

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.

Dr. S Chatterji is Professor & Head at the Electrical Engineering Department, NITTTR, Sector 26, Chandigarh, India – 160019 (phone: +91-172-2791552; e-mail: chatterjis@yahoo.com).

Mrs Shimi is Assistant Professor at the Electrical Engineering Department, NITTTR, Sector 26, Chandigarh, India – 160019 (phone: 09417588987; e-mail: shimi.reji@gmail.com).

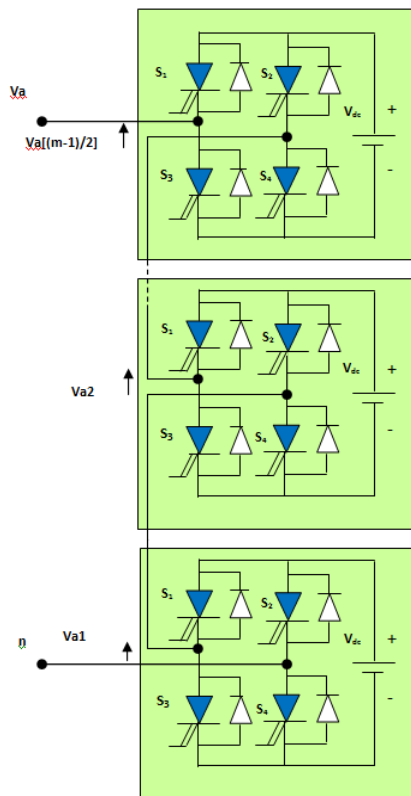


Fig. 1 Single-phase structure of a m-level cascaded inverter

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.

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

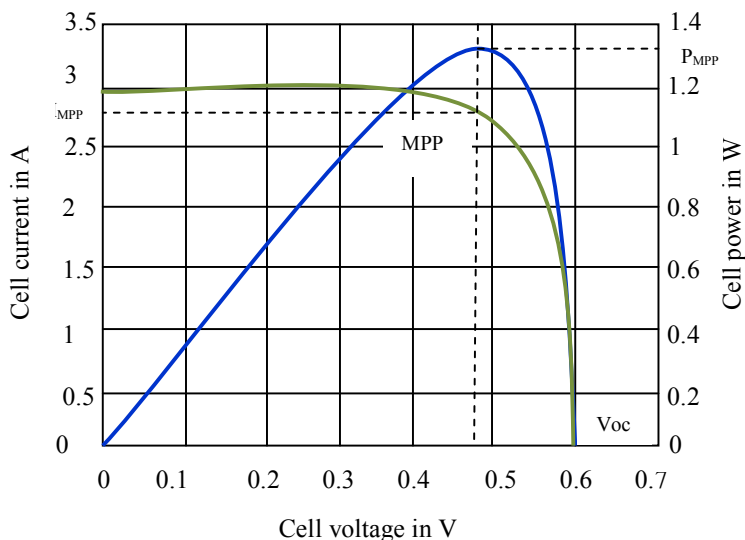


Fig. 3 V-I and P-V characteristics curve of PV cell

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.

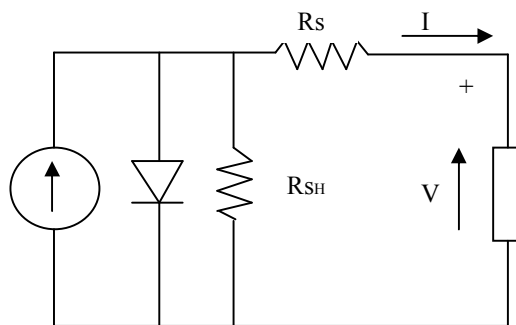


Fig. 2 Single diode model of a PV cell

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.

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:

$$I = n_p I_{ph} - n_p I_0 \left[\exp\left(\frac{qV}{kT a n_s}\right) - 1 \right] \quad (2)$$

where I and V are the PV array output current and voltage respectively, I_{ph} is the photo-current that is equal to short-circuit current I_{sc} , 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 :

$$I = N_p I_{ph} - N_p I_0 \left[\exp\left(\frac{V+R_s I}{A V_t a}\right) - 1 \right] - \frac{V+R_s I}{R_p} \quad (3)$$

where, I_{ph} and I_0 are the photovoltaic and saturation currents of the array and $V_t = N_s k T / q$ is the thermal voltage of the array with N_s 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:

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

where $I_{pv,n}$ is the light-generated current at the nominal condition (usually 25°C 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:

$$I_0 = (I_{0,n} \left[\frac{T_n}{T} \right]^3 \exp\left(\frac{qE_g}{ka} \left[\frac{1}{T_n} - \frac{1}{T} \right]\right)) \quad (5)$$

where, E_g is the bandgap energy of the semiconductor and $I_{0,n}$ is the nominal saturation current:

$$I_{0,n} = \frac{I_{sc,n}}{\exp\left(\frac{V_{oc,n}}{a V_{t,n}}\right) - 1} \quad (6)$$

with $V_{t,n}$ being the thermal voltage of N_s series-connected cells at the nominal temperature T_n . At normal levels of solar irradiance, the short-circuit current can be considered equivalent to the photocurrent I_{ph} , i.e. proportional to the solar irradiance S (W/m^2). 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 I_{sc} 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

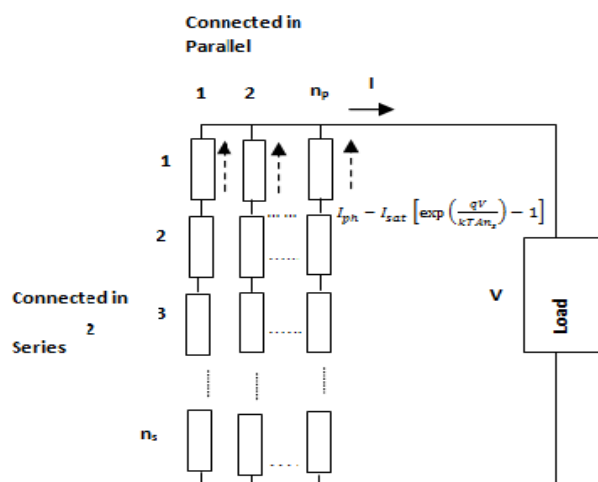


Fig. 4 Equivalent circuit of PV module

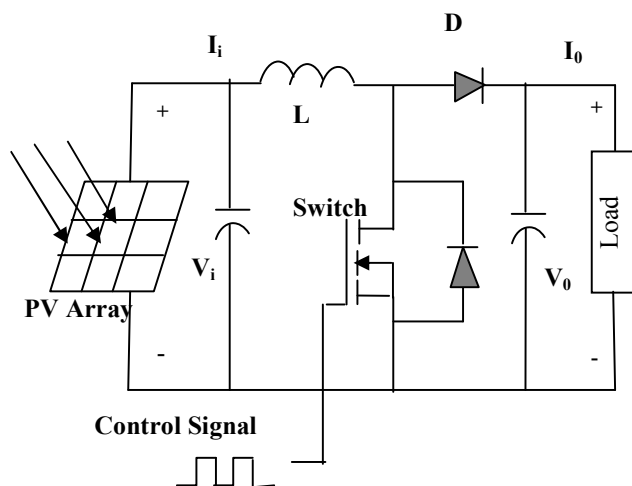


Fig. 5 The configuration of boost converter

Fig. 5 shows use of boost converter for elevating the output voltage V_o respect to the input voltage V_{in} by fixing the duty

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

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

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 $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ and α_5 and fires the 11 level cascade multi-level inverter. The whole system can be interfaced with a nano grid.

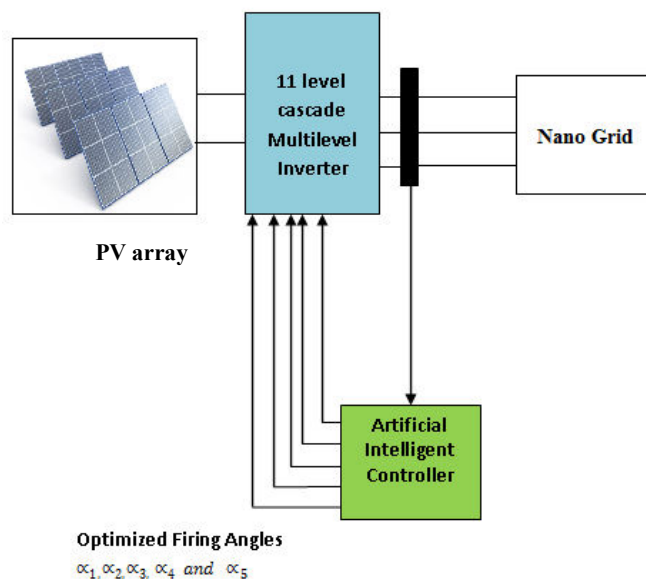


Fig. 6 Block diagram of the proposed system

VI. SIMULATED CIRCUITS AND WAVEFORMS

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

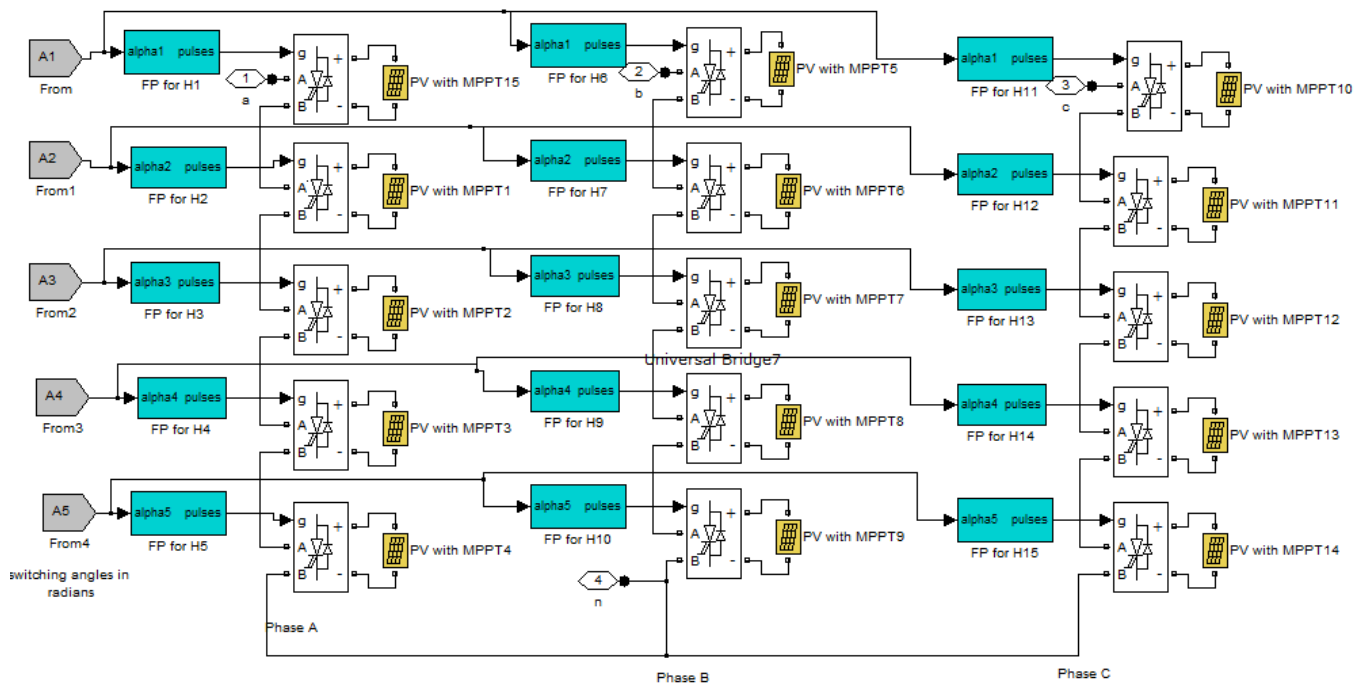


Fig. 7 Subsystem of the solar powered 11 level cascade multi-level inverter

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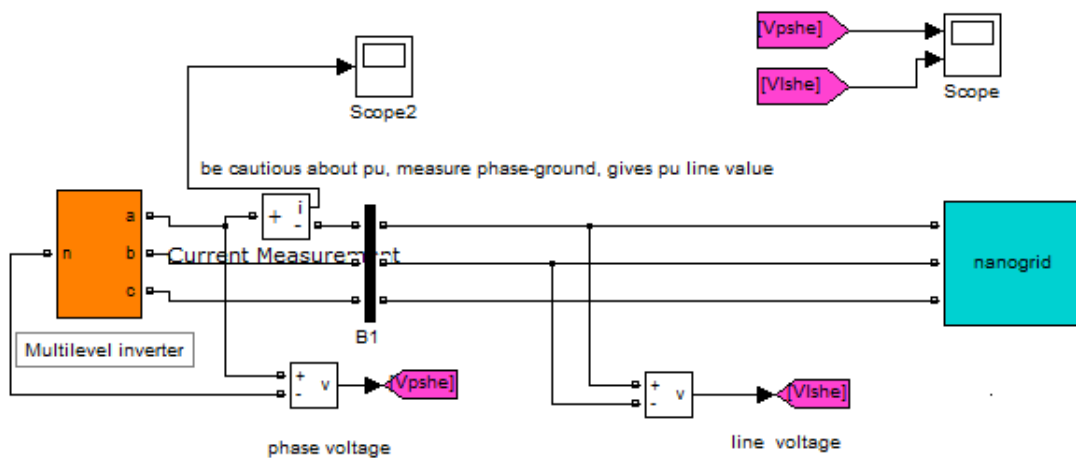


Fig. 8 Solar powered multi-level inverter connected to the nano grid

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.

REFERENCES

- [1] Carlo Cecati, Fabrizio Ciancetta, "A Multi-level Inverter for Renewables with Fuzzy Logic-based Control", IEEE Conference Publication, International Conference on Clean Electrical Power, 9-11 June 2009, Page(s): 227 - 231.
- [2] L.G. Franquelo, J. Rodriguez, J. I. Leon, S. Kouko, R. Portillo, M. A.M. Prats, "the age of multi-level converters arrives", IEEE Industrial Electronics Magazine, June 2008, pp. 28-39.
- [3] L.M. Tolbert, F. Z. Peng, T. G. Habetler, "Multi-level Converters for Large Electric Drives," IEEE Transactions on Industry Applications, vol. 35, no. 1, Jan./Feb. 1999, pp. 36-44.
- [4] J. Rodriguez, J. S. Lai, and F. Z. Peng, "Multi-level Inverters: Survey of Topologies, Controls, and Applications," IEEE Transactions on Industry Applications, vol. 49, no. 4, Aug. 2002, pp. 724-738.
- [5] J. S. Lai and F. Z. Peng, "Multi-level Converters – A New Breed of Power Converters," IEEE Transactions on Industry Applications, vol. 32, no. 3, May/June 1996, pp. 509-517.
- [6] M. Bouzguenda, A. Gastli, A. H. Al Badi, T. Salmi, "Solar Photovoltaic Inverter Requirements for Smart Grid Applications", IEEE PES Conference on Innovative Smart Grid Technologies - Middle East (ISGT Middle East), 17-20 December, 2011
- [7] E. Ortjohann, M. Lingemann, W. Sinsukthavorn, A. Mohd, A. Schmelter, N. Hamsic, D. Morton, "A General Modular Design Methodology for Flexible Smart Grid Inverters", IEEE Power & Energy Society General Meeting, 26-30 July, 2009.
- [8] C. K. Duffey and R. P. Stratford, "Update of Harmonic Standard IEEE-519: IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems," IEEE Transactions on Industry Applications, vol. 25, no. 6, Nov./Dec. 1989, pp. 1025-1034.
- [9] H. S. Patel and R. G. Hoft, "Generalized Harmonic Elimination and Voltage Control in Thyristor Inverters: Part I –Harmonic Elimination," IEEE Transactions on Industry Applications, vol. 9, May/June 1973, pp. 310-317.
- [10] H. S. Patel and R. G. Hoft, "Generalized Harmonic Elimination and Voltage Control in Thyristor Inverters: Part II –Voltage Control Technique," IEEE Transactions on Industry Applications, vol. 10, Sept./Oct. 1974, pp. 666-673.
- [11] P. N. Enjeti, P. D. Ziogas, J. F. Lindsay, "Programmed PWM Techniques to Eliminate Harmonics: A Critical Evaluation" IEEE Transactions on Industry Applications, vol. 26, no. 2, March/April. 1990. pp. 302 – 316.
- [12] J. N. Chiasson, L. M. Tolbert, K. J. McKenzie, Z. Du, "A New approach to solving the harmonic elimination equations for a multi-level converter," IEEE Industry Applications Society Annual Meeting, October 12-16, 2003, Salt Lake City, Utah, pp. 640-645.
- [13] T. Sripral Reddy, Dr. B.V.Sanker Ram, Dr. K. Raghu Ram "The Simulation And Analysis Of Multi-level Inverter Fed Induction Motor Drive", International Institute of Engineering and Technology Reserch Center, Vol No. 1, Issue No. 1, pp 043-049,2011.
- [14] E. Cengelci, S. U. Sulistijo, B. O. Woom, P. Enjeti, R. Teodorescu, and F. Blaabjerg, "A New Medium Voltage PWM Inverter Topology for Adjustable Speed Drives," in Conf. Rec. IEEE-IAS Annual Meeting, St. Louis, MO, Oct. 1998, pp. 1416-1423.
- [15] F. Filho, L. M. Tolbert, B. Ozpineci, Y. Cao, "Real Time Selective Harmonic Minimization for Multi-level Inverters Connected to Solar

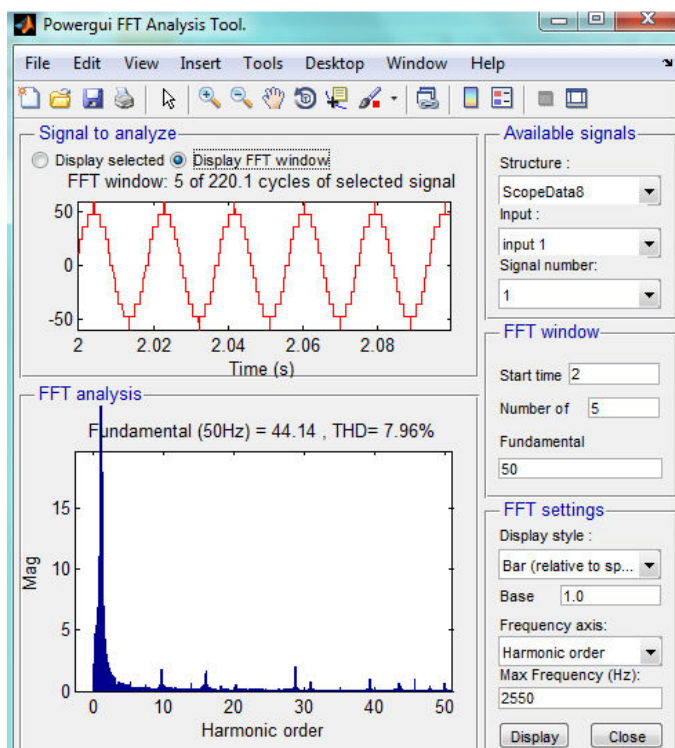


Fig. 9 FFT Spectrum of the System with MATLAB optimization tool

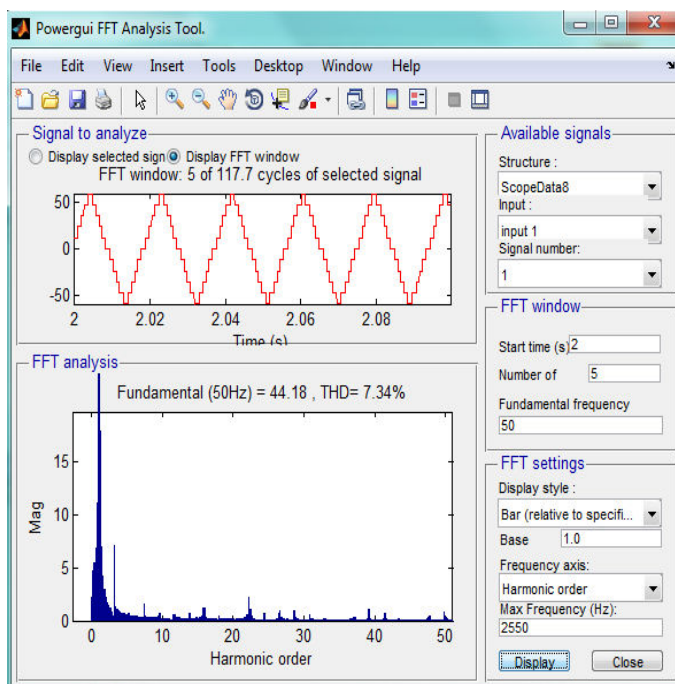


Fig. 10 FFT Spectrum of the System with ANN

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.

- Panels Using Artificial Neural Network Angle Generation," IEEE Transactions on Industry Applications, vol. 47, no. 5, Sept.-Oct. 2011, pp. 2117-2124
- [16] U. Boke, "A simple model of photovoltaic module electric characteristics," European Conference on Power Electronics and Applications, pp.1-8,Sept. 2007.
- [17] O. Gil-Arias, E. I. Ortiz-Rivera, "A general purpose tool for simulating the behavior of PV solar cells, modules and arrays," 11th Workshop on Control and Modeling for Power Electronics, pp. 1-5, Aug. 2008.
- [18] R. Ramaprabha, B. L. Mathur, "MATLAB based modelling to study the influence of shading on series connected SPVA," 2nd International Conference on Emerging Trends in Engineering and Technology, pp. 30-34, Dec. 2009.
- [19] Marcelo G. Gazoli J. and Filho E., "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays", IEEE Transactions On Power Electronics, vol. 24, no. 5, May 2009, p.p.1198-1208.
- [20] Hairul Nissah Zainudin, Saad Mekhilef "Comparison Study of Maximum Power Point Tracker Techniques for PV Systems" Proceedings of the 14th, International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010.
- [21] Mouloud A.Denai, Frank Palis, Abdelhafid Zeghebe,"ANFIS Based Modelling and Control of Non-Linear Systems: A Tutorial", IEEE International Conference on Systems, Man and Cybernetics, 2004.
- [22] J. S. R. Jang, "ANFIS: Adaptive Network-Based-Fuzzy Inference System", IEEE Transactions On Systems, Man And Cybernetics, VOL. 23, NO. 3,MAY/JUNE,1993
- [23] Bimal K. Bose ,"Neural Network Applications in Power Electronics and Motor Drives—An Introduction and Perspective", IEEE Transactions On Industrial Electronics, VOL. 54, NO. 1, February, 2007.
- [24] T. Ilakkia, G. Vijayagowri ,"Hybrid PV/Wind System for Reduction of Harmonics using Artificial Intelligence Technique", IEEE- International Conference On Advances In Engineering, Science And Management (ICAESM -2012) March 30, 31, 2012.