Abstract—Multistage grid connected inverter for solar PV based system is discussed in this paper. Also the types of multilevel inverter are discussed. Normally the line commutated inverter has square shaped waveform of line current, which has large amount of harmonic and produces excess of heat which causes damage to the transformer winding. Because a perfect square wave contains 48% THD. To reduce these harmonics, multilevel inverter gives the output current waveform which is nearly sinusoidal in nature. This line current has smaller amount harmonics as compared to line commutated inverter. Basically, multilevel converter technology is based on the synthesis of the ac voltage from several different voltage levels on the dc side. i.e. by increasing of DC voltages, the levels of the output increases, which produce a staircase wave which approaches the sinusoidal wave with lower harmonic distortion. Multilevel inverter also used for electric drives applications for same reason i.e. harmonic reduction. The simulation can be done by MATLAB/SIMULINK. In simulation model we can use DC source instead of PV module.

I. INTRODUCTION

The reducing cost of solar module and developments in power electronic devices makes solar power easily useful for power generation in bulk amount.[1] But solar module gives the square wave shaped current wave. A single stage converter has 48% THD for perfect square wave of current.[2] Therefore there is lot of research is going on to increase the efficiency of photovoltaic power plant and decrease the system losses and cost. So, to reduce this THD level in current, the multilevel inverter is used between PV and grid, which generates output at low switching frequencies with high efficiency and low distortion.

MOSFET/IGBT’s are also used for multilevel inverter. But it has some disadvantages like higher switching frequency, lower power handling capability and reliability. Therefore Thyristors are used to overcome the disadvantages of MOSFET/IGBT’s.

Grid connected multilevel inverter is simulated using MATLAB/SIMULINK. Basically multilevel inverter with RLE load is simulated. This model is worked as both inverter and rectifier/converter by adjusting firing angles i.e. when switching angle is greater than 90 degree then it will work as inverter. Instead of DC source we can use solar PV module. Because it also gives DC supply. Using this process we can get the various levels of output.

II. PV SYSTEM AND GRID

Now days, solar energy is widely used for power generation. Because it has lot of advantages, i.e. Energy independence, Environmentally friendly, Required “Fuel” is already distribute freely everywhere, It needs minimum maintenance, Maximum reliability, and these systems are easily expanded.[3]

- Equivalent circuit of PV And I-V Characteristics

![Equivalent circuit of PV solar cell.](image)

Basically solar cell is P-N junction. And when it exposes to light then current is generated which is proportional to solar irradiance. Fig.1 shows the equivalent circuit of PV cell. And fig.2 shows the V-I characteristic of PV cell. [4]

![V-I characteristics of solar cell.](image)
The network made for supplying electrical energy from generating station to consumer, is known as electric grid which consist of transmission and distribution lines. The electric grid may be a advanced network that is an integral part of our society. Running the grid in the presence of expanding fuel expenses and developing ecological concerns will requires new technology and ways to use them. Whereas the renewable power technology will be an important part of our power generation. In future, any technology except renewable, can’t fulfill all energy needs. So this power generation has to connect with grid. But for connecting to grid, some requirements of grid must be fulfilled, i.e. supply should not contain more amount of harmonics, etc.

III. MULTILEVEL INVERTER

For providing electricity to grid, the supply should have low amount of harmonics. But the solar PV based system is having output of square wave shape. And as we know pure square wave contains 48% THD. So to reduce this amount, multilevel inverter is used. Multilevel inverter gives stepped wave output which is nearly sinusoidal in nature. So, multilevel inverter is used as grid connected inverter for solar PV based system. There are three types of multilevel inverter as follows:

A. Diode-Clamped Multilevel Inverter

Diode-clamped multilevel inverter is shown in fig.3. to produce m levels of output, it requires (m-1) capacitors on DC bus side. Fig.3 shows three levels DCMLI. And it has two capacitors C1, C2. This MLI has following characteristics:

- High-Voltage Rating Required for Blocking Diodes.
- Unequal Device Rating.
- Capacitor Voltage Unbalance.[5]

Advantages:

a. Efficiency is high.
b. Filters are not required for reducing harmonics.
c. Reactive power flow can be controlled.

Disadvantages:

a. For high levels, more number of diodes are required.
b. Real power flow control for individual converter is difficult.

B. Flying capacitors multilevel inverter [FCMLI]

Fig.4 shows the schematic of FCMLI. Each phase leg has identical structure. The voltage level between clamping point is given by series connection of capacitors. The capacitors of different legs are independent of each other. This inverter requires (m-1) capacitors for m level output. [5]

Advantages:

a. Extra ride through capability during power outage.
b. Filters are not required for reducing harmonics.
c. It gives proper switching combination to balance different voltage levels.
d. Real and reactive power flow can be controlled.

Disadvantages:

a. High numbers of capacitors are required for high level.
b. For real power transmission switching frequency and losses are high.

C. Cascade Multilevel Inverter

Cascade multilevel inverter is shown in fig.5. Which avoids the used of clamping diodes and voltage balancing capacitors. It has separate DC sources for each bridge therefore, it is called as cascade multilevel inverter with separate DC sources.
[SDC’s]. Every bridge generates three levels of output –Vdc, 0, Vdc. Each bridge is having four switching devices. [5]

Advantages:
   a. Less number of components are required.
   b. Extra diodes and capacitors are not required.

Disadvantages:
   a. For the real power conversion, separate DC sources are required

IV. HARMONIC REDUCTION IN INVERTER OUTPUT

Generally, for harmonic reduction from inverter output waveform filters are used. If output contains high frequency harmonics, these can be reduced by low-size filters. For the attenuation of low-frequency harmonics, the size of filter components increases. This makes filter circuit costly and bulky. Therefore for reduction of harmonics in output waveform of inverter following techniques are used: [5]

A. Harmonic Reduction By PWM

In PWM technique, by generating several pulses per half cycle, low order harmonics are eliminated. Fig.6 shows the output voltage waveform that can be obtained from a single phase full bridge inverter. This waveform requires ten commutations per cycle [=360 degree] instead of two in an unmodulated wave. By this method lower order harmonics are eliminated from output waveform. But, this technique has some disadvantages like; the amplitude of fundamental voltage is decreased from the amplitude of fundamental component of unmodulated wave. And this method requires extra commutations therefore it has more switching losses. [6]

B. Harmonic Reduction by Transformer Connections

Fig.7 shows the harmonic reduction technique by transformer connections. Output waveform from two or more inverters can be combined by means of transformer to get a net output with reduced harmonic content. In this technique the output waveform of two inverters must be same but phase shifted from each other. The amount of decrease of voltage level in this method is less than PWM method. The disadvantage of this technique is that it requires more number of inverters and transformers. [7, 8]

C. Harmonic Reduction By Stepped-Wave Inverters

In this technique, pulses of different width and heights are superimposed to produce a stepped wave output with reduced harmonics. Fig.7 shows the schematic of this technique. In this method two transformers of different turn ratio are used. This method produces the waveform nearer to sinusoidal nature.

This method is also known as harmonic reduction method by multiwinding transformer. This method is mostly used for reduction of harmonics. Because, as compared to square wave it produces stepped wave output which has minimum number of harmonics. [9, 10]

II. SIMULATION RESULTS

A. Three level inverter by multi-winding transformer

Fig.9. Switching Pattern.
VI. CONCLUSION

Multilevel inverter for three levels is successfully implemented. We found that, by increasing level of inverter, THD of the line current of the grid-tie multilevel inverter has been reduced to 30% (instead of 48% for conventional line commutated inverter). If proper filter circuit is used, THD can be reduced further. With reduced THD, multilevel inverter can be a better substitution for square wave inverter in various solar PV based system.

III. REFERENCES