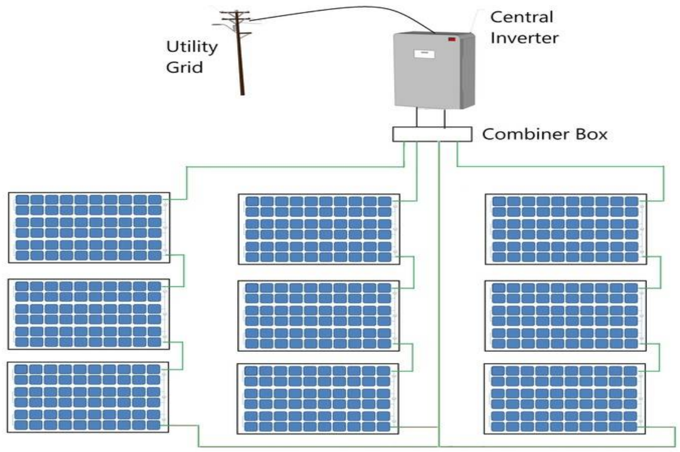

Fig. 2 Central Inverter

This is a PV array that consists of three strings, where each string has three series connected modules. Before these strings are connected to the utility grid power conditioning unit is required as an interface between the array and the grid. Designers can use one central inverter as illustrated in Figure 2, where all strings are connected to the DC side of the inverter and the single AC output is connected to the utility grid.

Advantages of a Central Inverter

1. The most traditional inverter topology
2. Easy system design and implementation
3. Low cost per Watt
4. Easy accessibility for maintenance and troubleshooting

Disadvantages of a Central Inverter

1. High DC wiring costs and power loss due to Voltage Drop.
2. System output can be drastically reduced in case of partial shading and string mismatch
3. Difficult to add strings or arrays for future expansion
4. Single failure point for the entire system
5. Monitoring at array level
6. Huge size (It is a disadvantage because the bigger size requires more land and creates a shading issue for the PV array.)

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B. STRING INVERTER

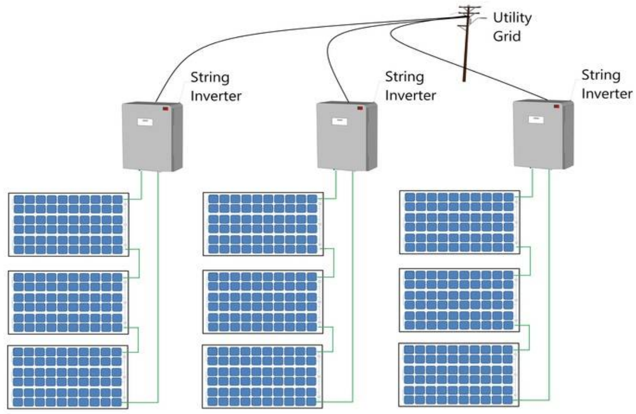

Fig. 3 String Inverter

Assuming a PV array that consists of three strings, another way to connect it to the grid is using three string inverter as illustrated in Figure 3. In this case, each PV string is connected to a single string inverter at the DC side, and all AC outputs of inverters are combined and connected to the utility grid.As the name indicates, each string of PV modules has itsown inverter. In this case, it moves closer to the PV modules level.

Advantages of a String Inverter

1. Smaller in size when compared to central inverters
2. Better MPPT capability per string
3. Scalability for future expansion by adding parallel strings
4. Short DC wires
5. Monitoring at string level

Disadvantages of a String Inverter

1. The installation requires special racking for the inverter for each string
2. Poor flexibility at partial shading
3. Higher per Watt cost than central inverter.

C. MICRO INVERTER

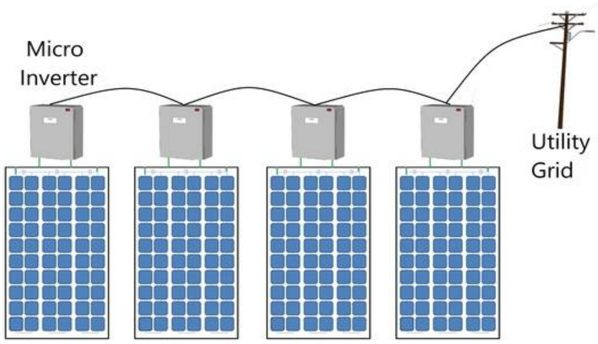

Fig. 4 Micro Inverter

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Micro Inverters are also referred to as module inverters. In this case, each module has one dedicated inverter connected on the back of the module. The module DC terminals are connected to the DC side of the inverter and then all AC wires of all terminals are combined and then connected to the utility interconnection point asillustrated in Figure 4. As the name suggests, each module has a dedicated inverter with a Microprocessor tracker.

Advantages of Micro Inverters

1. Resilience to partial shading effects as compared to the central and string inverters.
2. Highest system flexibility for future expansion
3. Minimum DC wiring costs
4. Monitoring at module level

Disadvantages of Micro Inverters

1. High per Watt cost
2. High maintenance costs
3. Difficult access for maintenance since the installation is under the PV modules

Section IV gives brief information on various topologies.

IV.TOPOLOGIES

The first photovoltaic system connected to the grid was by the thyristor controlled inverter in 1980. In the mid 1990 IGBT, MOSFET technology was extensively used for the inverter technology, where MOSFET was more dominating.

The transformer less grid connected photovoltaic inverters on the basis of their internal structure or topology are

1. H Bridge type 2. NPC (neutral point clamped) type

The various types of H bridge type inverters are

1. Basic full bridge type

Based on the modulation the FB inverters are classified as

1. BP (bipolar modulation) inverter
2. UP(unipolar modulation)inverter
3. Hybrid modulation

2. H5 inverter
3. HERIC inverter
4. REFU inverter
5. FB type with DC bypass
6. FB zero voltage rectifier

The various types of NPC type inverters are

1. Half bridge inverter 2. Conergy NPC inverter

A. H BRIDGE TYPE

1. BP MODULATION INVERTER

In this inverter the switches in the structure of inverter are switched diagonally. This has no zero output voltage. This has a very low leakage current and EMI. Have a lower efficiency around 96.5%. The switching ripple in the current is high resulting in higher filtering requirements.The practical PV inverter topology based on the full-bridge (FB) inverter is shown in Figure 5 below.

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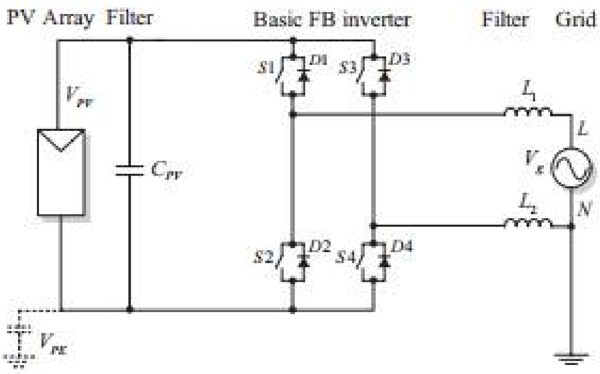

Fig. 5 Basic FB inverter

2. UP MODULATION INVERTER

In this inverter the switches are switched at high frequency with mirrored sinusoidal reference. Two zero output voltage states are possible. The switching ripple in the current is low resulting in lower filtering requirement. The have core losses. This has leakage current and EMI. The efficiency is up to 98%.

3. HYBRID MODULATION INVERTER

In this inverter one leg is switched at grid frequency and another at high frequency. Two zero output voltage states are possible. The switching ripple in the current is high resulting in higher filtering requirements. This have high leakage current peaks and EMI. The efficiency is up to 98%

4. H 5 INVERTER

In this inverter extra fifth switch in the positive bus of the DC link is used to increase efficiency. The switches are switched at high frequency and grid frequency. Two zero output voltage states are possible. Three switches conducting at a time cause higher conduction losses. They possess low leakage current and EMI. The efficiency is up to 98%. Extra switch is present which isolates the PV panels from high frequency content. The figure 6 illustrating H5 inverter topology is shown below.

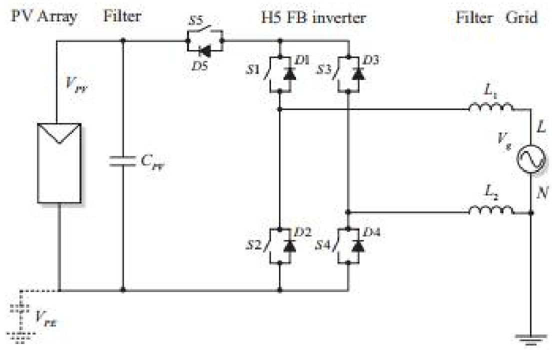

Fig. 6 H5 inverter

5. HERIC INVERTER

In the classical H-bridge inverter by adding a bypass leg in the AC side using two back-to-back IGBT's. The switches diagonal are switched at high frequency and IGBT switches at grid frequency. Two zero output voltage states are possible. Two extra switches usage is a drawback. Unlike H5 inverter there are two switches conduct at a time. The efficiency is up to 95.6%. The figure 7 illustrating HERIC inverter topology is shown below.

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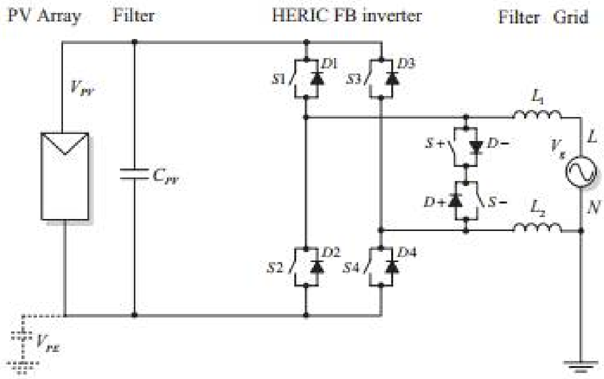

Fig. 7 HERIC inverter

6. REFU INVERTER

In this inverter there is a half bridge within the AC side bypass and a by passable DC-DC converter.AC bypass is done using a diode in series with the unidirectional IGBT switch to nullify the freewheeling diode path and minimising losses. Otherwise a boost converter can be used which is activated when input DC voltage is lower than the grid voltage.Switches one same leg are switched at high frequency and IGBT switches at grid frequency. This leads to low leakage current and EMI. But this inverter requires double DC voltage and two extra switches. The efficiency is up to 98%. The figure 8 illustrating REFU inverter topology is shown below.

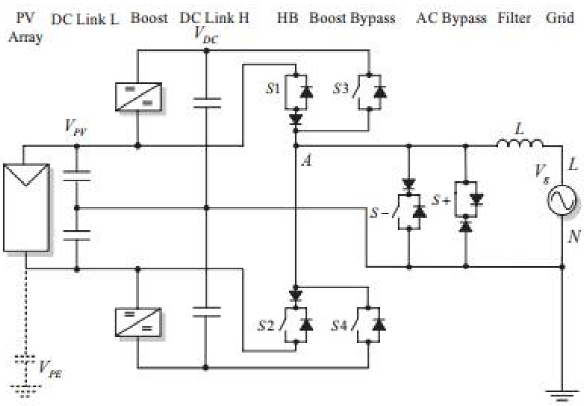

Fig. 8 REFU inverter

7. FB DCBP INVERTER

This inverter is a classical H-bridge with two extra switches in the DC link and also two extra diodes clamping the output to the grounded middle point of the DC bus. To isolate PV panels from grid during the zero voltage states DC switches are used with the rating of half the DC voltage. As four switches conduct at a time higher conduction losses are obtained. The efficiency is up to 96.5%. The figure 9 illustrating FB DCBP inverter topology is shown below.

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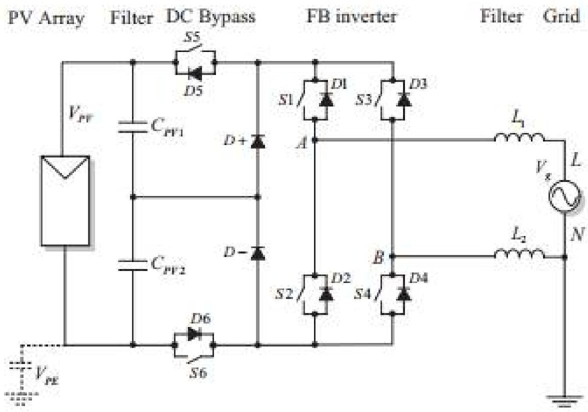

Fig. 9 FC DCBP inverter

8. FB ZVR INVERTER

This topology is derived from HERIC in which a diode clamp on DC midpoint and a diode bridge and one switch on ACside. Zero voltage is obtained by turning the FB off. Diagonal switching like bipolar modulation is done. During dead time clamping, bipolar output voltage is obtained leading to the increased losses across the filter. This is advantageous than HERIC in terms of high efficiency and low leakage. The efficiency is up to 96% and works at any power factor.The figure 10 illustrating FB ZVR inverter topology is shown below.

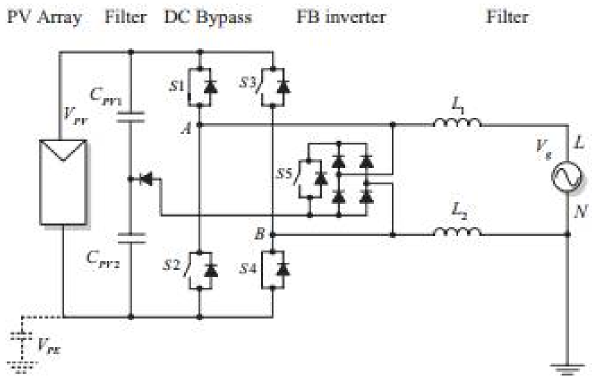

Fig. 10 FB ZVR inverter

B. NPC TYPE

1. NPC HALF BRIDGE INVERTER

In this inverter the idea is to obtain zero voltage by clamping the output to the grounded middle point of DC bus. Two extra diodes are used in parallel to each leg. To reduce the switching losses, reduce voltage rating of outer switch by one fourth of PV voltage. It requires double voltage input and has low leakage current and EMI. Unbalanced switch losses occur and introducing any inductor in middle point leads to leakage current. The efficiency is up to 98%. The figure 11 illustrating NPC Half Bridge inverter topology is shown below.

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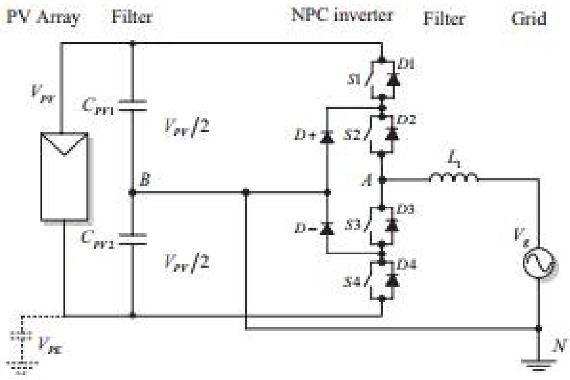

Fig. 11 NPC Half Bridge inverter

2. CONERGY NPC INVERTER

In this inverter the zero voltage is achieved by clamping the output to the grounded middle point of the DC bus using two switches depending on sign of current. Two zero voltage states are possible. Reduction in voltage drop is due to single switch conduction at a time and balanced switching losses unlike classical NPC. Conergy inverter has higher efficiency than NPC and has low leakage current and EMI. The efficiency is up to 96.1 %.The figure 12 illustrating Conergy NPC inverter topology is shown below.

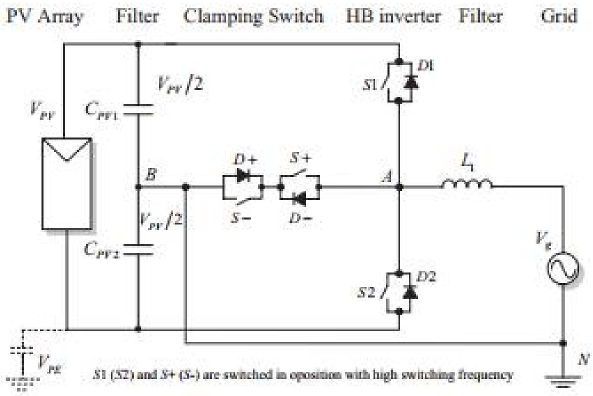

Fig. 12 CONERGY NPC inverter

Table 1 gives an overview of the features, advantages, disadvantages, efficiency and applications of available topologies as described in above section

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S. No	Type of Topology	Advantages	Disadvantages	Efficiency (η %)	Applications
1.	Bipolar modulation (BP)	Very low leakage current and EMI	Lower efficiency, high core losses	96.5	-
2.	Unipolar modulation (UP)	High efficiency, lower core losses	High leakage currents and EMI	98	-
3.	Hybrid modulation	Lower core losses, Higher efficiency	Only works for two quadrants operation, high filtering requirements, High leakage current peals and EMI	98	-
4.	H5	Lower core losses, higher efficiency, low leakage current and EMI	Extra switch, high conduction losses	98	SunnyBoy 4000/5000 TL
5.	HERIC	Lower core losses, high efficiency, very low leakage current and EMI	Two extra switches	95.6	Sunways (in AT series 2.7-5 KW)
6.	REFU	Lower core losses, high efficiency, very low leakage current and EMI	Double DC voltage, two extra switches	98	Three phase series Refusol (11/15 KW)
7.	FB-DCBP	Lower core losses, higher efficiency, very low leakage current and EMI	Two extra switches and diodes, higher conduction losses	96	Ingeteam in Ingecon (2.5/3.3/6KW)
8.	FB-ZVR	Lower core losses, high efficiency, very low leakage current and EMI	One extra switch and four diodes, increased losses across the filter	96	-
9.	NPC Half Bridge	Lower core losses, higher efficiency, very low leakage current and EMI , reduced switching losses	Unbalanced switch losses, two extra diodes	96.5	3 phase inverters
10.	Conergy NPC	Lower core losses, higher efficiency, very low leakage current and EMI, Balanced switching losses	Requires double voltage input in comparison with FB	98	IPG series string inverters

Table 1

V. CHARACTERISTICS OF A GOOD INVERTER

1. Its output voltage waveform should be sinusoidal.
2. Its output voltage and frequency should be controllable in the desired usage i.e., inverter must keep *V/f* constant.
3. The semiconductor devices used in the inverter should have minimum switching and conduction losses.
4. Its overall cost must be minimum and reliable.
5. Its working life must be long.
6. Minimum electromagnetic interference (EMI) should be produced.
7. Filter requirements should be small..

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VI.CONCLUSION

The photovoltaic cell generates DC power depending on various factors. The grid is 230v therefore Photovoltaic modules cannot be directly coupled with the grid. Thus it require some interface that is inverters which convert the dc output voltage of the photovoltaic system to the AC and makes it suitable for connecting with the grid. With the development is solar inverter technology the market value is also increasing. According to the research report, the India solar inverter market will grow at a considerable CAGR(Compound Annual Growth Rate) by 2020 due to growing power demand coupled with the incompetency of government to meet demand-supply gap, rising investment in smart cities, product innovation and inclining competition in solar inverter market. In the view of good inverter's characteristics, CONERGY NPC inverter topology is best suitable for reliable operation.

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