Electrical Power and Energy Systems 47 (2013) 157–167

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

# An experimental investigation on a multilevel inverter for solar energy applications

Venkatachalam Kumar Chinnaiyan [a,*], Jovitha Jerome [b], J. Karpagam [c]

[a] Department of Electrical and Electronics Engineering, Dr. NGP Institute of Technology, Coimbatore 641 048, India
[b] Department of Instrumentation & Control Systems Engineering, PSG College of Technology, Coimbatore 641 004, India
[c] Department of Electronics and Communication Engineering, Dr. NGP Institute of Technology, Coimbatore 641 048, India

ARTICLE INFO

*Article history:*
Received 10 December 2011
Received in revised form 17 October 2012
Accepted 20 October 2012
Available online 5 December 2012

*Keywords:*
Inverters
Power electronics
Solar energy
Drives
Power converters
Multi level inverter
Field programmable gate array

ABSTRACT

The main objective of the proposed work is to design, develop and test a three phase multilevel inverter with the modern power electronic switches to reduce the power quality issues in solar power conversion system. Due to the increased usage of power electronic converters for processing the power in all walks of our life, the power quality problem become the hot research topic in the recent years. As the power level increases, the voltage level is increased accordingly to obtain satisfactory efficiency. The multilevel power converter has shown growing popularity. The fundamental advantages of multilevel converter topologies are low distorted output waveforms and limited voltage stress on the switching devices and hence the reduced electromagnetic interferences. The main disadvantages are higher complexity and more difficult control; it can be overcome by using modern digital controllers. In this paper, the performance parameters are analyzed with the developed prototype of the three phase cascaded multilevel inverter for solar energy conversion designed with digital controller for reduced power quality issues with three phase AC motor drive. The main objective is to obtain the better quality of output waveform on the inverter output with suitable control strategy on the experimental hardware setup.



## 1. Introduction

Consumption of energy has become a daily necessity in modern civilization for the comfort and convenience of humanity, and the amount of energy consumption has served as an indicator for the standard of living and the degree of industrialization. It has long been recognized that associated with this excessive daily energy consumption is an adverse impact on the environment we live in, resulting in deterioration of the local and global environment. However, utilization of energy from different sources tends to have different kinds and different degrees of impact on the environment. The energy from renewable sources may be considered to have minimal or neutral impact on the environment.

An energy system is like a double-edged sword; its use would normally bring about economic growth and social advancement as a whole, and comfort and convenience for individuals. On the other hand, a persistent and large-scale use of a particular energy system will also bring about inevitable negative environmental, social and economic impact, and when this negative impact is accumulated beyond a tolerance limit, permanent damage or catastrophe would occur. Since the Industrial Revolution, increased energy use has brought about economic prosperity and an improved standard of living. It is fully expected that this trend would continue without the any degradation on the environment, economic and social growth. The target or objective is then to develop a magic energy system or systems that have no negative environmental, economic and societal impacts, which we refer to as "green energy". Any energy system that has reduced or minimal adverse impact might be considered as "greener" energy. This definition of green energy implies that green energy, as the eventual long-term objective, will provide an important attribute for sustainable development. This is because attaining sustainable development requires the use of energy resources and technologies that do not have adverse environmental, economic and societal impact. Clearly, single energy resources such as fossil fuels are finite and thus lack the characteristics needed for sustainability, while others, such as renewable energy sources, are sustainable over the relatively longer term. Green energy sources are solar, wind, biomass, hydro, nuclear, geothermal, etc. Energy economics in the present era refers to energy market, electricity market, Carbon di-oxide ($CO_2$) credit trading, clean development mechanism, Emission credit/trading, investment and payback time. With the advent of modern materials and the reduction of the cost, the solar energy based power system; it becomes the most preferred eco friendly power generation concept in the recent past [13].

## 2. Solar radiation and daylight measurement

Systematic measurements of diffuse solar energy and the global (total) irradiation incident on a horizontal surface are usually

* Corresponding author. Tel.: +91 9942999111.
*E-mail addresses:* Kumarchinn@hotmail.com (V. Kumar Chinnaiyan), jjovitha@yahoo.com (Jovitha Jerome), sujisumi@rediffmail.com (J. Karpagam).

0142-0615/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2012.10.025

undertaken by a national agency, which is the national meteorological office in many countries. The measurement network includes pyranometers, solarimeters, or actinography instruments for this purpose. In practice, it is very important to appreciate the order of measurements prior to any modeling. The present state of solar radiation and daylight models is such that they are approaching the accuracy limits set out by the measuring equipment [20]. Radiation in the visible region of the spectrum is often evaluated with respect to its visual sensation effect on the human eye. In many countries, diurnal bright sunshine duration is measured at a wide number of places. The hours of bright sunshine are the time during which the sun's disk is visible. On a clear day with a cloudless sky the burn does not start until 15–30 min after sunrise and usually ceases about the same period before sunset. This period varies with the season. On the other hand, under periods of intermittent bright sunshine the burn spreads.

Irradiation, which is defined as the solar power per unit area, solar radiation is radiant energy per unit area. Solar radiation is determined by summing solar irradiance over time and it is expressed usually in units of $kW/m^2$ per day. Solar energy has an advantage over other renewable energy sources. It is more efficient in terms of the power that can be produced from a given area of land [12]. According to one estimate, solar power plants can produce about six times more power than bio fuels or wind. Solar power's advantage over water power is even greater.

## 3. Inverters

Inverters accept an electrical current in one form and output the current in another form. An inverter converts Direct Current (DC) into Alternating Current (AC), whereas a rectifier converts AC into DC. There are also DC–DC converters, which step up or step down the voltage of a DC current. Inverters convert DC power from the batteries or solar array into 60 or 50 Hz AC power. Inverters can be transformer based or high-frequency switching types. Inverters can stand alone, be utility interconnected, or be a combination of both [14]. As with all power system components, the use of inverters results in energy losses due to inefficiencies. Inverters are an interesting option due to the great variety of low-cost appliances that run on AC.

Inverters are a key component to most Photo Voltaic (PV) systems installed in grid connected or distributed applications. Aside from the modules themselves, inverters are often the most expensive component of an installed PV system, and frequently are the critical factor in terms of overall system reliability and operation. Utility interactive PV systems installed in residences and commercial buildings will become a small, but important, source of electric generation over the next 50 years. This is a new concept in utility power production, a change from large-scale central generation to small-scale dispersed generation [16]. The basic system is simple; utilizing a PV array producing DC power that is converted to AC power via an inverter to the grid is very simple, yet elegant.

The AC produced by inverters can have square, modified sine, or quasi sine waves and pure sine wave outputs. The pure sine wave is high cost, high efficiency, and has the best power quality. Modified sine wave is mid-range cost, quality, and efficiency. Square wave is low cost and low efficiency, and it has poor power quality that is useful for some applications. Square wave signals can be harmful to some electronic appliances due to the high voltage harmonic distortion. All inverters emit electromagnetic noise.

The harmonic frequencies and their magnitudes that appear on a system are governed by the shape of the distorted wave. The output capacity of an inverter is expressed in Volt Amperes (VA). During start up, devices such as motors require a VA power input several times greater than continuous power. This demand exists for only a brief period of time. Most motors use 20% more power and run hotter with modified sine wave than with pure sine wave.

Maximum output power is the maximum number of Watts the inverter can produce continuously. Harmonic distortion is distortion of the output waveform (2–35%). The solar energy is harnessed with the use of Bosch Solar Cell M 3BB C3 1200 which has higher efficiency compared to the other solar panels available in the market and the other notable features are High annual yields, even with sub optimal levels of sunlight, thanks to excellent performance in weak light conditions, Pioneering three bus bar technology reduces the series resistance and helps to boost the power output in the module. Fig. 1A and B shows the current voltage characteristics and spectral response of the PV cells respectively.

### 3.1. Grid tied inverters

Grid-tied inverters are widely used in Europe, Japan, and the United States to inter tie PV systems with the electric utility grid. These inverters convert the DC power to AC power in synchronization with the electric grid (UL 1741). When the grid goes down, the inverters go off by design. PV system utility interconnection considerations include safety, anti islanding, and power quality. The inverter should be correctly wired and have proper wire sizes, fusing, and breaker sizes and types. PV system anti islanding protection methods include grid shorted, grid open, anti islanding inversion synchronization, over or under frequency, and over or under voltage. The typical solar power generation with grid tied inverter system is shown in Fig. 2.

### 3.2. Multi level inverters

The multilevel inverters perform power conversion in multilevel voltage steps to obtain improved power quality, lower switching losses, better electromagnetic compatibility, and higher voltage capability [2]. Considering these advantages, multilevel inverters have been gaining considerable popularity in recent years.

In the recent past, the multilevel inverters have drawn tremendous interest in the field of high voltage and high power applications. In the researches of multilevel inverters, its corresponding control strategies are one of the research hot areas. One of the most important problems in controlling a multilevel voltage source inverter is to obtain a variable amplitude and frequency sinusoidal output by employing simple control techniques [15]. Indeed, in voltage source inverters, non fundamental current harmonics cause power losses, electromagnetic interference and pulsating torques in AC motor drives.

Harmonic reduction can then be strictly related to the performance of an inverter with any switching strategy. Multilevel inverters can increase the power by $(m - 1)$ times than that of two-level inverter through the series and parallel connection of power semiconductor devices [10]. Comparing with two level inverter system having the same power, multilevel inverters has the advantages that the lower harmonic components on the output voltages, Electro Magnetic Interference (EMI) problem could be decreased much. Due to these merits, many studies about multilevel inverters have been performed at simulation level and very few with hardware implementations [1].

### 3.3. Types of multilevel inverters

The multilevel inverter is best suited for the application which demands the finest quality of the AC supply waveforms. The multilevel inverters have many advantages when compared with conventional two level inverters as listed in Table 1.