The International Journal of Energy & Engineering Sciences, 2020, 5 (1) 1-11
ISSN: 2602-294X - Gaziantep University


# HARMONIC ANALYSIS OF STAND ALONE PHOTOVOLTAIC SYSTEM AT LOW IRRADIANCE CONDITIONS

**Suleyman ADAK[1], Hasan CANGİ[2*]**

[1]Department of Electrical & Enegry, Vocational School, Mardin Artuklu University, Mardin, Turkey
[2]Department of Electrical & Electronics Engineering, HasCan Engineering, Mardin, Turkey
Corresponding author: hasancangi@yahoo.com

## ABSTRACT

This paper investigates the design, modeling, and simulation of harmonic analysis of stand-alone photovoltaic (PV) system at low irradiance conditions. PV systems have been increasingly used in the generation of electrical energy, either as a means of providing electricity in areas where there is stand-alone systems or by providing electricity to the grid connected systems. Pyranometer was installed for controlled data acquisition system and used to collect the spectral irradiance data. It is clear that total harmonic distortion (THD) is very sensitive when solar irradiance changes. The THD values are high up to 130% in the morning and evening hours when the solar irradiance is low and also when the solar irradiance is affected by sudden changes like passing clouds. But when the solar irradiance is high during the day, the current THD value gets reduced below the value of 10%. Also, fluctuating solar irradiance resulted in reduction of active power generated by off-grid PV system reducing the overall efficiency of the solar system.

**Keywords**: Off-grid system, power quality, solar irradiance, harmonics, renewable energy sources

## 1. INTRODUCTION

The energy demand in the world is consistently increasing, and new types of energy sources must be found in order to supply the future energy demands. Due to the increasing fuel prices and related environmental concerns, renewable energies become an important source to supply electricity to buildings and industrial sectors. The energy demand in the world is consistently increasing, and new types of energy sources must be found in order to supply the future energy demands. Renewable sources of energy such as solar, wind, geothermal have gained popularity owing to consuming of conventional energy sources such as coal, gas and oil. Solar energy is one of the cleanest forms of energy sources and the main energy resource for all of the life processes, and the basic condition causing varied physical phenomenon and

processes in the atmosphere. Photovoltaic (PV) array, which converts sunlight to electrical power [1-3]. The use of photovoltaic systems as clean source of energy from the sun has been quickly increasing. Solar PV is most popular owing to its significant advantages, such as no fuel costs, no pollution, no noise, and little maintenance. Matlab/Simulink is quite suitable to design the modelling circuit, and to learn the dynamic behaviour of different converter structures in open loop. Thus we can analyse the harmonic that will be generated by the off-grid PV systems, and thus design the circuit in simulation program. The principle of stand-alone PV system is as given in Figure 1.

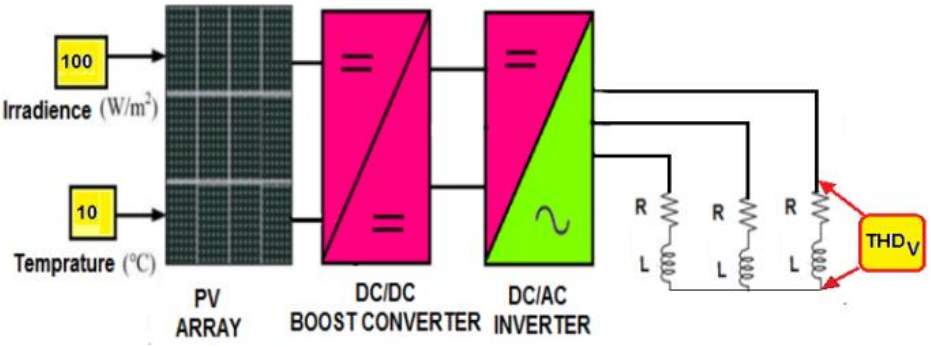


**Figure 1.** Off-grid solar system principle scheme

DC voltage is induced when solar irradiance falls on the PV panel. The amount of induced voltage depends on the amount of solar irradiance falling on PV panel, and the climatic parameters. As a result of this study, low temperatures and high solar irradiance intensities are more suitable for obtaining high & efficient power from PV panels.PV power generation technology is one of the most important researches in the field of renewable energy, which is significant in practice to mitigate the worldwide energy crisis. Stand-alone PV system can be used to provide power for remote loads that do not have any access to power grids, and are used to provide energy for local loads. The efficiency of photovoltaic systems varies between 15-20% depending on the panel type. The modules only operate at nominal power under standard operating conditions. In order to increase the amount of energy produced, a large number of PV modules are connected in series and parallel. The pollution of the modules, the angle of incidence of the rays, the canopy and the air being too hot or too cold affect the energy production efficiency of the modules. Off-grid photovoltaic modules generate electrical energy during the day and store it in the accumulator and the energy required for the load is taken from the accumulator.

## 2. HARMONICS IN SOLAR SYSTEM

Harmonic currents are being generated by nonlinear electronic loads, or non-sinusoidal sources. Harmonic currents flowing through power system impedances generate voltage harmonics and distort the supply voltage. The nth harmonic is equal

to n times the fundamental frequency, namely n*f, where n is a positive integer. When n is a positive fractional number, an inter-harmonic (n*f) is generated. Inverters produce aforementioned harmonics that affects Total Harmonic Distortion (THD), Distortion Factor (DF) and Power Factor (PF). Harmonics increase heat losses, power bills, and reduce system efficiency in power system. Inverters, DC/DC boost converter, and battery chargers are the most significant harmonic sources in PV power systems [2-4]. Non-linear waveform of inverter output voltage is given as an example in Equation 1.

$$\begin{aligned} v(\omega t) = {} & 12.77\,sin(\omega t - 1.1) + 1.527\,sin(2\omega t + 4.576) + 0.1905\,sin(3\omega t + 84.34) \\ & + 0.6921\,sin(4\omega t - 58.38) + 1.049\,sin(5\omega t + 144.1) \\ & + 0.8947\,sin(6\omega t - 43.75) + 0.4659\,sin(7\omega t + 95.75) \\ & + 0.4967\,sin(8\omega t - 30.89) + 0.8114\,sin(9\omega t - 73.87) \\ & + 0.8356\,sin(10\omega t + 142.1) + 0.5985\,sin(11\omega t - 43.58) \\ & + 0.49.24\,sin(12\omega t128.4) + 0.7028sin(13\omega t - 43.36) \end{aligned} \quad (1)$$

Graphics of Equation 1 is as given Figure 2.

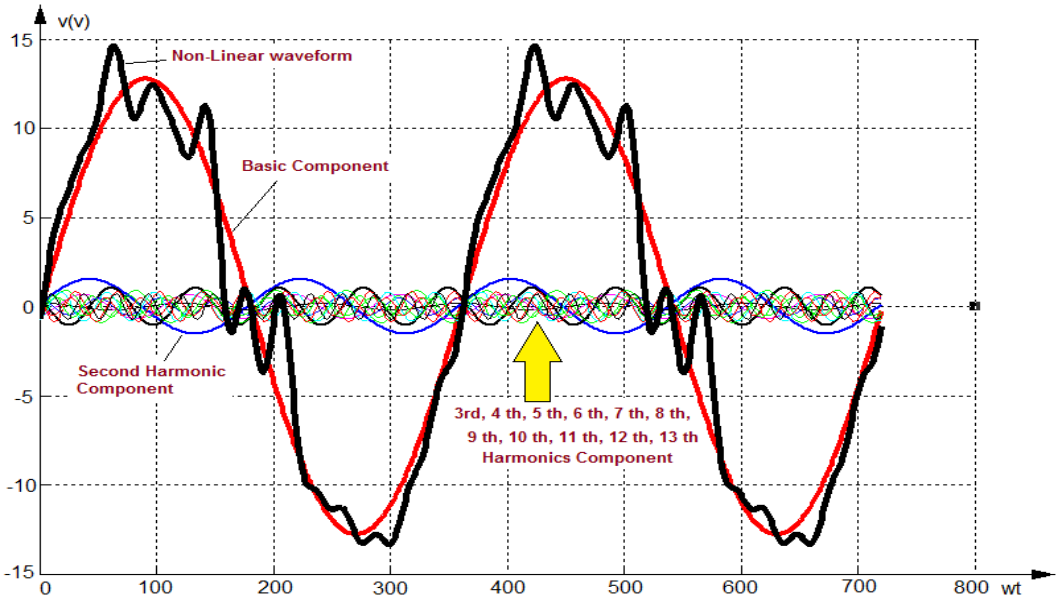


**Figure 2.**Non-linear waveform and their harmonic components

The decrease in harmonics is also proportional to an increase in solar irradiation levels. Harmonics have become increasingly necessary to calculate their influence when making any additions or changes to the power systems. As these higher frequency harmonic currents flow through the power system, they can cause, overheating and system hardware damage, such as:

- Overheating of electrical distribution equipment such as cables, transformers, battery PV panels.
- High voltages and circulating currents is caused by as a result of harmonic resonance,
- Increased internal energy losses in connected such as, PV array, DC/DC convereter and solar inverter.
- Causing elements failure owing to high total harmonic distortion.
- Shortened life span of solar device,
- False triggers at power electronic devices,
- Errors measurements in the measuring,
- Fires in wiring and distribution systems,
- Crest factors and related to problems,
- Decreasing the solar system power factor.

Harmonic components can be generated in the PV system by any variety of non-linear converters such as DC/DC boost converters and DC/AC inverters. These converters are a harmonic source in the PV system. The PV system must be protected from harmful effects of harmonics. PV systems incorporate power electronic interfaces, which generate a level of harmonics potentially leading to current and voltage distortion. High frequency harmonics that appear due to power semi-conductors switching are reduced by selected the optimal carrier frequency. Total harmonic distortion for voltage is the summation of all harmonic components of the current waveform compared against the fundamental component of the voltage wave,

$$THD_v = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1} \quad (2)$$

Harmonics causing serious pollution problem for solar system and they also reduce the quality or the energy supplied to the consumer. Sun light irradiance variation also affects the amplitude of the harmonic components. All harmonics decrease the quality of a power PV system and loads connected to it. The high THD have negative effects on off-grid PV power system such as equipment overheating motor vibration, neutral overloading and low power factor. If the harmonics components are equal to the "0", total harmonic distortion for voltage ($THD_V$) will be equal to the "0".There are many benefits of low harmonic distortion in electrical installations such as noise less operation, less power loss, and longer life span. THD value affects the whole system in the power system. Harmonic components are pollution in the PV power system. Power electronics based devices used in PV power systems cause the formation of harmonic components. This pollution rate is constantly increasing with the use of DC / DC, DC / AC converters and DC and AC choppers in PV power systems.

## 3. APPLICATION OF MATLAB/SIMULINK IN PV SYSTEM

The photovoltaic array converts the sunlight into electricity. The photovoltaic array consists of parallel and series of photovoltaic modules. The cell is grouped together to form the panels or modules. The model of photovoltaic array is obtained from the photovoltaic cells and depends on how the cells are connected [8-10]. Because no power is provided during the hours of darkness, the stand alone systems must generate and store sufficient energy during the day to satisfy the peak daily load. The storage should also be sufficient to cover several days when no sunlight is available. Batteries are normally used as a buffer to provide the necessary storage to guarantee short term continuity of supply by storing surplus energy during the day for use during the night and during periods of overcast skies [11-12]. Unfortunately it is not practical to store the summer's surplus energy for use during the winter. Figure 3 shows the change of solar irradiance throughout the day.

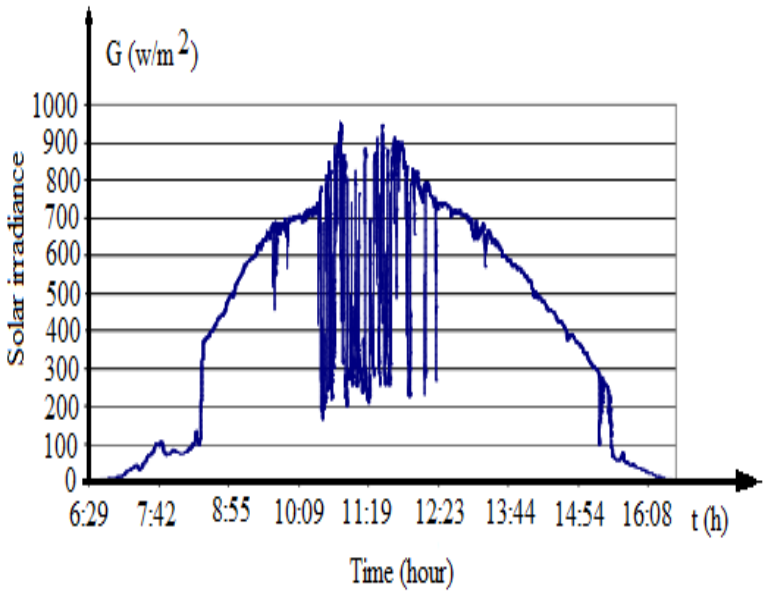


**Figure 3.**Changing of solar irradiance all day long

It has been shown that current THD increases with a decrease in solar irradiation (w/m²) levels and that current THD decreases with an increase in inverter output current or power [13-14].The topologic structure of the management PV system is shown in Figure 4, which consists of PV array, DC/DC converter and inverter, which connects at inductive R-L load. An ideal switch is used in DC/DC boost converter so as to observe the output without any kind of loss across the switch. The voltage and current produced at the terminals of a PV can feed a DC/DC converter, and connect to an inverter to produce AC current. Stand-alone solar system which consists of PV Array, battery bank, DC/DC boost converter, charge controller, solar inverter, and inductive R-L load. Then main emphasis is to be placed on the photovoltaic system, the modelling and simulation photovoltaic array, the MPPT control and the DC/DC converter, total harmonic distortion values depend on PWM's carrier frequency will be analyzed and evaluated. The step of modelling with Matlab/Simulink of the

photovoltaic system is shown respectively and simulation results are provided. The Simulink model of the PV could be used in the future for extended study with different DC/DC converter topology and solar inverter. In the following we will examine a system implementation with two microcontrollers. One will be responsible for the battery charge controller with MPPT and the other one with the DC/DC boost converter, DC/AC power inverter and R-L load. The proposed system is modelled and simulated under Matlab/Simulink under low irradiance. Stand-alone PV system schematic diagram of this system is given in Figure 4.

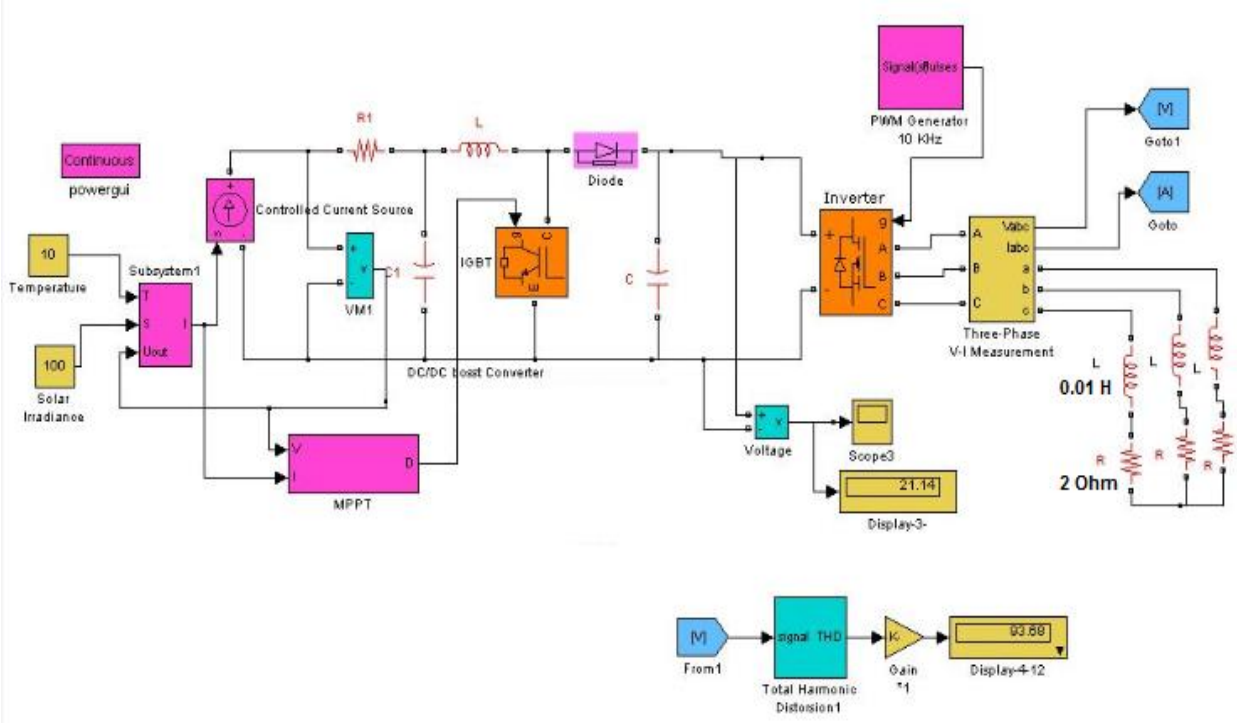


**Figure 4.** Principle scheme of stand-alone solar system (for 100 (W/m$^2$, 10 $^0$C)

The PV system was modelled by using the Matlab/Simulink program and then the simulation results showed that the THD value increased due to the low radiation level. Power quality is considered to be one of the important criteria for the design of any electric power generation system. Hence it is necessary to identify and analyze the factors that are responsible for the deterioration of power quality. In this regard, it was found that fluctuating solar irradiance has strong inter-relation with power quality index. The solar irradiance dependent level of harmonic distortion due to off- grid PV system was investigated. One inherent problem with PV systems, however, is the necessity to convert the PV array's direct current to the electrical grid's alternating current, which is implemented by means of pulse-width modulation (PWM). Such electronic switching introduces more distortion into the grid which already contains some harmonics that are caused by nonlinear loads. DC link in solar system contains pulsation. Large electrolytic capacitors are connected to the DC link so as to absorb this pulsation so that the DC link voltage ripple can be kept small. Figure 4.shows a Matlab/Simulink diagram of typical solar PV renewable sources of energy. The integrated system has PV array as sources of energy. Therefore, the characteristic of

energy storage for a PV system will be explained as well as some specification and standards for a off- grid connected PV system. The effect of fluctuating solar irradiance on the harmonics component of solar photovoltaic system was examined. It was clear that current THD is very sensitive to changes in solar irradiance condition. Table 1 shows the value of the harmonic components in the photovoltaic system.

**Table 1.** Harmonic components of output solar inverter

| **Harmonic components of stand-alone photovoltaic system at low irradiance** | | |
|---|---|---|
| ***Harmonics Component*** | ***Amplitude(V)*** | ***phase angle (Degree)*** |
| 1 | 12.77 | -1.1 |
| 2 | 1.527 | 4.567 |
| 3 | 0.1905 | 84.34 |
| 4 | 0.6921 | -58.38 |
| 5 | 1.049 | 144.1 |
| 6 | 0.8947 | -43.75 |
| 7 | 0.4659 | 95.75 |
| 8 | 0.4967 | -30.89 |
| 9 | 0.8114 | -73.87 |
| 10 | 0.8356 | 142.1 |
| 11 | 0.5985 | -43.58 |
| 12 | 0.4924 | 128.4 |
| 13 | 0.7028 | -43.36 |
| 14 | 0.7979 | 139 |
| 15 | 0.6662 | -53.17 |
| 16 | 0.5246 | 125.3 |
| 17 | 0.6373 | 92.18 |
| 18 | 0.761 | -43.83 |
| 19 | 0.7037 | 139.4 |
| 20 | 0.5661 | -47.44 |
| 21 | 0.5987 | 133.2 |
| 22 | 0.7272 | -42.03 |
| 23 | 0.7217 | 135 |
| 24 | 0.646 | -57.51 |
| 25 | 0.5813 | -70.54 |
| 26 | 0.6866 | 130.9 |
| 27 | 0.7254 | -42.36 |
| 28 | 0.6428 | 135.3 |
| 29 | 0.5812 | -47.44 |
| 30 | 0.6536 | 135.8 |
| 31 | 0.718 | -40.12 |
| 32 | 0.6703 | 121.9 |
| 33 | 0.5935 | 167.4 |

| | | |
|---|---|---|
| 34 | 0.6278 | -51.09 |
| 35 | 0.7022 | 135.5 |
| 36 | 0.689 | 120.78 |
| 37 | 0.613 | 131.3 |
| 38 | 0.6819 | 137 |
| 39 | 0.6012 | -45.89 |
| 40 | 0.6986 | -44.95 |

Presence of harmonics leads to overloading of consumers electrical installation, terminal voltage rise and flicker, increased heating of neutral conductors, increased induction motor and transformer heating as well as saturation effects in the core, interferences on telecommunication lines, protective relays malfunction and failure of power factor correction capacitors. Hence it is important to identify the causes for harmonic generation along with its nature of influence in the off-grid PV systems performance to ensure the satisfactory operation, design of component ratings, protection settings and optimization of controller present in off-grid PV system. Normally harmonics is created due to any non-linear nature of characteristics. The level of harmonic distortion in currents and voltages caused by off-grid PV systems is the subject of several international standards. When the PV inverters operate under low solar insulation and low power levels, more unwanted harmonics are generated. This has a huge impact on the power quality of the grid as well as capital and maintenance costs. The main aim of this work is to analyse the harmonic components at low radiation. The amplitudes of output inverter harmonic components are given in Figure 5.

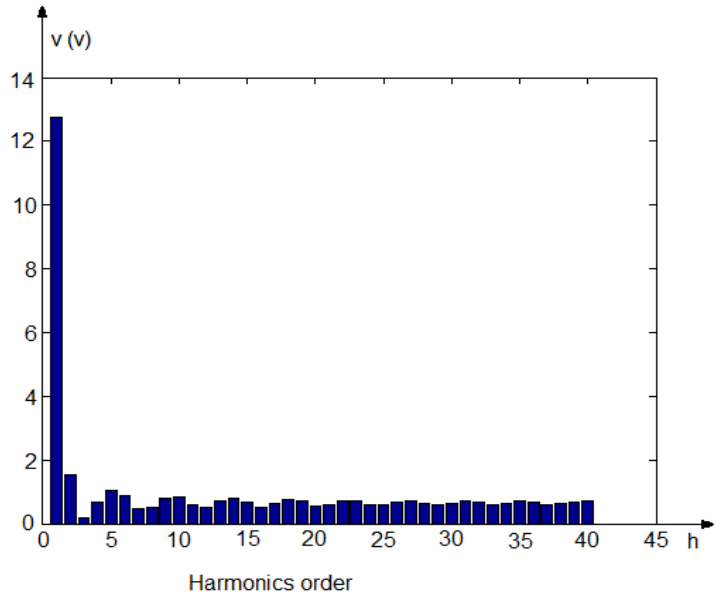


**Figure 5**. Spectrum voltage harmonics of inverter

The problems caused by the harmonics are well defined; we cannot justify an incident on the installation due to their presence. The effects can be shown instantly switch failure, incorrect operations in static equipment, etc. and in the long term capacitor battery resonance, transformer overheating, conductors and motors, measurement errors from measurement instruments, thermal losses, etc. The most effective way to eliminate the negative effects of the harmonic components on the off-grid PV system is to use active filters. By exceeding the maximum conductor isolation temperature by only 10$^{o}$C motors and transformers reduce their working life practically by half. There are two operational modes in the system according to the different working statuses of PV panels, battery and mains supply. Solar electric or photovoltaic technology is one of the biggest renewable energy resources to generate electrical power and the fastest growing power generation in the world. Photovoltaic-based inverter outputs current harmonic distortion belongs to solar irradiances are primarily discussed in this paper. System structure and working modes are analyzed in detail firstly and then total harmonic distortion belong to solar irradiances practical and theoretical analyses have been realized by the simulation. Matlab /Simulation have been donate examine the harmonic components at low irradiance.

The negative effects of THDv are such disruption, heating the batteries, overheating the cables and poor quality of the electrical energy. Power inverters are electronic device or circuitry that changes direct current to alternating current. Solar inverter output voltage waveforms not sinusoidal therefore, they contain harmonic components. Output voltage of square wave is acceptable in low and medium power, whereas, in high power applications ask sinusoidal waveforms.

## 4. CONCLUSION

Harmonic components other than the basic frequency are destroyed by the active filter. In order to improve energy quality and efficiency in solar systems, it is necessary to use active filters. Pyranometer was installed to collect the spectral irradiance data. Out of various data collected, three days with high, average and low intensity of solar irradiance were selected for analysis. For whatever may be the case, it is clear that current total harmonics distortion is very sensitive to changes in solar irradiance condition. The current THD values are high up to 130 % in the morning and evening hours when the solar irradiance is low and also when the solar irradiance is affected by sudden changes like passing clouds. But when the solar irradiance is high during the day, the current THD value gets reduced below the value of 10 %. At low solar irradiance condition, the current THD increases significantly high from 10% to 130% which is above the recommended standard. By comparing the results of voltage THD, it can be deduced that fluctuating solar irradiance

## REFERENCES

[1] Parthasarathy S, Anandkumar N.V. Effect of Fluctuating Solar Irradiance on the Quality of Power Generated by Solar Photovoltaic System. International Journal of Advanced Engineering Research and Technology (IJAERT) Volume 5 Issue 9, September 2017, ISSN No.: 2348 – 8190.

[2] Rustemli S, Cengiz M.S. Active fitler solutions in energy systems. Turk J Elec Eng & CompSci, 2015, 23: 1587 – 1607 doi:10.3906/elk-1402-212.

[3] Wang F, Duarte J. L, Hendrix M. A. M, Ribeiro P.F. Modeling and analysis of grid harmonic distortion impact of aggregated DG inverters. IEEE Trans. Power Electron., 2011,vol. 26, no. 3, pp. 786–797.

[4] Kececioglu O.F, Acikgoz H, Yildiz C, Gani A, Sekkeli M. Power Quality Improvement Using Hybrid Passive Filter Configuration for Wind Energy Systems. Journal of Electrical Engineering Technology", 2017, 12, 2370-2375. DOI: 10.1016/j.sbspro.2015.06.211.

[5] Kaushika N.D, Nalin K, Gautam, Kshitiz K. Simulation model forsizing of stand-alone solar PV system within the connected array. Solar Energy Materials & Solar Cells.,2005, 85, pp. 499–519.

[6] Watson N.R, Arrillaga J. Harmonics in large systems. Electric Power Systems Research, 2003, 66 (1), pp. 15-29.

[7] Ozdemir A, Ferikoglu A. Low cost mixed-signal microcontroller based power measurement technique. IEE Proceedings-Science Measurement and Technology, 2004, 151, 253-258. Doi: 10.1049/ip-smt: 20040242 –JUL.

[8] İzgi E, Öztopal A, Durna B, Kaymak M.K, Sahin A.D. Short–mid-term solar power prediction by using artificial. Solar Energy, 2012, vol.86, pp.725-733.

[9] Dugan R.C, McGranaghan M.F, Santoso S, Beaty H.W. Electrical Power Systems Quality. Second Edition, McGraw-Hill, 2004.

[10] Adak, S, Cangi, H. Analysis and Simulation Total Harmonic Distortion of Output Voltage Three Level Diode Clamped Inverter in Photovoltaic System, Bitlis Eren University, Fen Bilimleri Dergisi, ISSN 2147-3129, 2015.

[11] Nema S, Nema R.K, Agnihotri G. Matlab/Simulink based study of photovoltaic cells/modules/array and their experimental verification. International journal of Energy and Environment, 2010, vol.1, No.3, pp.487-500.

[12] Cangi H, Adak S. Analysis of solar inverter THD according to PWM's carrier frequency. International Conference on Renewable Energy Research and Applications (ICRERA); November 2015: DOI: 10.1109/ICRERA.2015, 7418694.

[13] Oliva A.R, Balda J.C. A PV dispersed generator: a power quality analysis within the IEEE 519. IEEE Trans. on Power Delivery, 2003, 18, 2 525-530.

[14] Cangi H. Analysis and elimination of harmonics at low irradiation level in PV systems. PhD Thesis, University of KSU University, Graduate School of Natural and Applied Sciences Department of Electrical-Electronics Engineering, 2019.