Artificial Intelligent (AI) Based Cascade Multi-Level Inverter for Smart Nano Grid

S. Chatterji and S. L. Shimi

Abstract—As wind, solar and other clean and green energy sources gain popularity worldwide, engineers are seeking ways to make renewable energy systems more affordable and to integrate them with existing ac power grids. In the present paper an attempt has been made for integrating the PV arrays to the smart nano grid using an artificial intelligent (AI) based solar powered cascade multi-level inverter. The AI based controller switching scheme has been used for improving the power quality by reducing the Total Harmonic Distortion (THD) of the multi-level inverter output voltage.

Keywords—Artificial Intelligent (AI), Solar Powered Multi-level Inverter, Smart nano grid, Total Harmonic Distortion (THD).

I. INTRODUCTION

LIMITATION of the energy sources and power quality are the major concern of this century, thus, most of the literature discuss the problems of natural resource depletion, environment impact, the rising demand of new energy resources and challenging technologies as solutions for such problems. The non-linear electronic equipment connected in the network produces undesired harmonic components and results in poor power quality thus, deteriorating the efficiency and performance of the system. To overcome these snags many different solutions have been proposed in the available literature. The multi-level converters are gaining high reputation because they are treated as power interfaces and such interconnection causes the electric grid to become the "load side" of the converter. Even in high power application it is flexible to interface the renewable energy sources such as PV arrays, wind, and fuel cells in the dc input portion of the multi-level inverter and they have better efficiency and output waveforms as compared to other standard two level pulse width modulated (PWM) converters [1]-[8].

The multi-level inverters use large number of power semiconductor devices for their switching thus, results in more switching losses and less reliability. But the industrial applications such as manufacturing are more dependent on induction motors and their inverter systems for process control. The IEEE 519 standard limits of THD of the output voltage of the converter circuit may be maintained for such applications [9]. The harmonics mitigation of multi-level inverter circuit is a very important issue in industries. The investigators have proposed the elimination theory to determine the switching patterns to eliminate the specific harmonics, such as 5th, 7th, 11th, and the 13th [10]-[12]. In case of 3 phase 11 level multi-level inverter, there are 15 dc sources, as the number of dc sources increases, the degree of the polynomials in these equations increases and thus, it becomes difficult to solve such a problem. The methods to solve such polynomial equations using elimination theory are discussed in [13]. The solar powered multi-level inverter introduces a lot of harmonics. Artificial intelligence based switching scheme is superior to the conventional methods for harmonic elimination. The knowledge of harmonic elimination for multi-level inverter is very necessary as it gives an idea about the switching pattern for harmonic elimination in case of 11 level cascade multi-level inverter [14].

II. MULTI-LEVEL INVERTER DRIVES (MLIDS)

The conventional inverter drives are most commonly used in industries. They consist of six power switches with pulse width modulation (PWM) switching arrangement. Output voltage and current waveform qualities deteriorate because of the use of conventional converters. In order to improve the waveform quality the switching frequency needs to be increased, this in turn results in higher switching losses. As the number of levels of multi-level inverter is increased the output staircase waveform is more close to a sine wave thus, very low distortion is obtained in the output.

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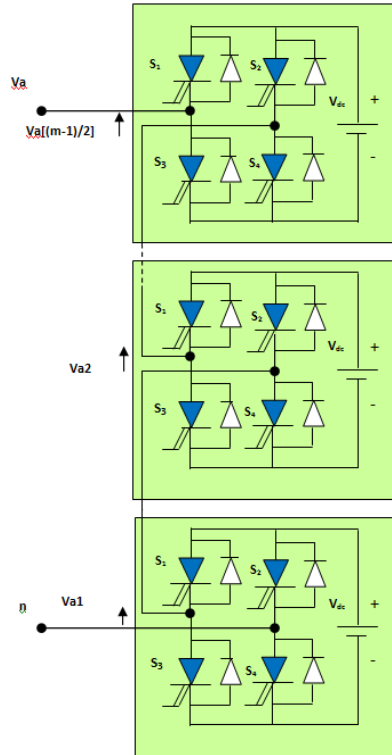
Fig. 1 Single-phase structure of a m-level cascaded inverter

The cascaded MLID is the main focus of this paper.

The Fig. 1 shows the single-phase structure of a m-level cascaded inverter. The output equation is as follows.

$$V(wt) = \sum_{n=1,3,5\ldots}^{\infty} \left[\frac{4V_{dc}}{n\pi} \{\cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3) + \cos(n\theta_4) + \cos(n\theta_5)\} \sin(nwt) \right] \quad (1)$$
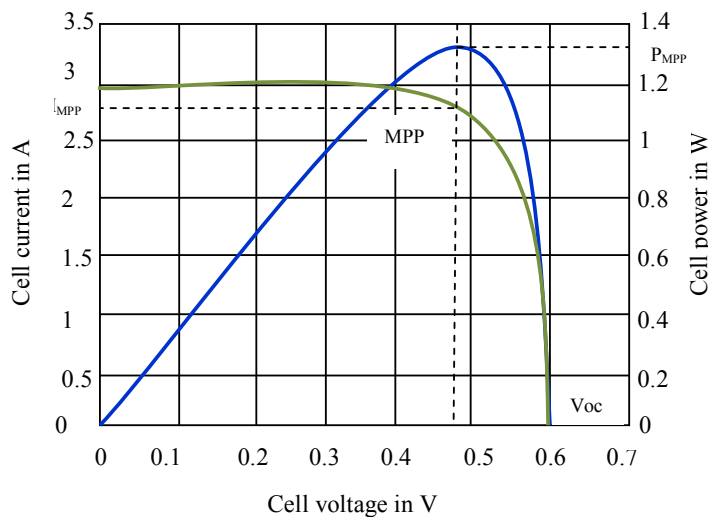
III. PV MODELING

Modeling of a solar cell is done by connecting a current source in parallel with an inverted diode along with a series and a parallel resistance as shown in Fig. 2 [15]. The series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current. The single diode model shown in Fig. 2 was adopted for simulating the PV module under different irradiance and temperature levels. The modeling of the PV cell was done in MATLAB/SIMULINK by writing the code in the embedded block. The PV cell subsystems were modeled and connected to the 11 level cascade multi-level inverter.
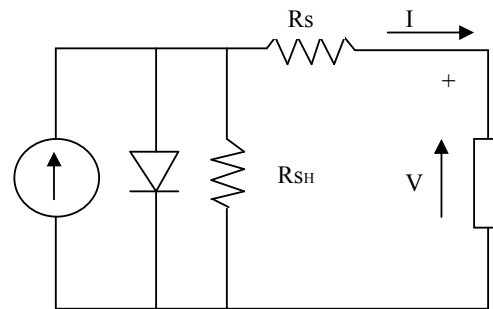

Fig. 2 Single diode model of a PV cell

In literature number of approaches and models are found in order to analyze the behavior of PVs [16]-[18].

The PV cell model used in this work is based on the single diode cell. The VI characteristics (in green) of a typical solar cell are as shown in the Fig. 3.

Fig. 3 V-I and P-V characteristics curve of PV cell

When the voltage and the current characteristics are multiplied we get the P-V characteristics (in blue) as shown in Fig. 3. The point highlighted as MPP is the point at which the panel power output is maximum [19]. Equation (2) is the basic expression for the photovoltaic current.

It has non-linear characteristics, and the basic mathematical model can be expressed as:

$$I = n_p I_{ph} - n_p I_o \left[\exp\left(\frac{qV}{kTan_s}\right) - 1 \right] \qquad (2)$$

where I and V are the PV array output current and voltage respectively, I_{ph} is the photo-current that is equal to shortcircuit current Isc, I_0 is the reverse saturation current, n_p is the number of modules connected in parallel, n_s is the number of modules connected in series, q is the charge of an electron, k is Boltzmann's constant, a is the p-n junction ideality factor, 1< a < 5 (a = 1 being the ideal value), and T is the cell temperature.

Practical arrays composed of several connected photovoltaic cells require the inclusion of additional parameters to the basic equation :

$$I = N_p I_{ph} - N_p I_o \left[\exp\left(\frac{V+R_sI}{AV_t a}\right) - 1 \right] - \frac{V+R_s I}{R_p} \qquad (3)$$

where, Iph and I0 are the photovoltaic and saturation currents of the array and $Vt = N_s kT /q$ is the thermal voltage of the array with Ns cells connected in series. R_s and R_p are equivalent series and parallel array resistances. The light generated current (I_{pv}) of the solar cells, depends on the series and parallel resistances. Datasheets only provides the nominal short-circuit current ($I_{sc,n}$), which is the maximum current available at the terminals of the practical device. The assumption $I_{sc} \approx I_{pv}$ is generally used in photovoltaic models because in practical devices the series resistance is low and the parallel resistance is high. The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation:

$$I_{PV} = (I_{pv,n} + K_I (T - T_n)) \frac{S}{S_n} \qquad (4)$$

where $I_{pv,n}$ is the light-generated current at the nominal condition (usually 25^0C and 1000W/m^2), T and T_n are the actual and nominal temperatures, S and S_n are actual and nominal radiation and the short-circuit current/temperature coefficient (K_I). Diode saturation currents (I_0) also depend on the solar radiation and the cell temperature as:

$$I_o = (I_{o,n} \left[\frac{T_n}{T}\right]^3 \exp\left(\frac{qE_g}{ka}\left[\frac{1}{T_n} - \frac{1}{T}\right]\right) \qquad (5)$$

where, Eg is the bandgap energy of the semiconductor and I0,n is the nominal saturation current:

$$I_{o,n} = \frac{I_{sc,n}}{\exp\left(\frac{V_{oc,n}}{aV_{t,n}}\right)-1} \qquad (6)$$

with $V_{t,n}$ being the thermal voltage of Ns series-connected cells at the nominal temperature Tn. At normal levels of solar irradiance, the short-circuit current can be considered equivalent to the photocurrent Iph, i.e. proportional to the solar irradiance S (W/m2). But this may result in some deviation from the experimental result, so a power law having exponent a is introduced to account for the non-linear effect that the photocurrent depends on. The short-circuit current Isc of the PV modules is not strongly temperature dependent. It tends to increase slightly with increase of the module temperature. For the purposes of PV module performance, modeling this variation can be considered
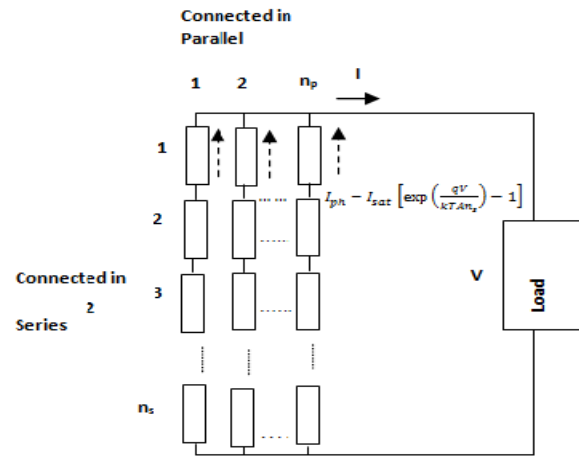

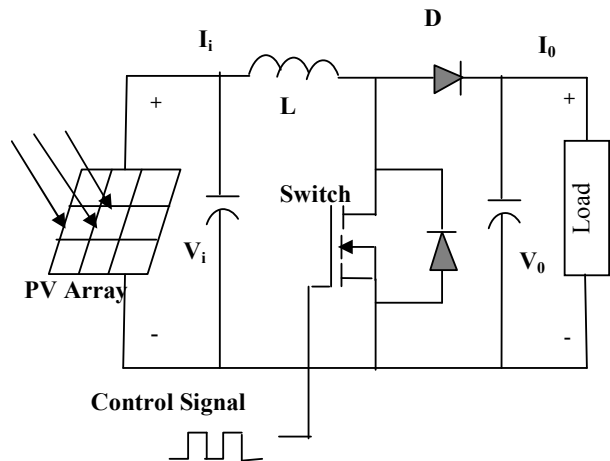Fig. 4 Equivalent circuit of PV module

Fig. 5 The configuration of boost converter

Fig. 5 shows use of boost converter for elevating the output voltage Vo respect to the input voltage Vin by fixing the duty

cycle D (with a pulse width modulator) according to the following relation :

$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \qquad (7)$$

IV. ARTIFICIAL INTELLIGENCE (AI) BASED CONTROL SCHEME

The AI techniques, such as expert system (ES), fuzzy logic (FL), artificial neural network (ANN or NNW), and genetic algorithm (GA) have recently been applied widely in power electronics and motor drives. The goal of AI is to plant human or natural intelligence in a computer so that a computer can think intelligently like a human being. A system with embedded computational intelligence is often defined as an "intelligent system" that has "learning," "self-organizing," or "self-adapting" capability. Computational intelligence has been debated for a long time, and will possibly be debated for ever. However, there is no denying the fact that computers can have adequate intelligence to help solving our problems that are difficult to solve by traditional methods. Intelligent control is the viable alternative to conventional control schemes [20]-[24].

V. PROPOSED DESIGN

It is found from literature that the 11 level cascade multi-level inverter is optimal as in the lower levels the total harmonic distortion is more and in the higher levels the switching losses are more. In this proposed method of the solar powered 11 level cascade multi-level inverter, ANN based control schemes for firing the inverter bridge has been used. The dc supply from the PV array to each H-bridge of the multi-level inverter should be isolated. Thus, separate PV arrays have been used for each H-bridge. This can even be achieved using a single PV array of higher rating and a forward converter. The block diagram of the proposed scheme is shown in Fig. 6.

The modulation index at the output bus of 11 level cascade multi-level inverter has been calculated and given as input to the AI based controller. The AI controller chooses the optimized firing angles α_1, α_2, α_3, α_4 and α_5 and fires the 11 level cascade multi-level inverter. The whole system can be interfaced with a nano grid.
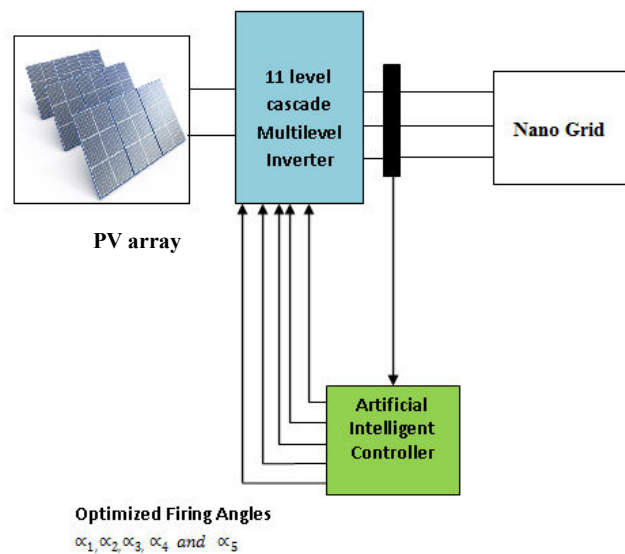

Fig. 6 Block diagram of the proposed system

VI. SIMULATED CIRCUITS AND WAVEFORMS

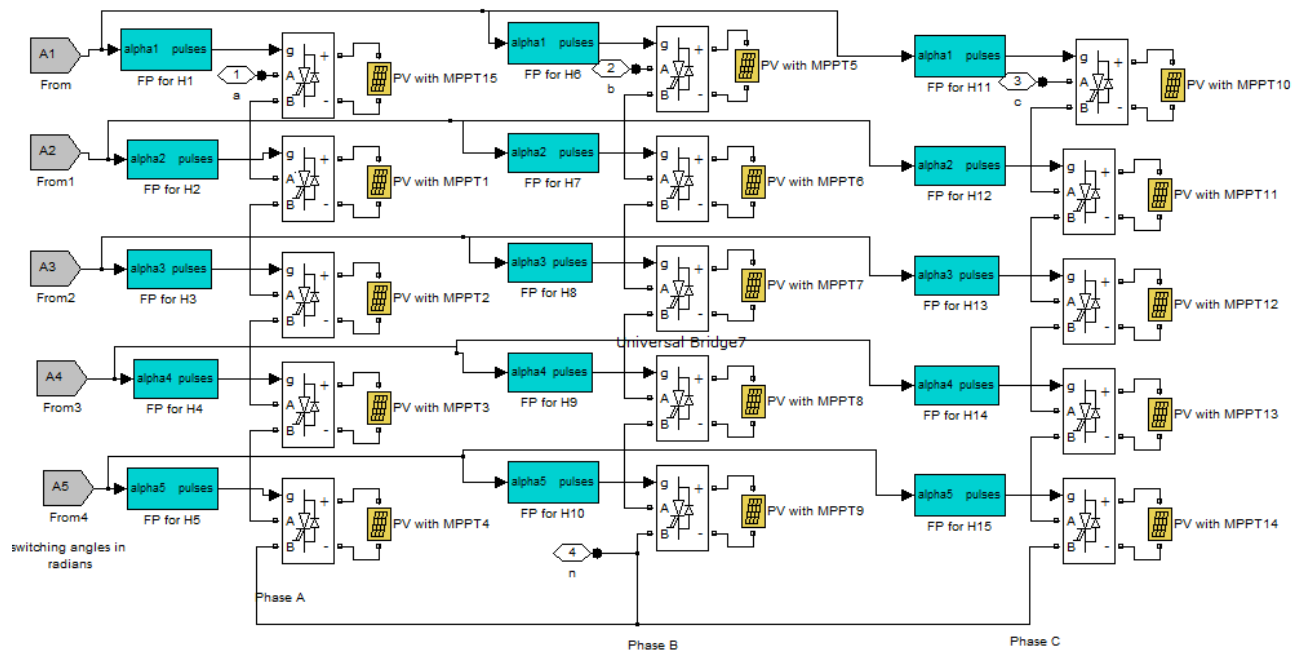The subsystem of the solar powered 11 level cascade multi-level inverter is shown in Fig. 7.

Fig. 7 Subsystem of the solar powered 11 level cascade multi-level inverter
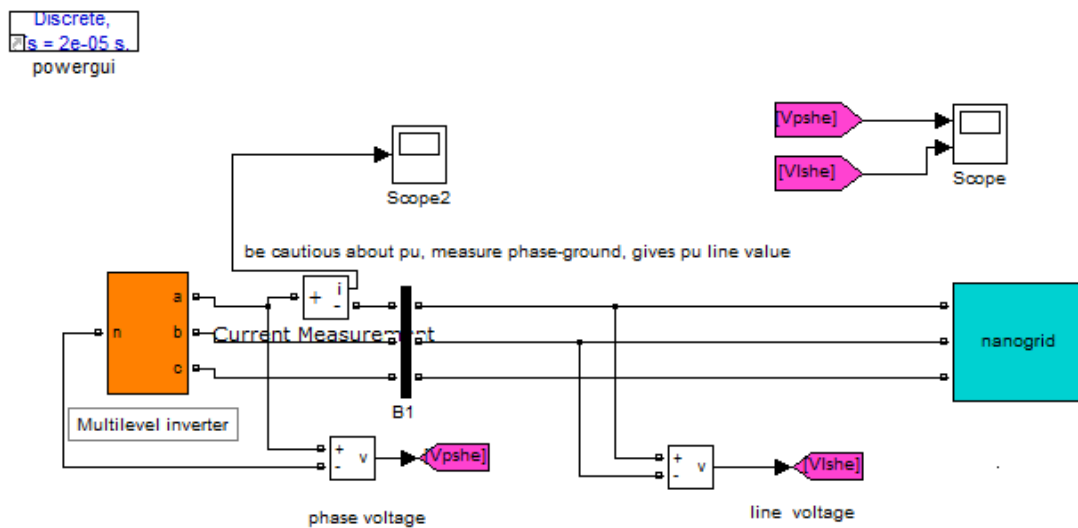

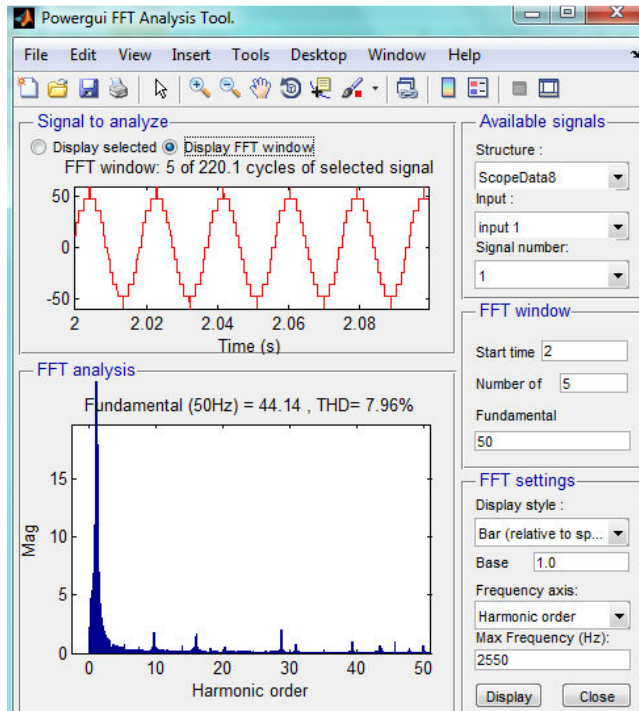Fig. 8 Solar powered multi-level inverter connected to the nano grid

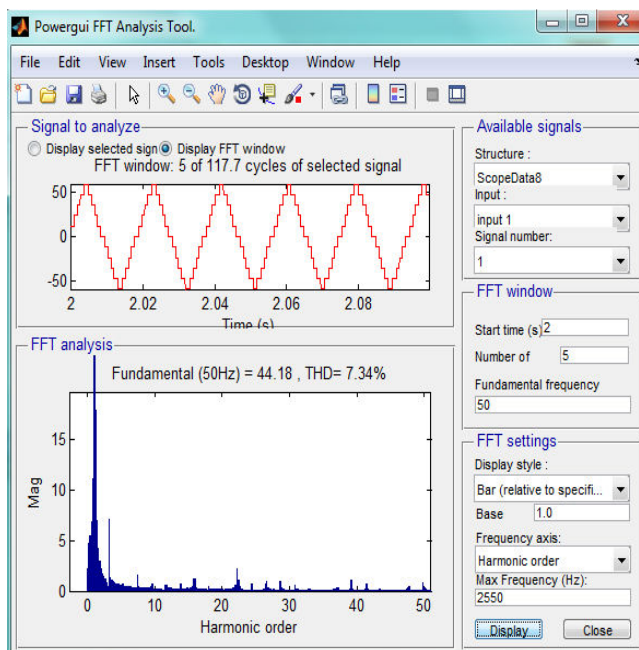Fig. 9 FFT Spectrum of the System with MATLAB optimization tool

Fig. 10 FFT Spectrum of the System with ANN

The FFT spectrum of the line voltage has been found using the FFT analysis tool. The FFT spectrum of the system with MATLAB optimization tool and ANN are shown in Figs. 9 and 10. The total harmonic distortion of the PV system connected to the nano grid is found to be 7.96% with MATLAB optimization tool and 7.34 % with ANN.

VII. CONCLUSION

An AI based three-phase solar powered 11 level cascade multi-level inverter integrated to a nano grid has been evolved, and its total harmonic distortion has been obtained by simulation results. The PV cell modeling was performed and the dc power for all the H-bridges were supplied through the PV cells. Attempts will be done to connect the multi-level inverter to the grid using artificial intelligent techniques. The total harmonic distortion of the PV system connected to the nano grid is found to be 7.96% with MATLAB optimization tool and 7.34% with ANN. The artificial intelligent techniques like Genetic Algorithm and ANFIS can be used to still reduce the total harmonic distortion.

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