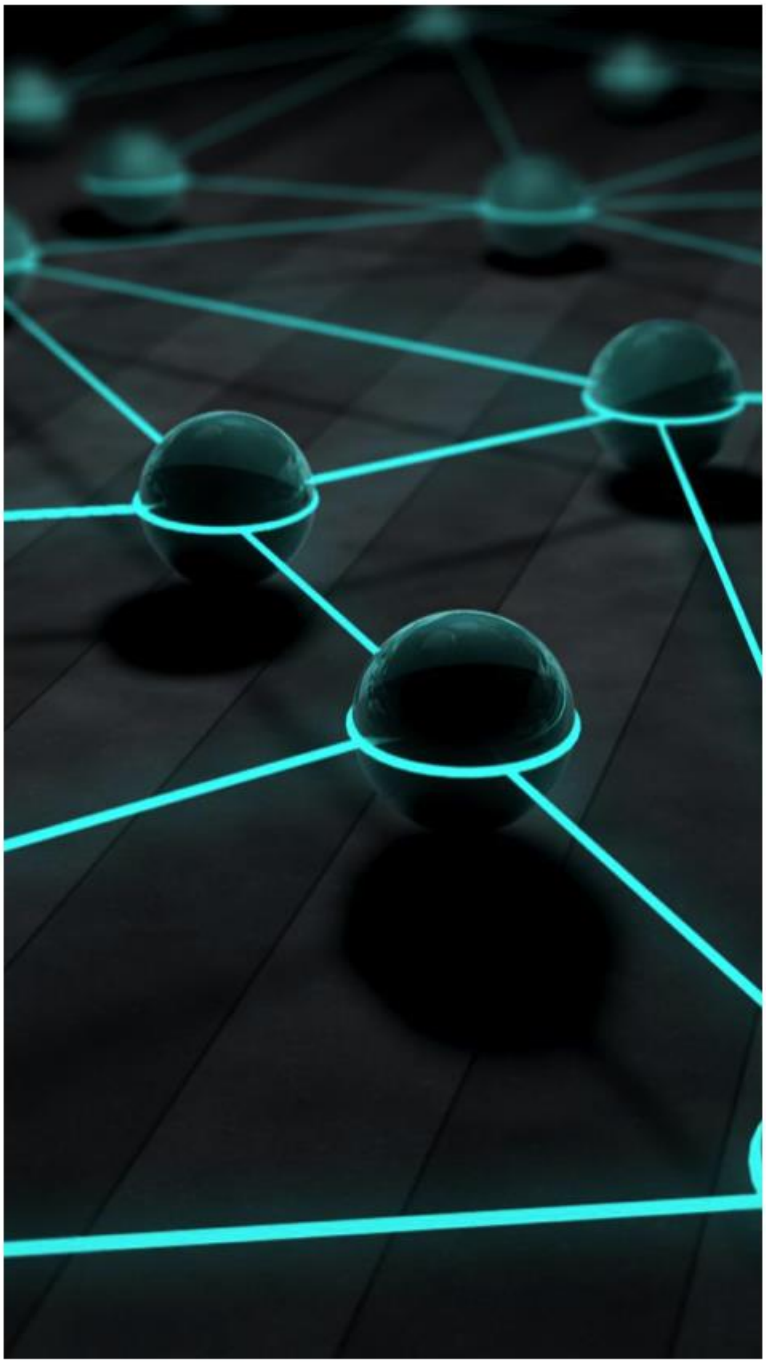
IJESG

International Journal of Energy and Smart Grid



Volume 6
Issue 1-2
2021

e-ISSN:2636-7904

Copyright © 2021

Email : ijesgrid@gmail.com
Visit our home page on www.dergipark.org.tr/ijesg

IJESG is an open access journal. This journal licensed under creative common 4.0 International (CC BY 4.0) license. You are free to share and adapt for any purpose, even commercially.

Under the following terms:

Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

No additional restrictions — You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

Notices:

You do not have to comply with the license for elements of the material in the public domain or where your use is permitted by an applicable exception or limitation.
No warranties are given. The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material.

EDITORIAL BOARD MEMBERS

Editor-in-Chief **:** Dr. Bilal Gümüş *(Dicle University, Turkey)*

International Editorial Board

- Dr. Josep M Guerrero *(Aalborg University, Denmark)*
- Dr. Md Maruf Hossain *(University of Wisconsin, USA)*
- Dr. Hasmat Malik *(Netaji Subhas Institute of Technology, India)*
- Dr. Kouzou Abdellah *(Djelfa University, Algeria)*
- Dr. Musa Yılmaz *(Batman University, Turkey)*

Publisher of Journal: Prof.Dr. Zulkuf Gülsün

REVIEWERS IN THIS ISSUE

Dr. Yurdagül Benteşen Yakut
Dr. M.Emin Asker
Dr. Mustafa Dursun
Dr. Heybet Kılıç
Dr. Hemlal Bhattarai
Dr. Fatih Koçyiğit
Dr. M.Rida Tür
Dr. Süleyman Adak

IJESG *International Journal of Energy and Smart Grid*
Vol 6, Number 1, 2021
ISSN: 2548-0332
e-ISSN 2636-7904

CONTENTS

Review Article

Research Articles

IJESG International Journal of Energy and Smart Grid Vol 6, Number 1-2, 2021
e-ISSN 2636-7904

Review Article

UNDERSTANDING SOLAR POWER SYSTEM AND ITS CONTRIBUTION TO FREQUENCY REGULATION – A REVIEW

Hemlal BHATTARAI*[1], Karma LODAY[2], Dipesh CHHETRI[3], Jai Ram RAI[4]

[*1]Centre for Lighting and Energy Efficiency Studies (CLEES), Jigme Namgyel Engineering College, Bhutan
[2,3,4]BEPE, Jigme Namgyel Engineering College, Bhutan
[*] Corresponding author; E-mail: b.hemlal@gmail.com

Abstract *Thirst for renewable power systems is gaining popularity in recent times. Solar power system due to its inherent advantages and availability is one such renewable energy system that is gaining penetration in power system sectors. The penetration of renewable energy sources in power systems is what is making the systems more concerned in terms of voltage and frequency stabilities. Overall understanding of solar power system is crucial in terms of construction, operations and possible means for enhancing the system stabilities where possible. This study covers the basic understanding of solar power in terms of construction, types along with a clear indication of solar power as one of the promising renewable energy options. Furthermore, the concept of the energy storage system and different options for energy storage are discussed as it is an essential requirement of the solar power system. The role of the energy storage system along with the basic concept of frequency regulation, the need for frequency regulations and the possible aspects of using solar PV plant for frequency are compared in this study.*

Keywords *Solar Power, Renewable Energy, Grid, Storage System, Frequency Regulations, State of Charge*

Received:06.11.2021 *Accepted:30.12.2021*

1. Introduction

Global demand for electrical energy is on the rise due to population growth as well are increasing developmental activities. On one hand, there is stress on power system networks to meet the growing load demands and on the other hand, there is a need for judicious extraction and use of energy sources. The pressure is also mounting from the concern pertaining to impacts of climate change where the holistic shift in renewable energy sources should be the priority. Almost 26% of the global electricity is from renewable sources and there are predictions that it will rise to 30% by 2024 [1]. There are commitments in line with realizations of 'Sustainable Development Goals (SDGs)' whereby countries are committing and shifting towards renewable energy initiatives. This is in the thirst for decarbonization of power system networks and initiatives towards becoming carbon neutral. Commitment from different countries in its strategic plan for going renewable has been realized with meaningful actions towards these directions. Penetration of solar and wind energy systems is quite significant in recent times along with hydropower.

One more reliable and user-friendly approach are driven towards solar power which has wider scales of growth starting from rooftop to solar farms which are contributing to meeting individuals' electricity demands and in many extends its connection and contributions to the power grid. Researchers have also found out that substantial rural communities depend on lighting and heating loads from renewable energy [2]. A deeper understanding of solar energy, radiation, solar power system, energy storage system and the frequency regulation concepts are thus crucial while exploring renewable energy sources as an option. It is critical to review the work done especially in the domain of energy storage as well as frequency regulations as solar power systems are variable power generations that are subjected to multiple factors. The best of the best energy storage system and the frequency regulation techniques are appropriate for given situations and conditions thus be key indicators for specifically realizing the potential of solar power system for its contribution to electrical power system networks.

The electric power system must meet two distinct challenges: maintaining a near-real-time balance between generation and demand, and adjusting generation (or load) to regulate power flows through particular transmission facilities. Because loads and generators are continually varying, it's challenging to balance generation and load in real-time. Regulation, contingency reserves (spinning reserve, supplemental reserve, replacement reserve), and voltage support are all services that storage technologies should be able to provide [3].

2. Understanding Solar Power System and their roles in power system networks

2.1. Why Solar Energy?

Energy from the sun is enormous and most of it goes untapped. The daily solar energy radiations are more than that of the energy used in a world for a year and it is a renewable source of energy. Furthermore, solar energy is freely available, environmentally friendly, sustainable and has strength for energy independence, the choice for it is most favorable. The solar radiation can be turned into thermal energy as well as electrical energy and realize the appropriate requirements [4].

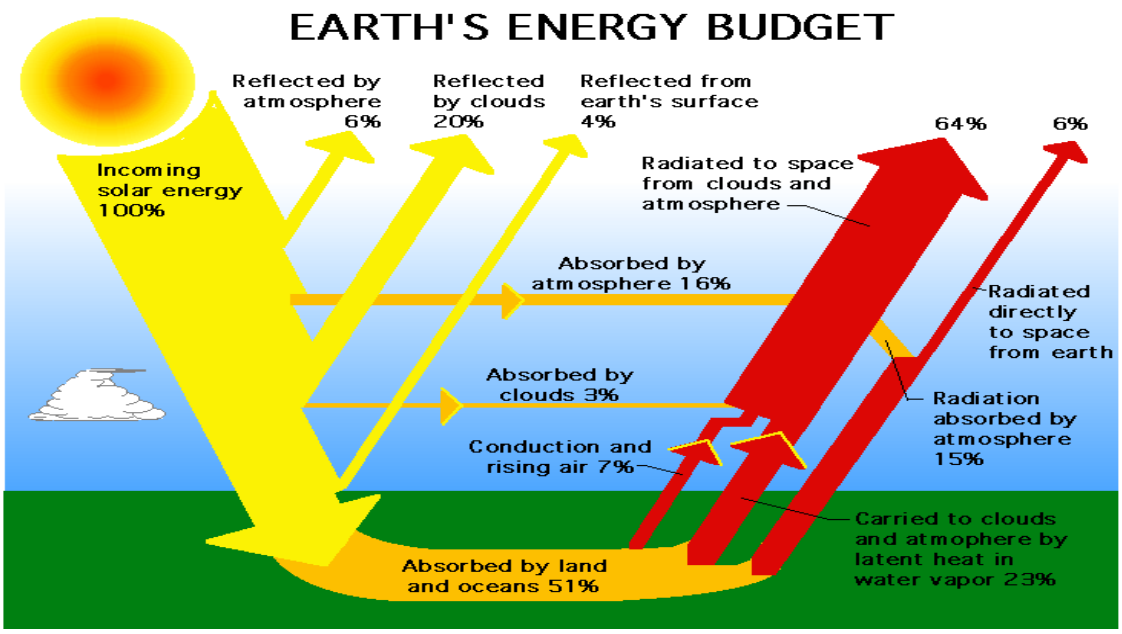


Fig.

Figure 1. Earth Energy Budget [5]

It is noted that major portions of solar radiation that reached the earth's surface are just radiated back and despite its numerous advantages it is hard to believe that it has not gained major penetration in power sectors where some pertaining issues related to higher cost involved in collecting, converting and storing.

Still, the use of solar electrical energy is rising fast in current times which are largely due to the attributes of positive aspects derived in terms of technologies, cost and ease of implementation. The lifespan of solar panels is 30 years and it can be customized based on size, colors and materials being used [6]. The construction of solar panels is such that it meets the requirements of energy generation as well as its conditions for usage in the exposed atmosphere.

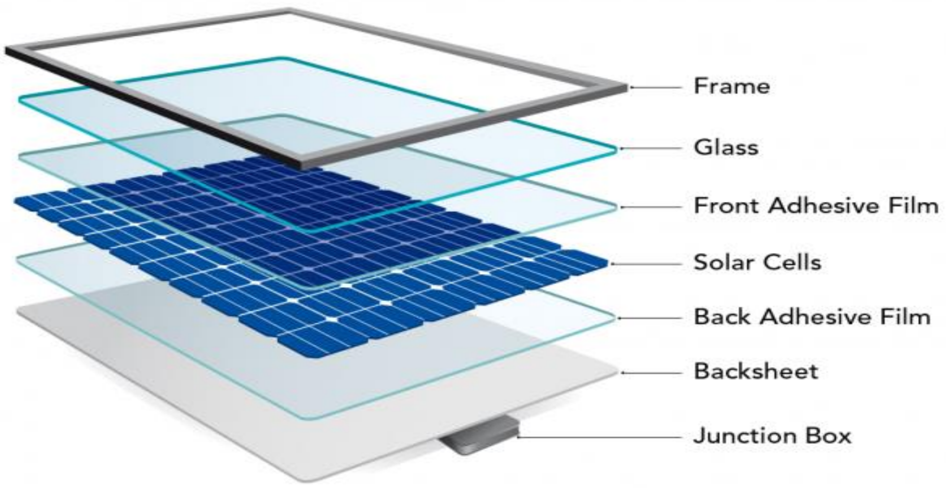


Figure 1. Solar Photovoltaic (SPV) Layers [7]

There are two common types of solar energy systems like 'Utility Intertie PV Systems (Grid Connected)', 'Stand Alone Solar Electric System'. The grid-connected solar energy system provides simple and cost-effective integration of solar power to utility power for energy requirements in smaller scales in residential/other buildings. Whereas the stand-alone system can well be applied in isolated building/structure or setup where there is no connection to utility power. The requirements can be implemented without or with usages of battery system (storage where necessary and feed in night time or in the case of cloudy weather).

Figure 3. On-grid and Off-grid components [8]

The mounting of solar panels can be either 'Fixed Mount' or 'Track Mount' based on the situation. the former is less costly as compared with the latter whereas the latter is most efficient as compared to the former as it has the capability of tracking the sun direction so as to achieve maximum solar radiation hitting the solar panels surface. In the majority of rooftop solar power systems, the use of fixed mounts is common due to price as well as other associated technical and practical difficulties.

The need to have greater insight into energy storage and frequency regulation is critical while talking about solar power systems. The penetration of solar power systems in the power utility grid will be more materialized when possible storage systems are incorporated as well there is special attention given to the frequency regulation when it is connected to the grid. Unlike hydropower, the fluctuations and weather dependency is high in the case of solar power system and more so it will generate D.C. voltages while the grid mostly/always is A.C in nature.

3. Why energy storage system is needed?

The need for energy is round the clock whereas the possibility of generating solar power is during the daytime. This has demanded the requirement of a storage system that can stock the excess power during the daytime and can be utilized during nighttime or even during cloudy weather. The grid-tied net-metered solar panels system is seen as more viable when there are bidirectional energy flow conditions can be realized. This will facilitate the excess energy if produced can be contributed to the grid and in other instances draw the required energy from the grid. The researcher has found that the extra energy can be used to charge the energy storage whereby the stored energy can safely be used after sunset so that the need for grid-connected utility power demand does not arise [9]. There are several types of energy storage technologies, including electrochemical, mechanical, and electrical/ magnetic fields as shown below;

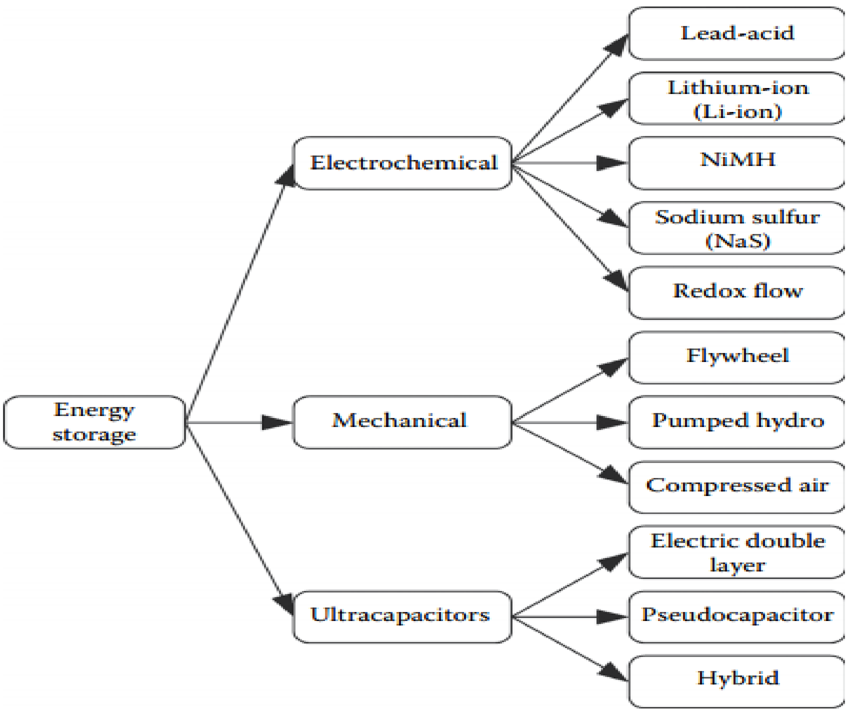


Fig. 4. Different types of Energy Storage Systems (ESS) [10].

Solar PV plants require short term support during clouding, load shedding and short-circuits. Such support can be provided by energy storage with high power capabilities rather than high energy capabilities [10]. Also, ESS with a faster discharge rate is preferred for such purposes. Modern ESS such as flywheels, ultracapacitors, Compressed Air Energy Storage and superconducting magnets are designed with such characteristics [11]. The characteristics of some of the commonly used ESS are shown below in figure;

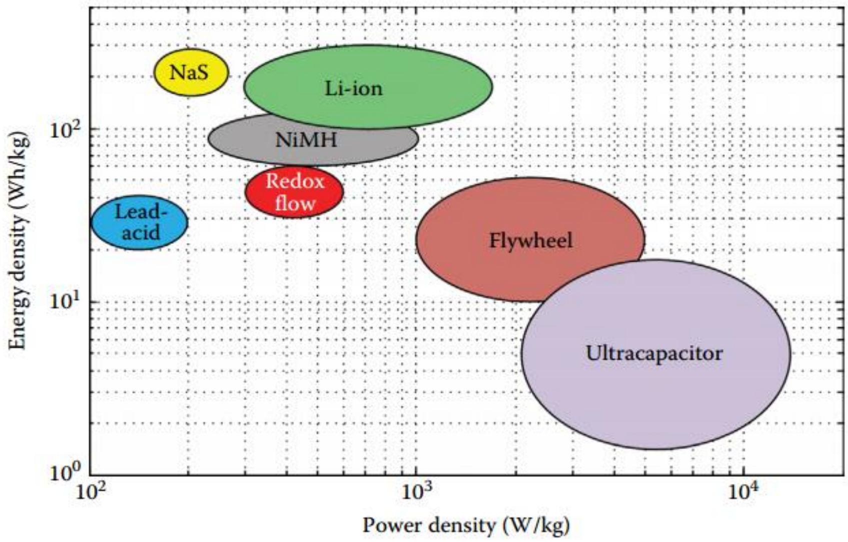


Fig. 5. Ragone plot for various types of Energy Storage Systems [10].

While consideration for frequency regulation, ESS with higher power density is preferred. There is a need for understanding the different options available for the energy storage system that are already in place and have their strength and weakness.

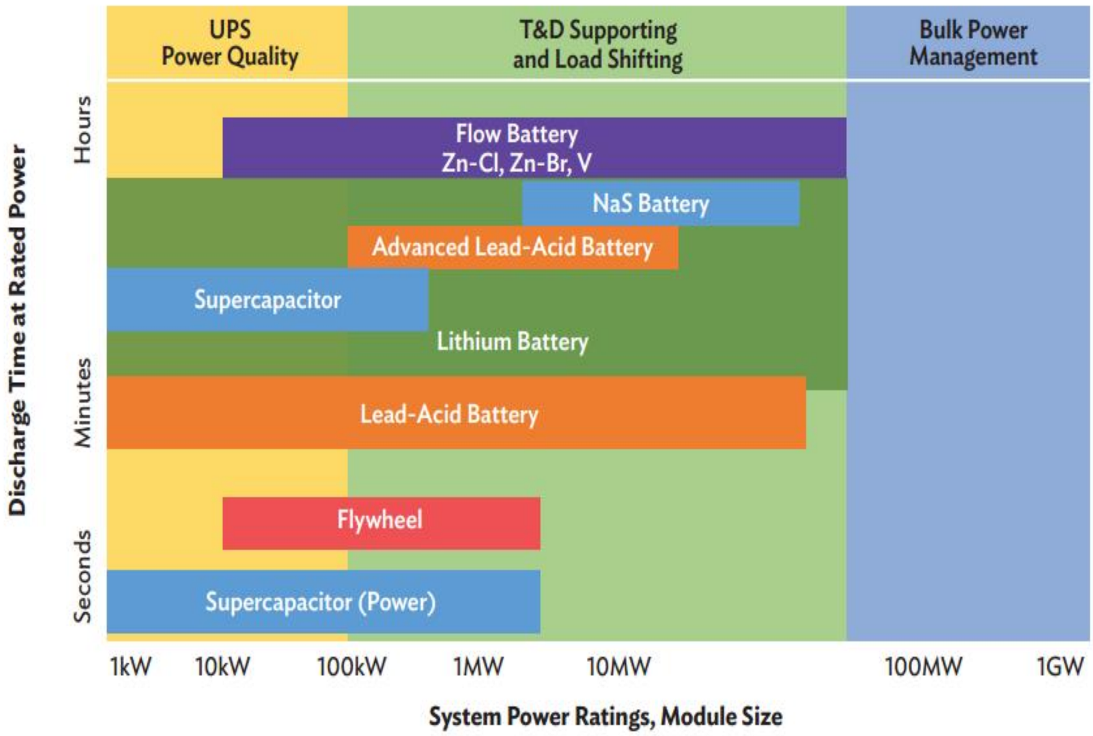


Fig. 6. Comparison of Power Output (in watts) and Energy Consumption (in watt-hours) for Various Energy Storage Technologies [12].

4. Frequency regulation

In a power system, frequency is a constantly changing variable that represents the balance between generation and demand. The regulation of frequency to have power system on permissible frequency range is crucial when there are constant changes in generation as well as load is observed in power system. With the growing need for renewable energy, conducting primary frequency management alone on the generation side has become not only prohibitively expensive but also technically complex. Demand-side frequency response is an innovative technique to address the growing demand for traditional power sources [13]. Also with solar power systems penetrating in power systems and their fluctuating generating situations, the thirst for 'Maximum Power Point Tracking (MPPT)' technologies are incorporated to achieve maximum possible generation. Solar photovoltaic power generation (PV generation), on the other hand, does not engage in any frequency regulation or oscillation damping function for the bulk power grid when operating in MPPT mode because the panels' output is maximized rather than coordinated with the grid. PV operations could be modified to include it in frequency support and small-signal stability control for bulk power systems as penetration grows [14].

4.1. Frequency regulation using solar PV system

With the increasing growth of renewable energy generation technologies making its impacts on global power system networks there are issues of frequency stability [15]. If operated as a stand-alone system, a solar PV system, as a renewable energy source, is often unable to follow load demand or participate in frequency regulation [16]. When a PV system is connected in a large power grid the issues pertaining to the impacts related to system frequency is neglected due to its capacity being much smaller as compared to power plant capacities but this issue is of concern when the larger-scale solar power system is connected to power grid [17].

By using reserve power from the array [16] and using interconnection with other renewable energy or non-renewable energy [18-19] the frequency is being regulated in the solar PV system. With the increase in the use of solar power plants all around the world, modern power plants demand not only generation support but also the need to use solar power plants for ancillary support. Solar power plants usually do not contribute to system frequency due to their decoupled nature from system dynamics [20]. In addition, the intermittent nature of solar power plants limits their ability to provide constant power as and when required [21]. However, with the use of 'Energy Storage Systems (ESS)', energy from the solar power plants can be stored and utilized as and when the system parameter changes. ESS can help to stabilize the electric power system by providing voltage and frequency support, load leveling and peak power shaving, spinning reserve, and other ancillary services.

Although BESS are among the oldest technologies, they are the most matured and developed ones as shared by ADB [12], but other researchers highlighted that BESS is not only capable of regulating frequency but also in improving them for both load-shedding and load increase cases [22]. Some of the BESS such as Li-ion batteries have a flexible characteristic because of which they can be used for multiple purposes including frequency regulation [23].

Mechanical storage devices are also employed for the ancillary service of both islanded and grid-connected systems. Flywheel is one such device that has shown considerable improvement in system stability by reducing frequency fluctuation [24]. Flywheels possess higher power density and lower energy density which makes them superior and suitable for frequency stabilization in RES technologies [25].

'Battery Energy Storage Systems (BESS)' is an economic choice and has a wide range of characteristics feasible for frequency regulation (such as fast ramp rate and power density). In addition, they are the most commonly used ESS as it is a matured technology. Hence, BESS is a good choice for frequency regulation. In the case of the battery, the commonly preferred ones are a Lead-acid battery, Li-ion battery and Sodium Sulphur (NaS) battery.

4.2. Frequency regulation using BESS with SPVP

When the grid frequency falls below a specified threshold, BESS can supply the PFR service by discharging (delivering active power) or absorbing active power from the grid (charging) when the frequency rises over that threshold. Between 0 and the maximum storage power, the necessary charging or discharging power is proportional to the frequency deviation and is linearly increased. Because of their quick response and high-power capabilities across time scales of up to 15 minutes, Li-ion BESS is well suited for PFR duty. Furthermore, when operated at 50% SOC, their calendar lifetime is extended.

One research shows how a battery energy storage system (BESS) with a frequency sensor controller may improve the frequency of an isolated island microgrid (FSC). The case has a Solar Photovoltaic Plant (SPVP) of a total installed capacity of 410 kWp, with over 50% instantaneous penetration. To mitigate the impact of SPV power production volatility on the microgrid, a BESS with the planned FSC was deployed. After that, load flow and transient stability analyses were performed with and without the use of the BESS. A simulation of transient stability was used to investigate the events of the greatest SPVP power plant tripping and all SPVP output powers with a 'Ramp Rate (RR)' of 70%/s. During these events, the frequency decreased below 57.3 Hz without being compensated by the BESS, which caused the load to trip. However, using the planned FSC of the BESS to support the microgrid's operation, the system frequency was well maintained [26].

IJESG International Journal of Energy and Smart Grid
Vol 6, Number 1-2, 2021
e-ISSN 2636-7904

In another study, it showed that the operation and control of hybrid photovoltaic power, ‘Diesel-Engine Generator (DEG)’, and BESS connected to an isolated power system a case study was conducted on the impact of BESS operations on the frequency stability of the hybrid system. Due to limited storage space, constraints on ‘State Of Charge (SOC)’ have also been introduced. In two scenarios, steady-state analysis of a hybrid system using step load response with PI controller and real-time performance analysis for a typical day with random fluctuation in load demand was carried out. The Genetic Algorithm is used to optimize the parameters of controllers. Matlab / Simulink platform is used to simulate a hybrid system model. According to simulation studies, the BESS system can contribute to frequency stability when the load increases and when the load decreases. This aspect of the BESS system will come in handy if it is used in conjunction with a hybrid Wind-PV system [22].

A flow chart depicting the hybrid system model's operational approach is shown in the figure below. A grid or an isolated power system can be used with the hybrid system. Variable loads are connected to the electricity system. The frequency of the electrical system changes whenever the load demand changes.

Changes in frequency are proportional to changes in load demand, therefore as load demand rises, system frequency falls, and vice versa.

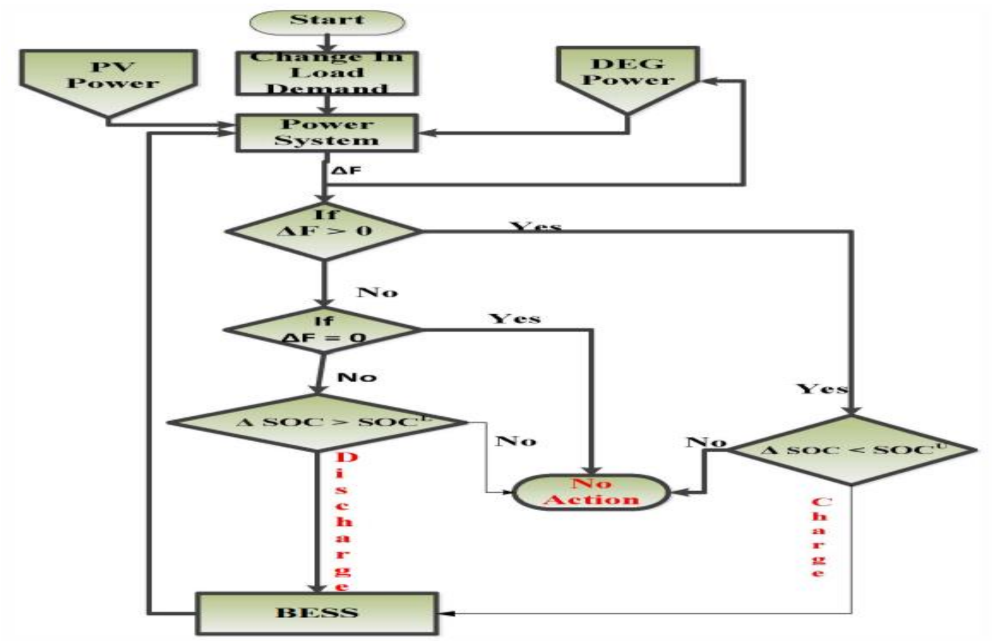


Fig. 7. illustration of operation strategy [22]

The frequency stability of the system must be constant. So, in order to achieve a change in frequency of zero, the power supply should be changed, which implies that if load demand increases, the power supply should be raised, and when load demand lowers, power should be reduced. On this basis, systems proceed as follows: when the change in frequency becomes negative, BESS supplies power to the system; however, before BESS can operate, it must go through a procedure in which the battery's state of charge (SOC) is compared to its lower limit of a state of charge (SOC^L). If the battery's SOC is higher than the SOC^L, BESS will deliver power to the grid or system before being discharged; otherwise, BESS will not produce power. In another scenario, if the frequency change is positive, BESS does not deliver power and reduces total power. Before charging the BESS, some of the surplus power was supplied to the battery system and its SOC as compared to its upper limit of a state of charge (SOC^U).

Vol 6, Number 1-2, 2021
e-ISSN 2636-7904

If the SOC is less than the SOC^U, the battery is charging and drawing power from the system; otherwise, the battery is not charging.

Furthermore, if electricity system resiliency is to be considered which is essential when there are issues with the grid during grid outrages as a consequence of any emergencies as well as extreme weather, the distributed solar photovoltaic systems can serve the purpose. This requires design consideration with ESS, hybrid fuel-use and microgrids but has to be supported by favorable regulatory measures so that power access during such circumstances be materialized [27].

4.3. Frequency regulation using De-loading method

In this method, effective control over the active power below the maximum power point (MPP) of the PV plant is achieved for numerous variations in solar irradiation and temperature to regulating the frequency of the plant [16]. This method is known as de-loading. A frequency droop control mode similar to that of synchronous generator's has also been developed following the same de-loading method [28]. This model uses a droop characteristic for varying irradiation to control the frequency for any loading condition as shown in the figure 8 below.

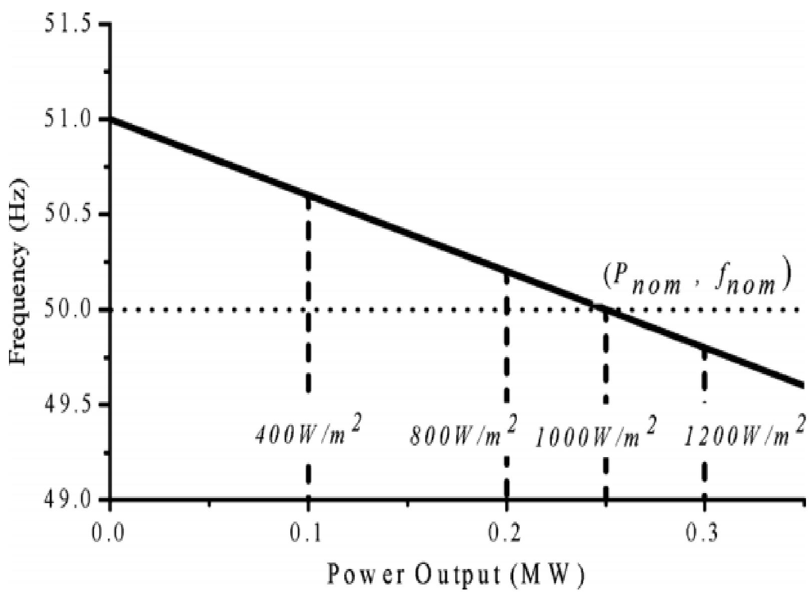


Fig. 8. Frequency drop for PV array [28]

De-loading techniques for the SPV plant by creating a power reserve in its MPPT curve are shown below in figure 9. This is achieved by changing the maximum power point 'V_{MPP}' to 'V_{deload}'. At 'V_{deload}', the SPV plant operates at normal frequency but as soon as the system frequency reduces, the point will move to the reference as shown as 2.

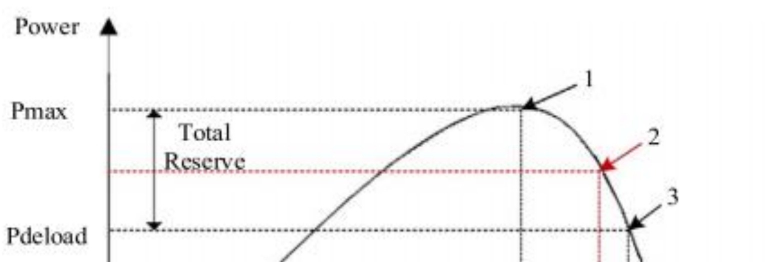


Fig. 9. De-loading technique [29]

A more optimized and intelligent technique to perform frequency control by the de-loading method has also been proposed [16, 30]. These methods involve the implementation of algorithms for the MPPT controller which can regulate the MPPT curve point according to the changes in the system frequency.

One of the studies done in U.S. Eastern Interconnection has reflected having several active power controls along with PV (Inertia control, governor control AGC control and PSS control) that are further employed with user-defined solar PV control that has potential for frequency regulation and oscillation damping in power system [31].

5. Discussion

Power generation from the renewable energy source and its penetration in power grids is gaining momentum whereby SPV plants are one main contributor. The SPV plant understanding thus becomes much crucial. Furthermore, due to the varying power generation nature of SPV as well as wind plants, there is a need to choose the best option for ESS too. From various types of ESSs, mechanical and electrical storage systems were found to have fast response characteristics that would support frequency regulation. However, BESS such as Li-ion and NaS was also found to have similar characteristics in addition to being a mature and cost-effective technology. Hence, BESS could be implemented for both grid and island mode operation of the SPV plant.

From the review of these techniques, it was found that SPV with ESS was more reliable than using the de-loading method. Although, the cost involved in implementing the de-loading method is lesser, however, there would not be full utilization of the energy generated by the SPV plant which could reduce its efficiency. Also, variation in irradiation poses complications in regulating frequency. Hence, using ESS such as BESS along with SPV plant would be a feasible option as it allows full utilization of energy produced, increase reliability and also, have multiple uses of ESS.

6. Conclusion

The solar energy system is growing across the globe and showing major penetration in power sectors in recent times. The need in understanding the solar power system and the trust in its capabilities are worth appreciating in a thirst for renewable energy. It is seen that solar radiation source, different components of an SPV plant and its advancement with modern technologies, various connection methods and other components of SPV farm are worth understanding when we think and act on the solar energy system. As the operating characteristics of the solar power system are weather dependent and there is a need to focus on energy storage systems. Also, the frequency regulations aspects seem important in power system networks when we have penetration of renewable energy sources to the grid network. The focus on SPVs contribution to frequency regulation using ESS is important to consider while working on the solar power system. Moreover, various comparisons and research show that BESS was a preferable choice of ESS for frequency regulation. Also, frequency regulation strategy using BESS shows that there is a relation between load demand, frequency and SOC of the battery and hence, these parameters are considered for maintaining the system's frequency. As a result, more research can be focused on realizing the best possible options capitalizing the potential of above mentions techniques with efficient controller/s and appropriate algorithms for making the reality of efficient frequency regulation using SPV plant.

References

[1] The growth of renewable energy: What does the future hold? Earth.Org - Past | Present | Future. (2021, May 11). https://earth.org/the-growth-of-renewable-energy-what-does-the-future-hold/

[2] Shinn, L.. *Renewable energy: The clean facts*. NRDC. (2018, June 15). https://www.nrdc.org/stories/renewable-energy-clean-facts

[3] Kirby, Brendan J. Frequency Regulation Basics and Trends. United States. . (2005). https://doi.org/10.2172/885974

[4] Ashok, S. Solar energy. Encyclopedia Britannica. (2021, October 22). https://www.britannica.com/science/solar-energy

[5] El-Basit, W. A., Abdel-Maksooud, A. M., Kamh, S. A., & Soliman, F. New Investigation on the Applications and Computer Simulation of Photovoltaic Cells and Storage Systems. International Journal of Engineering Sciences & Research Technology, (2015). 478-490.

[6] IRENA. Solar. International Renewable Energy Agency. https://www.irena.org/solar

[7] Generating electricity: Solar cells. Let's Talk Science. (2020, December 11). https://letstalkscience.ca/educational-resources/backgrounders/generating-electricity-solar-cells

[8] SunEdison.. Solar energy system components: On-grid and off-grid. Solar Power | Renewable Energy | Green Energy Blog. (2021, March 20). https://sunedisoninfra.com/blog/solar-energy-system-components-on-grid-and-off-grid/

[9] Energy Sage. How do solar batteries work? An overview. Get competing solar quotes online | EnergySage. (2021, September 16). https://www.energysage.com/energy-storage/storage-101/how-do-batteries-work/

[10] Blaabjerg, F., & Ionel, D. M. Renewable energy devices and systems with simulations in MATLAB® and ANSYS®. (2017). https://doi.org/10.1201/9781315367392

[11] Ogunniyi, E. O., & Pienaar, H. Overview of battery energy storage system advancement for renewable (photovoltaic) energy applications. 2017 International Conference on the Domestic Use of Energy (DUE). (2017). https://doi.org/10.23919/due.2017.7931849

[12] ADB. Handbook on battery energy storage system. Asian Development Bank, (2018). http://dx.doi.org/10.22617/TCS189791-2.

[13] Obaid, Z. A., Cipcigan, L. M., Abrahim, L., & Muhssin, M. T. Frequency control of future power systems: Reviewing and evaluating challenges and new control methods. *Journal of Modern Power Systems and Clean Energy*, *7*(2018). (1), 9-25. https://doi.org/10.1007/s40565-018-0441-1

[14] Liu, Yong, Gracia, Jose R., Hadley, Stanton W., & Liu, Yilu. Wind/PV Generation for Frequency Regulation and Oscillation Damping in the Eastern Interconnection. United States. https://doi.org/10.2172/1113693

[15] González-Inostroza, P., Rahmann, C., Álvarez, R., Haas, J., Nowak, W., & Rehtanz, C. The role of fast frequency response of energy storage systems and renewables for ensuring frequency stability in future low-inertia power systems. *Sustainability*, *13*(2021). (10), 5656. https://doi.org/10.339013105656

[16] Pappu, V. A. Implementing frequency regulation capability in a solar photovoltaic power plant. (2010). https://scholarsmine.mst.edu/masters_theses/4798/.

[17] Zhu, M. The impact of new energy generation on grid frequency. (2019). https://doi.org/10.1063/1.5089086

[18] Tada, K., Sato, T., Umemura, A., Takahashi, R., Tamura, J., Matsumura, Y., Taguchi, T., & Yamada, A. Frequency control of power system with solar and wind power stations by using frequency band control and Deadband control of HVDC interconnection line. *Journal of Power and Energy Engineering*, *06*(2018). (09), 48-63. https://doi.org/10.4236/jpee.2018.69007

[19] Dash, S. Load Frequency Control of Solar PV and Solar Thermal Integrated Micro grid using Narma-L2 Controller. (2020). https://arxiv.org/abs/2004.05776

[20] Vidyanandan, K., & Senroy, N. Improved frequency regulation in wind-PV-DG hybrid microgrid using wind turbines. 2016 IEEE 6th International Conference on Power Systems (ICPS). (2016). https://doi.org/10.1109/icpes.2016.7584249

[21] Kim, J., Kim, H., Kim, S., Jeon, J., & Choi, H.. Designing an energy storage system fuzzy PID controller for Microgrid islanded operation. *Energies*, *4*(2011) (9), 1443-1460. https://doi.org/10.3390/en4091443

[22] Singh, S., Singh, S. K., Chanana, S., & Singh, Y. Frequency regulation of an isolated hybrid power system with battery energy storage system. Power And Energy Systems: Towards Sustainable Energy. (2014) https://doi.org/10.1109/pestse.2014.6805286

[23] Parthasarathy, C., Sirviö, K., Hafezi, H., & Laaksonen, H. Modelling battery energy storage systems for active network management—coordinated control design and validation. *IET Renewable Power Generation*, *15*(2021). (11), 2426-2437. https://doi.org/10.1049/rpg2.12174

[24] National Grid Electricity System Operator NGESO, "Black Start from Non-Traditional Generation Technologies: Power Island Strength and Stability in support of Black Start," National Grid Electricity System Operator NGESO, United Kingdom, 2019

[25] Hajiaghasi, S., Salemnia, A., & Hamzeh, M. Hybrid energy storage system for microgrids applications: A review. *Journal of Energy Storage*, *21*(2019)543-570. https://doi.org/10.1016/j.est.2018.12.017

[26] Hsu, C., Cheng, T., & Huang, H. Battery energy storage system for frequency regulation of isolated island Microgrid. *Sensors and Materials, 33*(2021). (4), 1245. https://doi.org/10.18494/sam.2021.3162

[27] NREL. Distributed Solar PV for Electricity System Resiliency. National Renewable Energy Laboratory, (2014)1-12. https://www.nrel.gov/docs/fy15osti/62631.pdf

[28] Xin, H., Liu, Y., Wang, Z., Gan, D., & Yang, T. A new frequency regulation strategy for photovoltaic systems without energy storage. *IEEE Transactions on Sustainable Energy, 4*(2013). (4), 985-993. https://doi.org/10.1109/tste.2013.2261567

[29] Dreidy, M., Mokhlis, H., & Mekhilef, S. Inertia response and frequency control techniques for renewable energy sources: A review. *Renewable and Sustainable Energy Reviews, 69* (2017), 144-155. https://doi.org/10.1016/j.rser.2016.11.170

[30] Aghamohammadi, M. R., & Abdolahinia, H. A new approach for optimal sizing of battery energy storage system for primary frequency control of islanded Microgrid. *International Journal of Electrical Power & Energy Systems, 54* (2014)., 325-333. https://doi.org/10.1016/j.ijepes.2013.07.005

[31] Liu, Y., Zhu, L., Zhan, L., Gracia, J. R., King, T. J., & Liu, Y. Active power control of solar PV generation for large interconnection frequency regulation and oscillation damping. *International Journal of Energy Research, 40* (2015). (3), 353-361. https://doi.org/10.1002/er.3362

IJESG International Journal of Energy and Smart Grid
Vol 6, Number 1-2, 2021
e-ISSN 2636-7904

Research Article

ELIMINATION OF HARMONIC COMPONENTS IN SOLAR SYSTEM WITH L AND LC PASSIVE FILTERS

Suleyman Adak[1*], Hasan Cangi[2]

[1] Mardin Artuklu University, Electrical and Energy Department, Mardin, Turkey, suleymanadak@yahoo.com
[2] HasCan Engineering Company, Mardin, Turkey,
hasancangi@yahoo.com
[*] Corresponding author; suleymanadak@yahoo.com

Abstract: *As a result of the increase in the use of power electronics-based converters (DC/DC to DC/AC) and non-linear loads, harmonic components occur in the solar networks. It is quite common to use passive LC and L filters to eliminate harmonics in the solar PV systems. The solar system analyzed and modeled consists of solar panels, DC boost converter, PWM controlled solar inverter and six pulsed uncontrolled rectifier. Six pulse uncontrolled rectifier used as load in off-grid solar system produces 5th, 7th, 11th, 13th etc. harmonic components. LC and L filters are used to reduce the solar inverter output current total harmonic distortion (THD_I). In the solar system, the THD_I value has been reduced to the limit values given by the standards.. LC and L filters are commonly used to eliminate harmonics in solar system. Their widespread use is due to their easy structure and control. Modeling and simulation of the stand-alone PV power system was carried out with Matlab/Simulink program. While the value of THD_I was reduced from 91.57% to 2.62% with the LC filter, the value of THD_I was reduced to 5.73% with the L filter. It has been observed that the performance of the LC in eliminating the harmonic components is better than the L filter. As a result, LC filter improves both the system efficiency and reduce the THD_I value.*

Key Words: *L filter, LC filter, Solar Inverter, Off-Grid Solar System, Total Harmonic Distortion*

Received:17.08.2021 *Accepted:17.12.2021*

1. Introduction

The global energy sector is mainly dependent on fossil fuels, which have detrimental effects on the environment and clean-air goals. Over the past few decades, the demand for solar energy has increased considerably due to concerns over the environment. In addition toot her factors, such as energy security, global warming, technological improvements and the need for reducing costs, photovoltaic (PV) systems are considered an alternative source of energy especially considering that these systems are clean and environment friendly. PV sources have been used in a lot of places lately as they bring the benefits to air pollution [1-3]. In recent years, the demand for solar energy sources has started to depend on factors, such as increasing efficiency of solar cells, developments in production technology of cells, etc.

The main reason for the formation of harmonics is nonlinear circuit elements used in electric circuits. These elements cause disorders in the sinusoidal waveform of current and voltage signals. Non-linear waveforms contain harmonic components. These harmonic components occur in integer multiples of the main components [2-4]. Harmonic distortion is generally caused by non-linear elements in electrical solar power systems. Harmonic currents generated by power electronics circuit elements, such as thyristor transistor, diode, mosfet transistor and igbt transistor cause a decrease in the power quality of stand-alone PV systems.

As a result, the use of non-linear circuit elements in solar systems increases the efficiency of harmonic components in the solar system. In addition, rectifiers, inverters and dc boost converters are sources of harmonics in solar systems. Due to the stability problems of LC and L filter a damping resistor can be added to LC and L filters [5, 6]. However, the resistor has power loss in off-grid PV power system. The scheme of a stand-alone PV power system is given in Fig. 1.

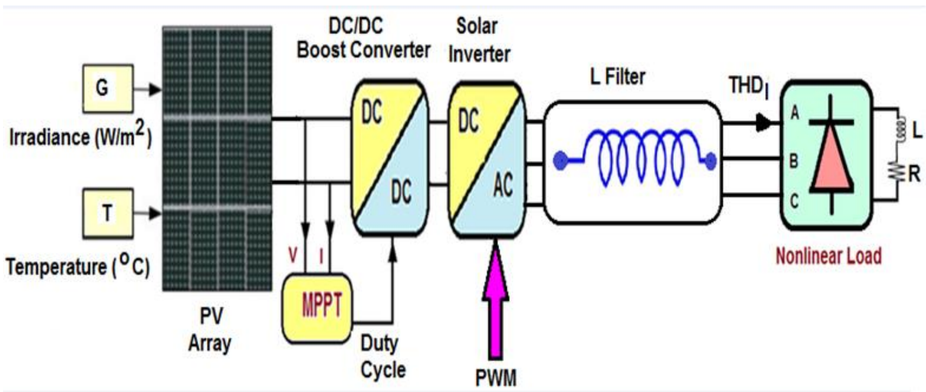


Figure1. Principle diagram of stand-alone PV system (with L filter)

There are many problems about power quality in off-grid PV systems. Among these problems, harmonics are one of the most important. Harmonic components must be eliminated absolutely. Output power generated by PV modules is influenced by the temperature of the solar cells, intensity of solar cell radiation and so forth. The typical module is made up of around 36 or 72 PV cells in series [7-9]. PV systems employ a frequent electrical energy storage algorithm so that the stored electrical energy is held for later use. The largely common storage contraption comprises of batteries in order to employ more striking mechanisms for storage. The maximum power point tracking (MPPT) occurs from a few hyperbolic curves [8-10].

Microcontroller based photovoltaic MPPT charge controller can be found by differentiating the cell power equation and setting the result equal to zero. This is known as the MPPT, and corresponds to the knee of the curve [11, 12]. The principle diagram of the elimination of harmonics with LC filter is as given in Fig. 2.

.

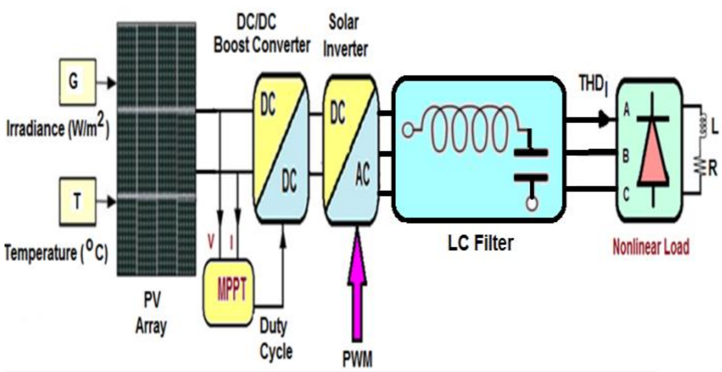


Figure 2. Principle diagram of off-grid PV system (with LC filter)

An insulated gate bipolar transistor (IGBT) is used to switch an element into a solar inverter. This element has non-linear characteristics. Therefore; the inverter produces harmonic components in PV systems. The increase in harmonic components causes the THD value to increase [13-15].

2. Harmonic Components in Stand-Alone Solar System

As a result of the increasing use of power electronics-based converters in the solar system, they have increased the efficiency of harmonic components in the solar system. The reason for the distortion of the voltage and current waveform in the solar system is the use of non-linear converters and loads. Non-linear circuit elements and loads distort current and voltage waveforms in solar systems, even if at low power. Harmonic components cause serious problems in power systems and reduce the quality of the energy transferred to the load. Semiconductor elements in the power electronics devices generate the THD_I [14- 16]. They also cause line losses and resonance problems in the solar system.

A six-pulse rectifier with R-L inductive load is used as a load in the off-grid PV system. Single component harmonics in the solar system have a negative effect on power quality as they have high amplitudes. The harmonic components produced by the converters in the solar system vary depending on the number of pulses [17-19]. As a result of the increasing use of power electronics-based devices in solar systems, harmonic components are increasing day by day. Equations (1) relate the harmonic current generated by the six-pulse rectifier. Six-pulse rectifier used as a load in the off-grid system, and produces 5^{th}, 7^{th}, 13^{th}, 17^{th}, etc. harmonic compenents. The equation for these harmonics as given in Eq. (1).

$$i(\omega t) = 15\text{Sin}(\omega t-0.16) + 2.99\text{Sin}(5\omega t+178.3) + 2.12\text{Sin}(7\omega t-179) + 1.35\text{Sin}(11\omega t-0.88)+ \\ +1.13\text{Sin}(13\omega t-0.49)+0.87\text{Sin}(17\omega t+179)+0.78\text{Sin}(19\omega t+179) \quad (1)$$

A result of changing spectrum of Eq. (1) is as shown in Fig. 3.

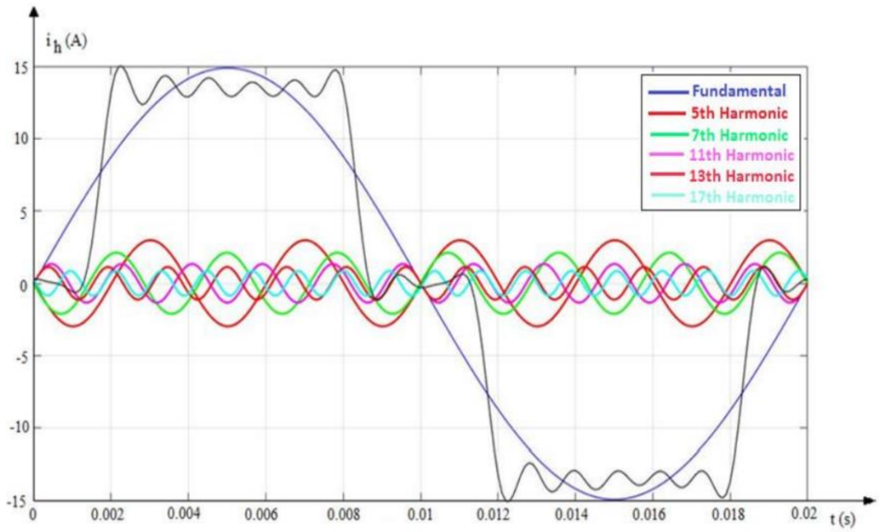


Figure 3. Six-pulse rectifier input current harmonics waveform

In the solar system, harmonic components cause distortion of the wavelength of the current and voltage and increase the THD_I. Increase in THDI value will cause damage or failure of devices in solar system. [18-20]. Some of the non-linear loads and converters that cause harmonic components in the solar system are as given below:

- Uninterruptible power supplies (UPS),
- Switched power supplies,
- Control circuits,
- Frequency converters,
- Battery chargers,
- Static VAR compensators,
- Variable frequency motor drives,
- Direct current converters,
- Inverters,
- Electric transport systems,
- DC/DC converter,
- Rectifier,
- Photovoltaic systems,
- Induction furnaces.

A common measure of the level of harmonic distortion present is THD_I. Total harmonic distortion is defined as the ratio of the harmonic components to the fundamental components. THD_I is defined as follows:

$$THD_I = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \quad (2)$$

Where, In is the effective values of the harmonic components, I1 is the effective value of the basic component. The current and voltage for stable and safe operation of the solar energy system must be sinusoidal waveform. However, these fundamental magnitudes lose their sinusoidal form due to harmonic components in the solar system. High THDI value has many disadvantages. These are equipment overheating, oscillating motors, neutral overheating and low power factor.

3. Elimination of harmonic components in off-grid solar system with L and LC passive filters

Four passive filters, L, LC, LCL and LLCL, are used to eliminate harmonic components at the solar inverter output. These passive filters have advantages and disadvantages When compared to each other. Finding the transfer function of the passive filter L and performing its analysis is quite easy compared to other filters [21, 22].

The cost of the LC filter is higher than the L filter. However, lower THD values are obtained with this filter compared to the L filter. It is necessary to eliminate harmonic components caused by nonlinear loads and converter and reduce the THDI value. This is very important for the efficiency and quality of energy [23- 24]. LC and L filters are placed between the solar inverter and the non-linear load. These filters are designed to eliminate harmonic components of solar system. L passive filter consists of inductance circuit element. In Figure 4, the principle diagram of the L filter is given.

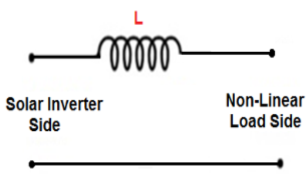


Figure 4. L filter modelling

A passive L filter has many advantages over an active harmonic filter, such as low power consumption, stable operation, reduction of THD_I and low cost. LC and L passive filters are generally used to eliminate harmonics in renewable energy sources such as wind power and solar power systems. These filters are used on the load side and improve the power quality of the solar energy produced in PV systems [25- 27]. The principle diagram of the LC filter is shown in Fig. 5.

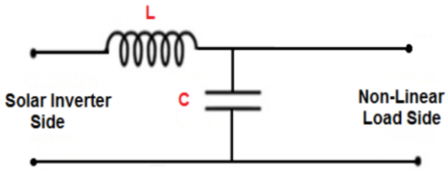


Figure 5. LC filter modelling

In solar off-grid power systems, passive LC filter is used to reduce harmonic components, improve power quality and reduce THD_I value. In the solar system, the harmonic components are eliminated by tuning L-C passive elements. LC filter should be used to keep the THD_I at the limit value specified in the standard. In the solar system, resonance has very destructive effects. To avoid resonance, the resonant frequency of the passive filter must be more than ten times the solar grid frequency and less than half of the inverter switching frequency [26- 28]. The resonant frequency should be in the range given in Eq. (3).

$$10\omega_0 \leq \omega_{res} \leq \frac{\omega_{sw}}{2} \tag{3}$$

Here, w_0 is the solar grid frequency (rad/s), w_{res} is the solar grid resonance frequency (rad/s) and w_{sw} is the inverter switching frequency (rad/s). The resonant frequency of the passive LC filter is defined as follows:

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} \tag{4}$$

Capacitor reactive power is

$$Q_c = 3.(2\pi f)CV_{rated}^2 \leq \alpha P \tag{5}$$

The value of the capacitor used in the LC filter is defined as:

$$C = \frac{\alpha P_{rated}}{3(2\pi f)V_{rated}^2} \tag{6}$$

A high-capacity capacitor is used. In order to prevent high inrush currents in the solar system. The value of the L inductance was chosen according to equation (7) in order to keep the ripple rate low.

$$L = \frac{V_{dc}}{2\Delta I_{ripple} f_{res}} \tag{7}$$

Here, Vdc is the output voltage of the boost converter, ΔI current ripple ratio, this value is selected as 5% of the rated current, fres resonant frequency of the filter. Passive LC filter is placed between the solar inverter and the non-linear load [29- 30]. A second stage LC filter has smaller size in applications. However, resonance frequency is still a problem of this filter. When low value filter inductance is used at the inverter output the THD_I value increases at low switching frequency.

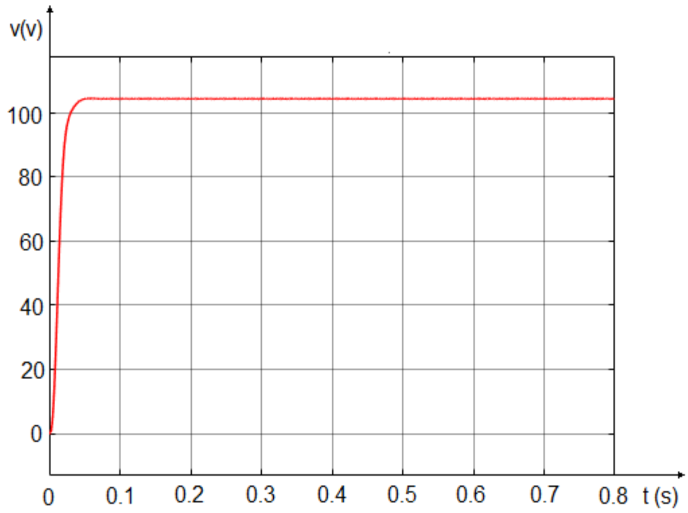


Figure 6. PWM inverter input voltage

Filter circuits must be installed for the elimination of harmonic components in the off-grid network. As a result, ohmic character is not fully effective in the power system. It is clear that the THD_I of the current of output inverter is 91.57 %. This value of THD_I is quite high. If the necessary precautions were not taken, it would cause a lot of damage to the solar PV system.

4. Elimination of Harmonic Components in Off-Grid Solar System with L And LC Passive Filters

A passive L, LC filters are required between a PWM inverter and the nonlinear load imposing and reducing harmonic compenents of the inverter output current. Simulations were made to find the harmonic components in the solar power system and to analyse their effects on the PV system. In this study, passive LC or L filters are used to eliminate harmonic components in power systems and improve power quality of solar system. The voltage harmonics are inevitable factors due to the pulse-width modulation (PWM) by the switching frequency of the PWM inverter.

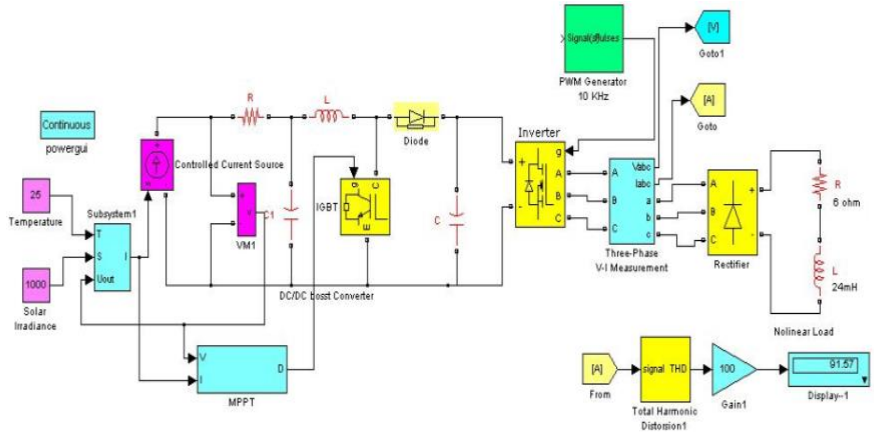


Figure 7. Matlab/Simulink model of stand-alone solar PV system (unfiltered)

For safety issues, disturbances caused by current harmonics should be avoided so they do not affect other loads connected to the same off-grid network. In order to attenuate current harmonics, input filters such as the simple inductive L and the LC combination structure are widely used in stand-alone PWM inverter applications

High-order harmonics in the solar power system affect the entire system, causing their distortion. In this study, two different filters, L and LC, were designed for the three-phase solar inverter and the performance analysis between them was made. The lowest size and the highest harmonic performance were obtained with the LC filter. A simulation model of the proposed off-grid solar system equivalent circuit is as shown in Fig. 8.

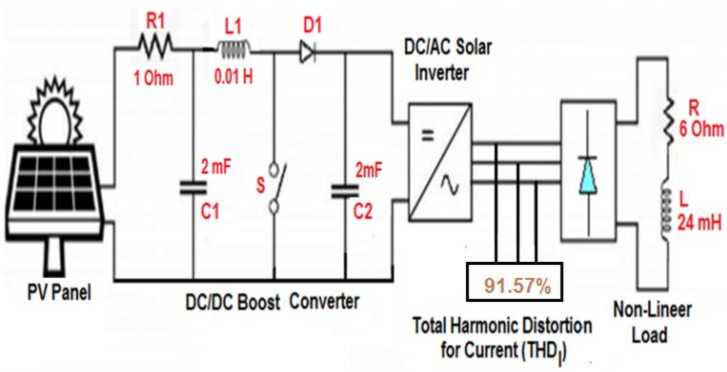


Figure 8. Equivalent circuit Model of stand-alone solar PV system (unfiltered)

As seen in Fig. 7, the total harmonic distortion was measured as 91.57%. This value is large enough to damage the off-grid system. It is absolutely necessary to reduce this value of harmonic distortion with passive filters. The six-pulse uncontrolled rectifier used as a load in the off-grid PV system is a harmonic source. The output voltage waveform of this uncontrolled rectifier is as shown in Figure 9.

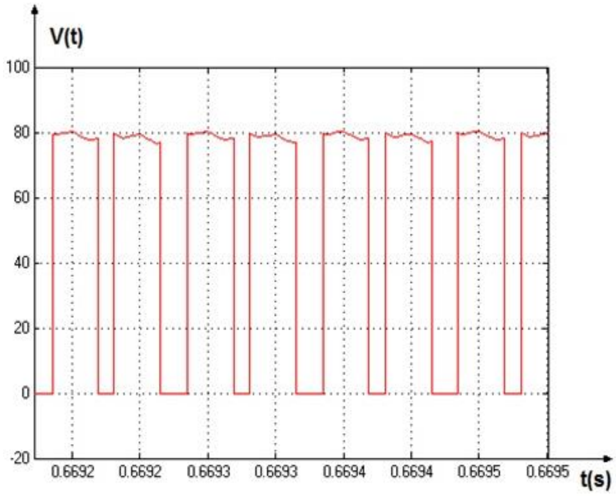


Figure 9. Six pulse uncontrolled rectifier output voltage

Matlab/Simulink program was used to perform performance analysis of passive LC and L filters in the solar PV system and to determine the THD_I value of the solar system. Harmonic components produced by converters and non-linear loads create resonance with the power system. Resonance has a great disruptive effect on the solar power system. Resonance conditions should be analysed for each harmonics in the solar system. The solar inverter output current waveform is as shown in Figure 10.

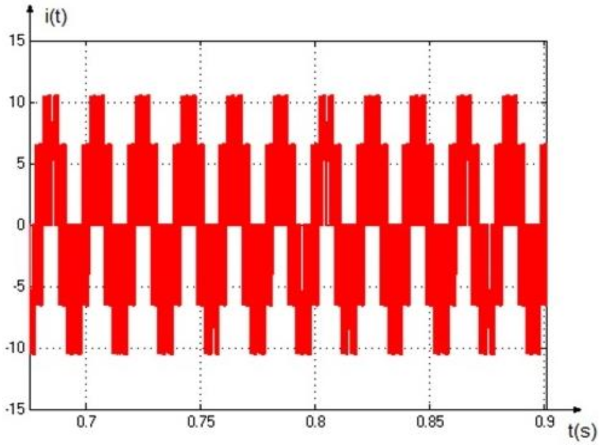


Figure 10. Inverter output current waveform (without filter)

The parameter values of the LC filter used in the stand-alone solar system are found from equ Eq.(6) and Eq. (7). These parameter values are as shown in Table 1.

Table1. Parameter values of the LC filter

Parameters of LC filter	The value of the parameters
C	82.99 μF
L	11.19 mH

The LC filter used to eliminate harmonics in renewable energy sources is a second order filter. There are some problems with the LC filter. One of them is that since the capacitor is connected in parallel with the coil, high frequency harmonics cannot be eliminated, even if the filter shows low impedance at high frequencies.

Converters used in solar systems, even at low power, distort current and voltage waveforms that are sinusoidal. As a result, harmonic components occur in the off-grid network. There are generally single and double harmonic components in the solar system. It has been obsessed that odd harmonic components are more effective than even harmonic components. After using LC filter, solar inverter output current THD decreased to 2.62%. It has been observed that the LC filter used to eliminate harmonic components provides high performance despite some risky situations.

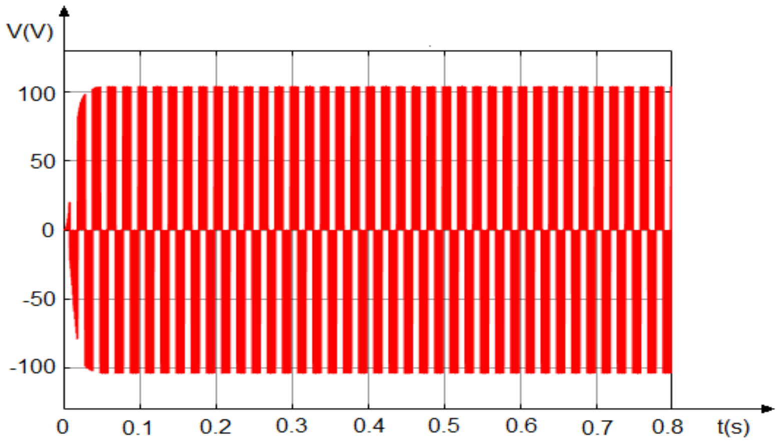


Figure 11. Inverter output voltage waveform

Passive LC and L filters are generally used to eliminate harmonic components in solar power systems. The cost of these filters is lower than the active filter. In addition, they are easy to use. Dominant harmonic components are detected in the solar power system and the passive LC and L filters are adjusted to eliminate them. In addition, the compensation process of the power system is carried out. Power quality is also improved by eliminating harmonic components in the solar system.

In this system, LC and L filters are used to eliminate low order harmonics, and improves off-grid PV power system efficiency. LC and L filters have many advantages. These advantages can be listed as follows:

- simple structures,
- Its low cost,
- To be highly efficient,
- Improvement of the power coefficient of the solar system.

In this study, models and analyses of passive LC and L filters were performed with Matlab/Simulink software program. The schematic diagram of the stand-alone PV power system after filtering with L filter is shown in Figure 12.

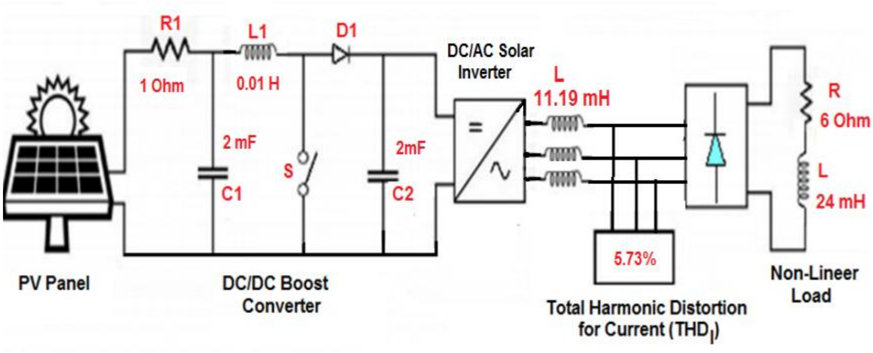


Figure 12. Off-grid PV system model with L filter

Non-linear elements cause serious harmonic pollution in stand-alone PV systems and reduce the quality of energy supplied to consumers. In this study, the elimination of harmonic components in the solar system and the improvement of the energy quality transferred to the load have been achieved. Considering the large number of non-linear loads connected to the power systems, it is inevitable that the THD_I value will increase. LC filter evaluation has been analyzed using Matlab/Simulink Power System ToolBox simulation environment, as shown in Figure 13. An LC passive filter is often used to interconnect an inverter to the load in order to filter the harmonic components produced by the PWM inverter. Although there is an extensive amount of literature available describing LC passive filter, there has been a gap in providing a systematic design methodology. The schematic diagram of the stand-alone PV power system after filtering with LC filter is shown in Fig. 13.

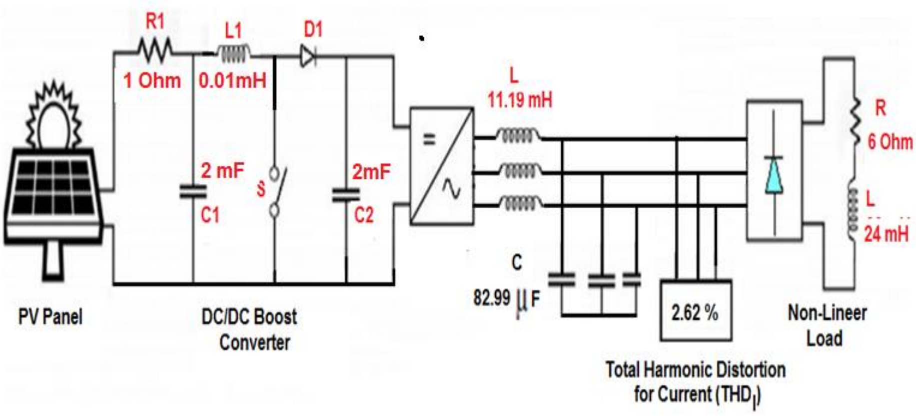


Figure 13. Off-grid PV system model with LC filter

After using LC filter in the solar system, the THD_I value was reduced from 91.57% to 2.67%. This value is below the limit value given by the standards. The results show that the harmonics distortion generated by solar inverter and non-linear load are reduced by using LC passive filter. In the off-grid solar grid, harmonic components cause increased losses, distortion in the sinusoidal waveform and a decrease in system efficiency. The most important harmonic source in solar systems are single-phase and three-phase converters. There are various precautions to reduce them. These precautions are as follows:

- Choosing a large cross-section of the neutral conductor,
- Preferring K factor transformers,
- Using passive LC or L filters,
- Using high-pulse converters.

As a result of connecting the LC passive filter between the inverter and the load in the off-grid network, the THDI value decreased below 5%. As the losses in the solar system decreased, the efficiency of the system increased. In addition, the minimum filter inductance is mathematically derived, which can reduce the size of the filter. The power loss in the LC filter can be decreased by using the minimum inductance. Furthermore, a stable current controller can be designed using the minimum damping resistance that is mathematically derived to obtain a lower power loss, less performance degradation in terms of the high frequency harmonic attenuation, and enough gain and phase margins of the current controller, which can guarantee the stable operation of the closed-loop system. The solar inverter output current waveform is shown in Fig. 14.

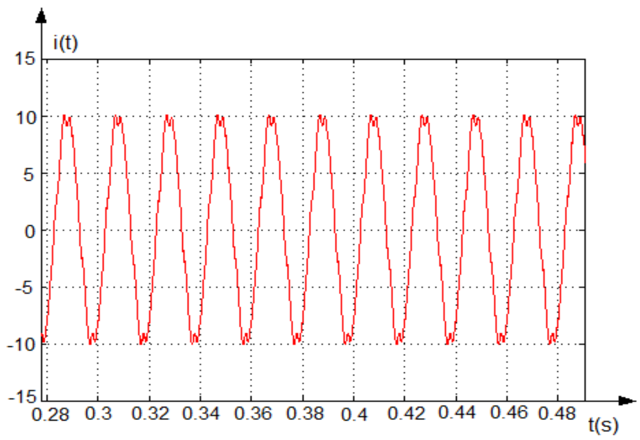


Figure 14. Inverter output current waveform

LC and L filters are used to reduce output current harmonics of output solar inverter, where THD_I% value exceed given in standards. LC filters have some disadvantages, such as current ripple on inductances, the total impedance of the filter, reactive power generated by the capacitor.

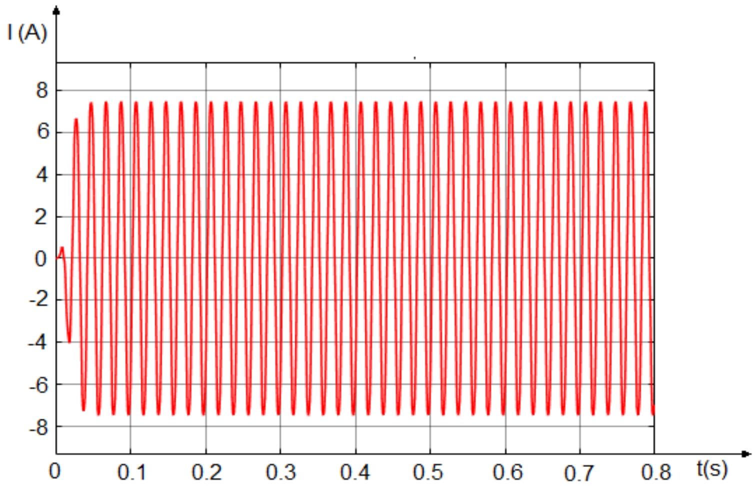


Figure 15. Load input current (with L filter)

LC and L filters application to mitigate harmonic component and improve the solar power quality of the off-grid PV system. The THD_I has been successfully decreased from 91.57 to 2.62% with LC filter and from 91.57 to 5.73% with L filter. In this study, LC and L filters design and performance analysis were performed. As a result, it has been observed that the LC and L filters provide a high performance.

Passive solar LC and L filters are placed between the solar inverter and the non-linear load. These filters are designed to eliminate harmonic components other than the fundamental component. However, these filters have risks such as creating series and parallel resonances. Therefore, the resonance conditions should be calculated separately for each harmonic components. Necessary measures can be taken against the resonance risk by using passive damping method. Since harmonic components affect all system elements in the solar system, they are pollution in the off-grid.

5. Results and Discussion

LC and L passive filters have many advantages in off-grid system, such as increasing the life of the stand -alone PV system devices, increasing the quality of energy transferred to the load and improving the power factor of solar system. LC and L filters also reduce many harmonics caused by six-pulse power uncontrolled converters and solar inverter. As a result, the THD_I value in the solar PV system falls below the limit values expressed by the standards.

LC and L passive filters are usually used to interconnect between solar inverter and non-linear load so as to filter the harmonics produced by solar inverter and non-linear load. As a result LC and L filters have been observed to suppress inverter side switching and non-linear load harmonic components. esign methodology for grid-interconnected inverter systems. The L and LC filters reduce the switching frequency ripple and helps in provides a low distortion current to the nonlinear load.

While the THD_I value was reduced with the LC filter from 91.57% to 2.62% in the solar system, the same value could only be reduced to 5.73% with the L filter. As a result, the performance of the LC filter is higher than the L filter in reducing the THD_I value.

References

[1] J. M. Carrasco, J.M., *et al.*, Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey, in *IEEE Transactions on Industrial Electronics*, 53(2006), pp. 1002-1016.

[2] Haydaroğlu, C., & Gümüş, B. (2017). Investigation of the effect of short term environmental contamination on energy production in photovoltaic panels: Dicle University solar power plant example. *Applied Solar Energy*, 53(20017), 1, pp. 31-34

[3] M. Liserre, T. Sauter and J. Y. Hung, "Future Energy Systems: Integrating Renewable Energy Sources into the Smart Power Grid Through Industrial Electronics," in *IEEE Industrial Electronics Magazine*, 4 (2010), pp. 18-37.

[4] Rüstemli, S., Okuducu, E., Efe, S. B., Elektrik Tesislerinde Harmoniklerin Pasif Filtre Kullanılarak Azaltılması ve Simülasyonu, *EVK2015*, *Enerji Verimliliği Kalitesi Sempozyumu*, 6(2015), pp.120-124, 4-6 Haziran, Sakarya.

[5] Ozdemir, A. Ferikoglu, A., Low cost mixed-signal microcontroller based power measurement technique, IEE Proceedings-Science Measurement And Technology, 151(2004), pp.253-258, ISSN : 1350-2344 - DOI : 10.1049/ip-smt:20040242, JUL Article, 2004 - WOS:000222969400004.

[6] Malla, S. G., Bhende, C.N., *Elsevier: International Journal of Electrical Power & Energy Systems*, 56 (2014), pp. 361-373.

[7] San-Sebastian, J., Etxeberria-Otadui, I. A., Rujas, Barrena, J. A. and Rodriguez, P. (2012). Optimized LCL filter design methodology applied to MV grid-connected multimegawatt VSC, *in Energy Conversion Congress and Exposition* (ECCE), IEEE, (2012) , pp. 2506-2512.

[8] TavakoliBina, M., and Pashajavid, E., An efficient procedure to design passive LCL filters for active power filters, *Electric Power Systems Research*, 79(2009), 4, pp. 606–614

[9] Muhlethaler, J., Schweizer, M. Blattmann, R. J., Kolar, W. and Ecklebe, A. (2013). Optimal design of LCL harmonic filters for three-phase PFC rectifiers, Power Electronics, *IEEE Transactions* on, 28(2013), 7, pp. 3114-3125.

[10] Sekkeli, M., Tarkan N., Development of a novel method for optimal use of a newly designed reactive power control relay. *International Journal of Electrical Power and Energy Systems*, 44 (2013), pp.736-742.

[11] Arifoğlu, U., *Matlab9.1-Simulink ve Mühendislik Uygulamaları*, Alfa Yayıncılık, 964p. İstanbul-Turkey, 2016.

[12] Liserre, M., Blaabjerg, and Hansen, S. Design and Control of an LCL-Filter-Based Three-Phase Active Rectifier, *IEEE Transactions on Industry Applications*, 41(2005), 5, pp. 1281-1291.

[13] 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*, (2015). ISSN 2147-3129.

[14] Yilmaz, A. S., Alkan, A, and H. Asyali, M., Applications of parametric spectral estimation methods on detection of power system harmonics, *Electric Power Systems Research*, 78, Issue 4, , (2008), pp. 683-693

[15] Jayaraman, M., Sreedevi, V.T, and Balakrishnan, R., Analysis and Design of Passive Filters for Power Quality Improvement in Standalone PV Systems, *Nirma University International Conference on Engineering (NUICONE),(2013),* ***DOI:*** *10.1109/NUiCONE.2013.6780164*

[16] Adak, S., Harmonics Mitigation of Stand-Alone Photovoltaic System Using LC Passive Filter, *Journal of Electrical Engineering & Technology*, (2021), https://doi.org/10.1007/s42835-021-00777-7.

[17] Lee, Y.J , Cho, P.Y., Kim, S.H., Jung, H.J., Design Methodology of Passive Damped LCL Filter Using Current Controller for Grid-Connected Three-Phase Voltage-Source Inverters, *Journal of Power Electronics*, 18 (2018), pp. 1178-1189. https://doi.org/10.6113/JPE.2018.18.4.1178

[18] Motahhir, S., El Hammoumi, A., El Ghzizal, A., Photovoltaic system with quantitative comparative between an improved MPPT and existing INC and P&O methods under fast varying of solar irradiation. Energy Rep 5(2019), pp.341–350

[19] Mustafa Ergin Şahin, E.M., Halil İbrahim Okumuş, I.H., Güneş Pili Modülünün Matlab/Simulink ile Modellenmesi ve Simülasyonu Modeling and Simulation of Solar Cell Module in Matlab/Simulink, EMO Bilimsel Dergi, 382013),5, pp.17-25

[20] Tan, R.H.G., Tai, P.LJ., Mok, V.H., Solar irradiance estimation based on photovoltaic module short circuit current measurement. In: IEEE international conference on smart instrumentation, measurement and applications (ICSIMA), (2015). https://doi.org/10.1109/PVSC.2015.7355816

[21] Karabacak, M., Kiliç, F., Saraçoğlu, B., Boz, A.F., Ferikoğlu A., Şebeke Bağlantılı Eviriciler için LLCL Filtre Tasarımı; Detaylı Bir Performans Analizi, *Politeknik Dergisi,* 19(2016), 3, pp. 251-260

[22] Bhonsle, D.C., Kelkar, R.B., Harmonic pollution survey and simulation of passive flter using Matlab. *In: International conference on recent advancements in electrical, electronics and control engineering (ICONRAEeCE*), Sivakasi, (2011), pp 230–236

[23] Adak, S., · Cangi, H., ·Eid, B., Yilmaz, A.S., Developed analytical expression for current harmonic distortion of the PV system's inverter in relation to the solar irradiance and temperature, *Electrical Engineering*, 103 (2021), pp. 697–704, https://doi.org/10.1007/s00202-020-01110-7

[24] Shuhui, Li, S., Fu, X., Ramezani, M., Sun, Y., Hoyun Won A novel direct-current vector control technique for single-phase inverter with L, LC and LCL filters, *Electric Power Systems Rese*arch, 125 (2015), pp. 225-244.

[25] Reznik, A. Simes, M.G., Al-Durra, A., Muyeen, S.M., LCL Filter Design and Performance Analysis for Grid-Interconnected Systems, in *IEEE Transactions on Industry Applications*, 50(2014), pp. 1225-1232.

[26] Kasule, A., Ayan, K., .Forecasting Uganda's Net Electricity Consumption Using a Hybrid PSO-ABC Algorithm, *Arabian Journal For Science And Engineering*, 44 (2019), pp. 3021-3031.

[27] E. İzgi, E., A. Öztopal, A B. Yerli, B M.K. Kaymak, M.K A.D. Şahin, A.D., Short-mid-term solar power prediction by using artificial neural networks, *Solar Energy*, 86 (2012), pp.725-733.

[28] Dursun, M., and M. K. DÖŞOĞLU, M.K., LCL Filter Design for Grid Connected Three-Phase Inverter, *2018 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 2018, pp. 1-4.

[29] Fidan, İ., Dursun, M., Fidan, Ş., Üç Fazlı Eviriciler İçin LCL Filtre Tasarımı ve Deneysel Analizi Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 7 (2019), pp. 1727-1743 *https://doi.org/10.29130/dubited.552951*

[30] Dursun, M. & Döşoğlu, M. (2018). Üç Fazlı Gerilim Kaynaklı Evirici için SDGM, ÜHDGM ve HDGM Tekniklerinin MATLAB/SİMULİNK ile Karşılaştırmalı Analizi . Düzce Üniversitesi Bilim ve Teknoloji Dergisi , 6 (4) , 983-999 . DOI: 10.29130/dubited.437845

IJESG International Journal of Energy and Smart Grid Vol 6, Number 1-2, 2021
e-ISSN 2636-7904

Research Article

ENERGY GENERATION PROSPECTS FROM SOLID WASTE OF KANO METROPOLIS MARKETS

***Abudharr Bello WAZIRI*[*1], *Siraj ALHASSAN*[2], *Jamilu Ya'u MUHAMMAD*[3], *Mohammed Abdullahi GELE*[4], *Munir USMAN*[5] *Audu Taofeek OLANIYI*[2]**

[1]Department of Mechanical and Production Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria
[2]Department of Mechanical Engineering, Bayero University, Kano, Nigeria
[3]Department of Mechanical Engineering, Nigerian Army University, Biu, Nigeria
[4]Sokoto Energy Research Centre, Services Unit, Sokoto, Nigeria
[5]Department of Welding and Fabrication, Jigawa State Polytechnic, Dutse
[*]*Corresponding Author: yjamilu87@gmail.com*

Abstract *The health and wellbeing of every community is intricately linked to its economic growth and standard of living. Poor solid waste management has an impact on the health and consequently economy of communities. Kano Metropolis markets have vital role to play on economic growth to Nigeria and some part of West African countries at large, on the other hand they contributes on the environmental challenges. This research work assess to way of mitigating this challenges by recycling the waste generated by these markets to convert the wastes into useful such as generating of electricity. The result of the work revealed that the food and vegetable wastes were found to larger percentage from the solid wastes followed by plastics wastes. Whereas, textile materials, paper glass/ceramics, wood, electronic and metals wastes were 21%, 15%, 12%, 12%, 8% and 32% were found as the remaining solid wastes respectively and the average power generation potential in June is higher than that of July by 1014.98 kWh/day due to the higher calorific values during the period.*

Keywords: *Dumpsites; Electricity; Landfills; Incineration; Solid Waste*

Received:8.10.2021 *Accepted:30.12.2021*

1. Introduction

Nowaday, population rate is always increasing from one city to another; therefore the quantity of waste generated every day is also increasing. Recently, researches proved that municipal solid waste generated from that cities annually is more than one billion tones which implies the cost of $205.4 billion per annum [1]. And by 2025, the quantity of solid waste is predicted to be more than two billion tonnes per year [2]; this causes solemn challenges environmentally [3].

Due to these challenges, an extensive waste management has become a more important globally. Zero solid waste management has been adopted as one of the policy in many cities of developed countries [4], [5]. They used landfills and incineration to generate heat and electricity to recycle their solid waste disposed.

Over 10 million tonnes of combustible solid waste are generated annually in Nigeria [6]. But the waste to energy (WTE) technology is not utilizing in Nigeria, hence the solid wastes disposed in a dumpsites are causing negative impact to the environment and health. Solid wastes can be used to generate electricity that will trap the problem of power electricity and help the environment to be clean. And with this electricity generation, the economy of the country would be enhanced which is one of the goals of Nigeria's Renewable Energy Master Plan (REMP), that is to achieve 400M in 2025 through biomass-based power plants [7].

Recently, it was proved that the average solid waste densities of some cities in Nigeria were 325 kg/m^3 [8], and average daily rates of 0.55 kg/capital/day, which give annual revenue generation of 25 million tons [9]. Moreover, rural-urban migration is always increasing which cause the high rate of solid wastes disposal in Nigerian cities, this makes the cities to necessitate implementing the waste to energy technology [10].

This work will focus on the potential of WTE technology potential to overcome the solid waste problem in some Kano metropolis markets. In many cities, waste-to-energy technology has been proves to be environmentally and economically beneficial to the cities as a means of recycling the solid waste disposed. Kano metropolis markets were selected because of their limited availability of space for waste disposal and lack of electricity in Kano metropolis.

2. Materials and Method

2.1. Data Collection

In this study, ten (10) markets from Kano Metropolis were randomly selected namely; Kanti Kwari textile market, Kofar Wambai plastic market, Sabon gari market, Singa market, Kurmi market, Rimi market, 'Yan Lemo fruit market, 'Yan Kaba vegetables market, Tarauni vegetables market and Farm centre computer and phone market. The waste management of each market was interviewed and gets permission to gather the solid waste from the dumpsite the markets.

Each selected market was visited bi-weekly for two months (June and July, 2021) in order to get the mass and volume of solid waste disposed in the selected markets daily. In each market, the researchers visited the waste management of the markets and get cordial understanding with them and explain the aim of the research with regard to the benefits of the market. For each market, the solid waste collected was poured inside the polyethylene containers and marked what contained with the marker.

2.2. Determination of Quantity of Waste Components

As mentioned above the solid wastes were categorized into ten namely: plastic, glass/ceramic, textiles, wood, metal, food, vegetables, paper, electronic waste, and others which represent any solid wastes other than one of the above mentioned. The weight of each category was measured using portable electronic weighing scales.

2.3. Characterization of Municipal Solid Waste

2.3.1 Bulk Density of the Solid Waste

A polyethylene container of the solid waste was used and its mass was determined as M_1 when empty. Waste collected from Dumpsite of the markets was poured into the container until it filled the container completely. The mass of the container together with the solid wastes were weighed and marked it as M_2.

The bulk density is given by the following equation [11]:

$$\rho_{bulk} = \frac{M2-M1}{V1} \tag{1}$$

Where: ρ_{bulk} is the bulk density in kg/m^3, M_2 is the mass of the container together with the solid wastes in kg and M_1 is the mass of empty container in kg.

The amount of waste disposal rate can be determined using the following equation [11]:

$$W_{disposed} = \rho_{bulk} V \tag{2}$$

$W_{disposed}$ is the mass disposed in kg, ρ_{bulk} is the average bulk density in kg/m^3 and V is the volume of the filled container in m^3.

2.3.2 Proximate analysis

This is used to obtain the moisture content, volatile matter, ash content as well as fixed carbon content.

i. Moisture content

The moisture content can be found by measuring the amount of mass lost from the solid after removal of water content from the waste by heating it and the equation below is used to get the moisture content [12]:

$$M = \frac{S-B}{S} \times 100 \tag{3}$$

Where; M is the moisture content, S and B are the mass of solid waste before and after heating respectively.

The solid waste sample was heated in an oven at 105oC for 2 hours and then cooled in a desiccators and reweighed.

ii. Volatile matter

Volatile matter is defined as the components of solid waste which deposited when heated at high temperature and it can be found using the following expression [12].

$$VM = \frac{A-B}{A} \times 100 \tag{4}$$

Where; VM is the volatile matter, A is the mass of the solid wastes after moisture content analysis, B is the mass after heating.

The remaining sample used for moisture determination was covered in a crucible and heated at 75^{o}C in a furnace for 2 hours. The crucible was later taken out of the furnace and cooled in a desiccators and reweighed.

iii. Ash content

After the solid wastes undergo combustion, there are some residues that are non-combustible. These non-combustible residues are called ash content and it is expressed in percent which is determined using the formula given below [12].

$$AC = \frac{A-B}{C} \times 100 \tag{5}$$

A is the mass of the non-combustible residue + mass of the container in kg, B is the mass of the container when empty and C is the initial mass of solid waste with moisture.

Fixed carbon content

Fixed carbon can be found by using the expression given below [13].

$$FC = 100 - M - VM - AC \tag{6}$$

Where; FC is the fixed carbon content, M is the moisture content, VM is the volatile matter and AC is the ash content.

2.3.3 Ultimate analysis

To get the percentage composition of Oxygen, the sum of the percentage composition of the elements (hydrogen, carbon, Nitrogen and Sulphur) and ash content was subtracted from 100. This analysis is called ultimate analysis.

$$O = 100 - (C + H + N + S + AC) \tag{7}$$

Where; O, C, H, N and S are the percentage of Oxygen, Carbon, Hydrogen, Nitrogen, Sulphur respectively, AC is the ash content.

Each element is determined through chemical analysis and expressed as a percentage of the total mass of the original waste sample.

2.3.4 Energy potential

The electrical energy potential is determined using the following equation [14]:

$$E_o = \frac{E_i \eta}{3600} \quad (8)$$

Where: E_o is the electrical energy output, E_i is the energy input and η is the conversion efficiency.

$$E_i = \dot{m} \times CV \quad (9)$$

Where; E_i is the energy input, $\dot{m}$ is the mass flow rate of MSW in kg/day and CV is the calorific value in kJ/kg.

The maximum gross efficiency for electricity production was given as 22% [19]. The energy potential was determined using equation 8 and 9

For the month of June,

Using equation (9);

$$E_i = \dot{m} \times CV$$

$$E_i = 59900 \times 18454.08 = 1105399392 \text{ kJ/day}$$

At η = 0.22 (minimum efficiency)

Using equation (8);

$$E_o = \frac{E_i \eta}{3600}$$

$$E_o = \frac{1105399392 \times 0.22}{3600} = 67552.19\ kWh/day$$

For the month of July,

Using equation (9);

$$E_i = \dot{m} \times CV$$

$$E_i = 59000 \times 18454.08 = 1088790720 \text{ kJ/day}$$

At η = 0.22 (minimum efficiency)

Using equation (8);

$$E_o = \frac{E_i \eta}{3600}$$

$$E_o = \frac{1088790720 \times 0.22}{3600} = 66537.21\ kWh/day$$

3. Results and Discussion

3.1. Results

The results obtained for Kano Metropolis Market solid waste in June and July are presented in Figure 1-4.

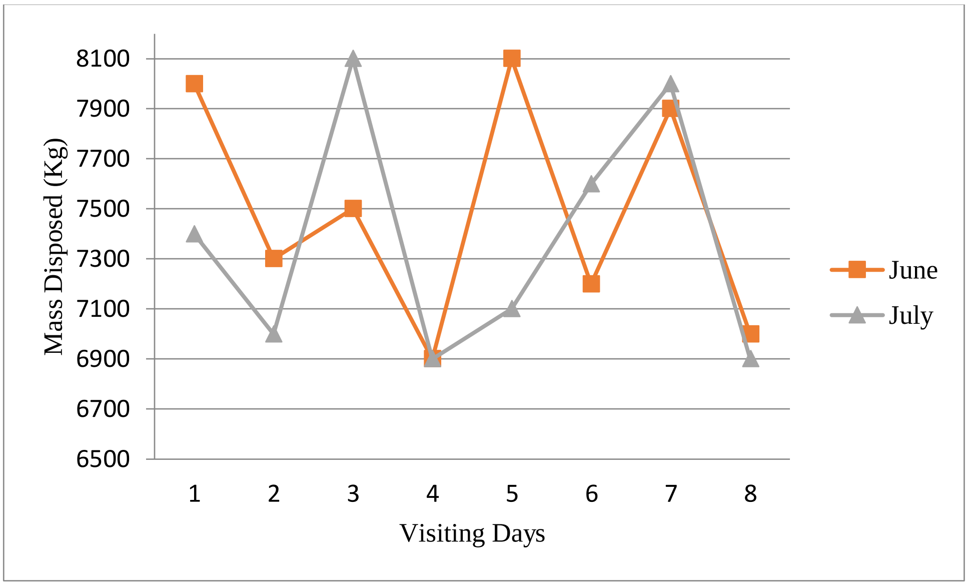


Figure 1. Daily disposal of combustible waste

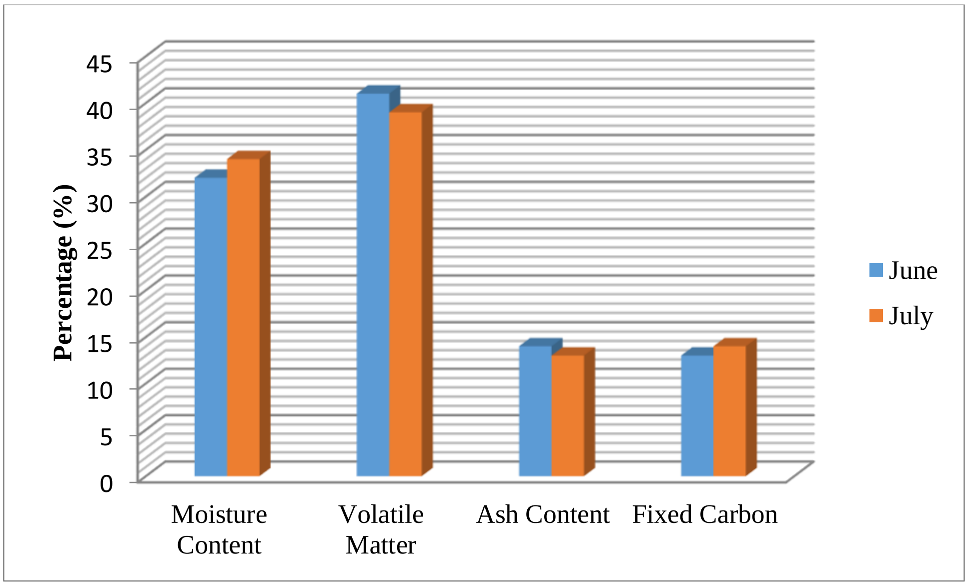


Figure 2. Proximate Analysis of Kano Metropolis Markets Solid Waste

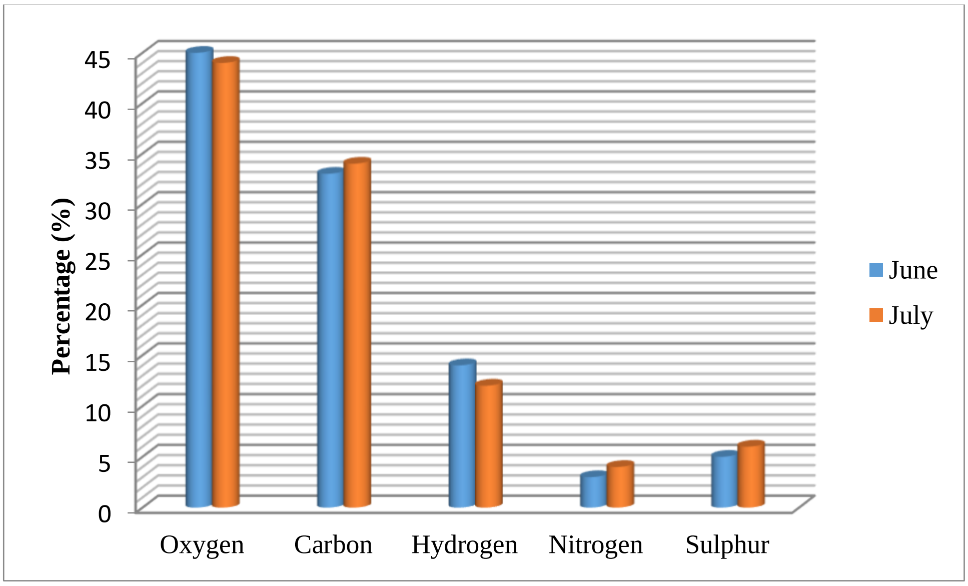


Figure 3. Ultimate Analysis of Kano Metropolis Markets Solid Waste

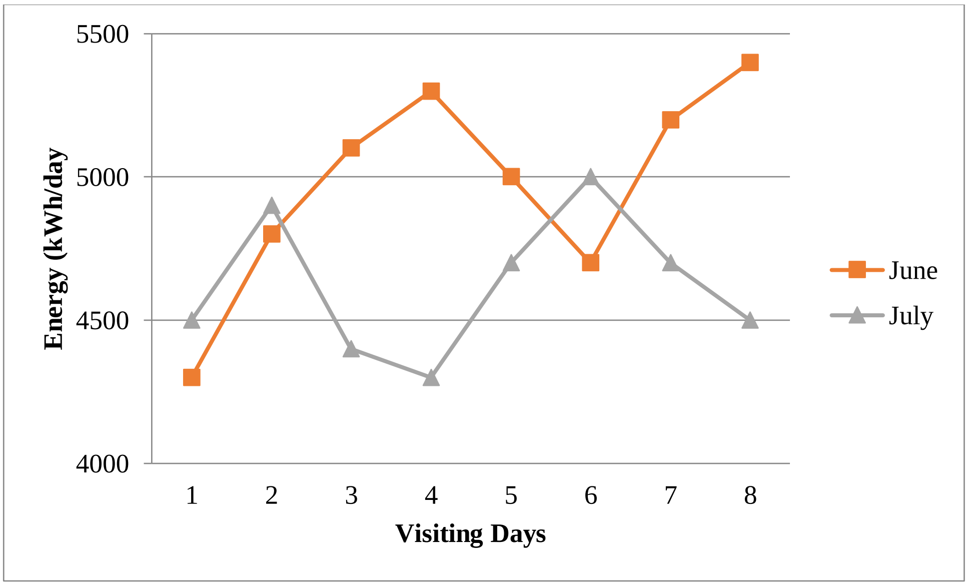


Figure 4. Energy output with recycling

3.2. Discussion of Results

The Analysis of solid waste composition indicates that 58% of the solid waste was from food and vegetable wastes. This is almost equal to the values of the result of a similar study done by Nabegu [15]. Plastic materials are much as 42% of the solid waste being generated in Kano metropolis markets. Textile, paper, glass/ceramics, wood, electronic and metals wastes were 21%, 15%, 12%, 12%, 8% and 32% were found as the remaining solid wastes respectively. This result concurred with the studies conducted at some states in Northern parts of Nigeria [16-18]. Recycling of these solid wastes was essential method since the electronic wastes were negligible quantitatively small but it has negative impact environmentally.

Kofar wambai, Sabon gari, Farm centre, ‘Yan Lemo and ‘Yan Kaba markets have more plastics, paper, electronics, fruit and food waste respectively. On the other hand the high percentage of textile wastes in Kantin Kwari. In June, 59900 kg/day of waste were disposed in the selected markets while 59000 kg/day were disposed in July. It can be seen from figure 1 that the waste disposed is in periodical form but the waste disposed in June is higher than that of July due to large congestion in the markets in May since it's the month that edil-fitr occurred.

The moisture content gradually increases from about 32% in June to about 34% in July. While the volatile matter decreases from 41% to 39% in June and July respectively and there is a slight increase and decrease in the ash content and the fixed carbon content from June to July as shown in Figure 2. Moisture content was higher in July, this is because the fully rainy season and high humidity. Whereas, the ash content was relatively low due to low inert materials in the waste.

Figure 3 shows the ultimate analysis of the solid waste and it was found that high amount of Carbon and Oxygen, however the Nitrogen and Sulphur content were relatively small. There is an increase in Hydrogen content from June to July.

From figure 4, the energy output was lower in July compared to that of June due to the lower calorific values during the period, it is also imperative to note that the kWh/ton was higher due to the higher calorific values of Kano metropolis markets solid waste. This result is in agreement with Diso [20] who found that 13MW of electricity could be produced from wastes in 1995 covering at least the entire Kano metropolitan area. All the waste samples considered have heat values greater than some well-known biomass-fuels and fall within the limit for the production of steam in electricity generation [21].

4. Conclusions

An assessment of solid wastes of Kano metropolis markets was conducted to obtain the suitability for energy production and the following are remarkable conclusions obtained:

i. The solid wastes of Kano metropolis markets disposal rate recorded were 59900 kg/day in June and that of July was 59000 kg/day.
ii. Food and vegetable wastes were found to larger percentage from the solid wastes followed by plastics wastes. Whereas, textile materials, paper glass/ceramics, wood, electronic and metals wastes were 21%, 15%, 12%, 12%, 8% and 32% were found as the remaining solid wastes respectively.
iii. The average power generation potential is 67552.17 kWh/day in June and that of July was 66537.21 kWh/day.

References

[1] Hoornweg, Daniel; Bhada-Tata, Perinaz. *What a Waste : A Global Review of Solid Waste Management. Urban development series; knowledge papers no. 15*. World Bank, Washington, DC. © World Bank. 2012. https://openknowledge.worldbank.org/handle/10986/17388

[2] Moya D., Aldás C., López G. and Kaparaju P. Municipal solid waste as a valuable renewable energy resource: A worldwide opportunity of energy recovery by using Waste-To-Energy Technologies. *Energy Procedia*. *134* (2017), pp.286-295.

[3] Brunner, P. H. and Rechberger, H. Waste to energy-key element for sustainable waste management. *Waste Management*. *37* (2015), pp. 3-12.

[4] Zaman, A. U. and Lehmann, S. The zero waste index: a performance measurement tool for waste management systems in a 'zero waste city.' *Journal of Clean Prod.*, 50(2013): 123–132.

[5] Zaman, A. U. Measuring waste management performance using the 'Zero Waste Index': the case of Adelaide, Australia. *Journal of Clean Prod.* 66(2014): 407–419.

[6] Uchendu, C. Municipal solid waste treatment and recycling technologies for developing countries: A typical Nigeria case study. *Journal of Solid Waste Treatment and Management*, 34(2008): 127-135.

[7] IEA (2011). Nigeria Renewable Energy Master Plan. Available at www.iea.org/policiesandmeasures/pams/nigeria/name-24808-en.php

[8] Ayuba, K. A., Abd-Manaf, L., Sabrina A. H. and Azmin, S. W. Current Status of Municipal Solid Waste Management Practise in FCT Abuja. *Research Journal of Environmental and Earth Sciences*, 5(2013) (6): 295-304.

[9] Ogwuleka, T. C. Municipal Solid Waste Characteristics and Management in Nigeria. *Iran Journal of Environmental Health, 6* (2009). (3): 173-180.

[10] Adejobi, O. S. and Olorunnimbe, R. O. Challenges of Waste Management and Climate Change in Nigeria: Lagos State Metropolis Experience. *African Journal of Sci. Res.*, 7(2012), (1): 346-362.

[11] Bichi, M.H. and Amotobi, D. A. Characterization of household solid wastes generated in Sabon-gari area of Kano in Northern Nigeria. *American Journal of Research Communication*, *1*(2009), 165–171.

[12] Nyoti Stephen, G. M., Owido, S., Nyaga, D., George, O. O., and John, M. M. Classification and Characterization of Solid Waste–Case Study of Egerton University and its Environs, Kenya. *International Research Journal of Engineering and Technology*, *11*(2016), 2395–56.

[13] Mboowa, D., Quereshi, S., Bhattacharjee, C., Tonny, K., and Dutta, S. Qualitative determination of energy potential and methane generation from Municipal Solid Waste (MSW) in Dhanbad (India). *Energy*. (2017). https://doi.org/10.1016/j.energy

[14] Daura, L. A. Electricity Generation Potential of Municipal Solid Waste in Kano Metropolis. *Journal of Scientific and Engineering Research*, *3*(2016), (4), 157–161.

[15] Nabegu, A. B. An analysis of municipal solid waste in Kano metropolis, Nigeria. *Journal of Human Ecology*, 31(2010), (2): 111-119.

[16] Daura, L. A., Enaburekhan, J. S., and Rufai, A. I. Characteristcs and Composition Analysis of municipal solid waste in Kano, Nigeria. *International Journal of Scientific and Engineering Research, 5*(2014), (9): 972–975.

[17] Lawal, A. M. and Garba, I. Study of the Energy Potential of Solid Waste in Bauchi Town. *International Journal of Computational Engineering Research*, 3(2013), (5): 1–7.

[18] Oumarou, M. B., Dauda, M., Abdulrahim, A. T., & Abubakar, A. B. Characterization and Generation of Municipal Solid Waste in North Central Nigeria. *International Journal of Modern Engineering Research*, *2*(2012), (5), 3669–3672.

[19] Baxter, D. and Baxter, D. Factors affecting energy efficiency of waste to energy plants. *Energy Materials Science and Engineering for Energy Systems*, 2(2013), (3): 166–174. DOI: 10.1179/174892408X373527

[20] Diso I. S. Waste Management Survey in Kano. The Energy Team Bayero University Kano. Report submitted to the Kano State Government. (1995).

[21] Jekayinfa, S. O. and Omisakin, O. S. The energy potentials off Some Agricultural Wastes as local Fuel materials in Nigeria, *Agricultural Engineering International: the CIGR Ejournal*. VII(2005), (05) 003.

IJESG International Journal of Energy and Smart Grid Vol 6, Number 1-2, 2021
e-ISSN 2636-7904

Research Article

MEASUREMENT AND EVALUATION OF POWER QUALITY PARAMETERS BATMAN PROVINCE APPLICATION

Naci OBUT [1*], Mehmet Rıda TÜR[2]

[*1] Dicle Electricity Distribution Inc. 72050 Batman, Turkey
[2]Batman University, Faculty of Engineering, Department of Electrical and Electronics Engineering, 72060 Batman,Turkey
[*] Corresponding author; E-mail: naci.obut @dedas.com.tr

Abstract *Energy quality is an important issue that concerns energy producers and consumers. In this regard, having power parameters at certain standards ensures that the energy quality is at a high level, and thus a high quality electrical energy is transmitted to the producer. Measuring power quality parameters is a major factor in preventing problems in electrical power plants and devices connected to electrical power plants. It is important to identify the problems, to reach the solution in a shorter way and to prevent the malfunctions that may occur in the systems. For the determination of technical quality in power plants; Measurement principles, technical quality parameters and limit values, technical quality measurements, evaluation of measurement results and the processes to be done ensure the preservation and continuity of technical quality. Power quality parameters (voltage effective value, voltage unbalance, voltage sag, voltage flicker, voltage harmonics) values must comply with TS EN 50160:2011 standards. As a result of the power parameters measurements made in the transformer center in Batman province, it was seen that some of the measurement values were not in the range of standard values. The power quality has been increased by performing the necessary maintenance and repair works related to these parameters*

Key words: *Power quality, Harmonics, Voltage flicker.*

Received: 06.12.2021 *Accepted:30.12.2021*

1. Introduction

With the development of technology, it is effective in changing the load characteristics of power systems. When we look at these load characteristics, power electronic devices, nonlinear loads, motor drivers etc. loads cause disruptive effects in power systems. Power quality can be explained as the electrical limitations required for a device to work efficiently for its intended use and to operate without any power loss. The presence of nonlinear loads connected to the distribution network causes the current and voltage to diverge from the ideal sinus signal. This situation is called power quality degradation [1-3].

Power quality parameters are directly related to the quality of the power plant, the transmission line and the quality of the electrical energy used by the consumer. The poor quality of power experienced in electrical facilities causes malfunctions and even breakdowns of devices, leading to serious problems in many industrial facilities. The occurrence of harmonics, voltage drops and voltage flickers due to the connection of loads to electrical installations presents power quality problems. In the Regulation on the Supply Continuity and Technical Quality of Electrical Energy published in 2006 (Directions, 2006), Distribution Facilities address the electrical energy needs of consumers; It is defined as the capacity to meet the frequency, amplitude, waveform and three-phase symmetry of the voltage in an uninterrupted and high quality manner within certain standards. In our country, the standard values of power quality parameters EN 50160 and IEC 61000430 (Regulation, 1999; 2003) European Standards apply [4, 5].

One of the purposes of the Electricity Network Regulation published by EMRA is to define the responsibilities of users connected to and affecting power systems and the criteria they must comply with. These criteria are system frequency and variation, system voltages and variation limits, transmission system voltage waveform quality, voltage spikes, voltage oscillations and flickers, phase unbalance, current harmonics [6,7].

Energy quality in power systems is the prevention of negativities in the network and sinusoidal wave disturbances in the current drawn from the network.

The term "power quality" refers to the reliability of the generated electrical energy and the ideal characteristics of the voltage and current magnitudes measured in electrical transmission and distribution networks. This term also includes any undesirable deviations and adverse effects on the customer and connected equipment as a result of malfunctions that may arise. Another problem of power quality is prolonged voltage interruptions. Total interruption or reduction in current, which is about a few milliseconds, directly causes an error in the data processing process. Also, another common problem with systems is their distortion, which is described as distortion. This problem is defined as high frequency signals that conflict with the main waveform of the power system and cause data loss in the system [8]. Another problem defined as flicker is the voltage fluctuations between 90-110% of the nominal value from the power supply and usually damages the load side of the system [9]. Interruptions in power systems are, in any case, long-running and zero-voltage situations. This is because in an electrical system, the circuit is de-energized and the power distribution is interrupted or the mains electricity is interrupted. It is inevitable that an outage situation will directly lead to data loss, quality degradation and damage to the equipment used in the system [10]. These interruptions are generally divided into two groups; short interruptions and long interruptions. Short interruptions occur if the energy source fails for a few milliseconds to a second or two. This is usually due to situations such as opening protection devices and disabling a faulty part of the network. However, large interruptions cause more serious errors, which are; insulation failure, lightning and insulator deterioration [11, 12]. On the other hand, if the power supply lasts longer than 1 to 2 seconds, the equipment in the system can be completely stopped if interruption occurs due to power system network hardware disruption, storms and/or other environmental factors [13].

2. Power Quality Measurements and Evaluation

In order to detect power quality problems, measurements are taken at regular intervals. After the measurements, the problem type is determined and the problems in the system are eliminated. Faults that may occur in the system are listed below. At the same time, in this section, the results of power quality measurements made in Batman Transformer Centers and the evaluation of the results will be made [14].

- Voltage Effective Value
- Voltage Imbalance
- Voltage Slump
- Voltage Flicker (Fliker)
- Voltage Harmonics – Total Harmonic Distortion

2.1. Voltage Effective Value

Overvoltages occur in power plants due to atmospheric and switching events. With the surge arrester or fixed capacitors connected at the supply point, overvoltages at certain levels can be damped and protect the network from overvoltages. Voltage drops can occur as well as overvoltages in the network.

Voltage drops may occur in power systems due to short-circuit events occurring at a remote point of the network. Short-term voltage drops damage the electrical devices, and it can take a long time to restart the devices (for example, PLCs used in industrial facilities are disabled when the voltage drops to 80-85% of the nominal value). By connecting appropriate surge arresters to overhead lines, the possibility of short-circuit faults is reduced. By doing these processes, the quality of power systems is increased [15].

The voltage level measured in power systems should be between +-10% of the declared nominal voltage value.

2.2. Voltage Unbalance

The absence of a 120 degree phase difference between the voltage phase angles, and the 3-phase voltage difference being more than 7V creates voltage imbalance and this problem is one of the power quality problems. Single-phase loads connected to power systems are the main cause of voltage imbalance. At the same time, problems such as not performing the necessary transposition processes due to the long overhead lines, and the voltage regulators not working properly are other causes of voltage imbalance. If the single-phase loads are distributed towards the phases and transposed operations are performed, the possibility of voltage unbalance is reduced [16].

2.3. Voltage Slump

Voltage sag is the short-term decrease of the effective value of the mains voltage (0.1 pu – 0.9 pu) at the rated frequency. It occurs due to the activation of high-powered motors in networks with low short-circuit power or as a result of late detection of short-circuit faults in the network by the switching elements. Due to voltage collapse, electrical devices may malfunction and if this situation becomes more frequent, it may cause the device to malfunction. Figure 1 shows the decrease in the sinus signal, which is the voltage sag event [17].

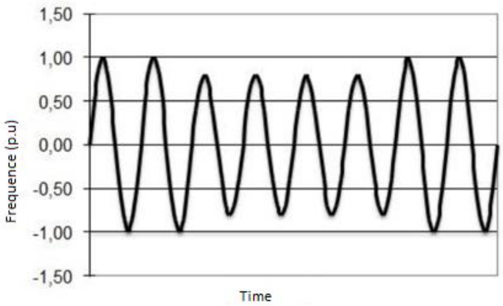


Figure 1. Voltage sag (Voltage Right)

2.4. Voltage Flicker (Fliker)

Flicker event is a sudden increase and decrease of loads in the network depending on time. This effect is mostly due to non-linear variable loads (eg arc furnaces). The luminous intensity or spectral distribution is manifested by the irregularity in visual perception caused by a light stimulus that fluctuates over time. There are two types of flicker as long-term flicker and short-term flicker [18].

- Short-term flicker (Pst): It expresses the flicker severity index measured in 10-minute periods.

- Long-term Flicker (Plt): It refers to the flicker severity index calculated according to the formula below from the Pst values measured during the two-hour time interval (12 consecutive measurements).

Table 1. Limit values for flicker severity.

Voltage Level	Flicker Intensity	
	Pst	**Plt**
V > 154 Kv	0,85	0,63
34,5 Kv < V < 154 kV	0,97	0,72
1 kV < V < 34,5 kV	**1,15**	**0,85**
V < 1 kV	1,15	0,85

2.5. Voltage Harmonics – Total Harmonic Distortion

When a zero source impedance voltage is applied to a non-linear load, the waveform of the resulting current will be different from the waveform of the voltage. This distorted current; located on its path only, such as transformers, conductors, and circuit breakers.

affect the elements. But zero source impedance is an ideal situation. In fact, the distorted current produces a voltage drop across the source impedance, which causes a distorted voltage to be applied to all loads after the source impedance.

It is possible to collect the effects of current and voltage harmonics in the power system under four main groups;

- Harmonic levels increase due to parallel and series resonance.
- Reduced efficiency in electricity generation, transmission and consumption.
- Reduction of the life of the plant elements as it weakens the insulation in electrical installations.
- Failures in facilities.

The sub-items of these groups are mainly problems such as:

- Formation of additional losses and increase in voltage drop
- Distortion of generator and network voltage waveform
- Damage of capacitors by exposure to excessive current
- Overheating and noisy operation in asynchronous and synchronous machines
- Faulty operation of measurement, protection and control systems
- Exposure of power system elements to overcurrent or overvoltage due to resonance events [19].

Harmonic currents and voltages are formed as a result of the distortion of the current-voltage sinusoidal wave, which is distorted due to non-linear loads (arc furnaces, regulators, switch-mode power supplies and devices such as inverters) or non-ideal generators connected to the system. With the formation of harmonics, transformer and neutral conductors heat up due to harmonic currents. Therefore, in order to avoid overheating, the neutral conductor cross-section and transformer power should be chosen in such a way that they are not affected by these harmonic currents. At the same time, it is necessary to use appropriate filters in order to absorb the harmonics created by the devices in industrial facilities that consume large power. Table 1.2 shows the acceptable harmonic voltage levels in the transmission system between 20 and 154 kV according to the Electricity Market Grid Code.

The intensity of distortion caused by current and voltage waves is expressed as 'Total Harmonic Distortion'.

- Total Harmonic Distortion expresses waveform distortion as a percentage, which is the ratio of the square root of the sum of the squares of the effective values of the voltage harmonic components to the effective value of the main component. Formula Equivalent (1) is given below

$$THB_V = \frac{\sqrt{\sum_{h=2}^{40}(U_h)^2}}{U_1} \times 100 \quad (1)$$

Table 2 Acceptable harmonic voltage levels in the transmission system between 20 and 154 kV according to the Electricity Market Grid Code.

Single Harmonics (Not Solid of 3)		**Single Harmonics (Solid Of 3)**		**Even Harmonics**	
Harmonic No "h"	Harmonic Voltage (%)	Harmonic No "h"	Harmonic Voltage (%)	Harmonic No "h"	Harmonic Voltage (%)
5	1,50	3	1,5	2	1
7	1,50	9	0,75	4	0,8
11	1,00	15	0,3	6	0,5
13	1,00	21	0,2	8	0,4
17	0,75	>21	0,2	10	0,4
19	0,75			12	0,2
23	0,50			>12	0,2
25	0,50				
>25	0,2+0,3(25/h)				
Total Harmonic DistortionLevel %3					

3. Measurement and Evaluation of Power Parameters at Batman Transformer Centers

The change in the resistance of the conductor as a result of the fact that the current passing through a conductor is not distributed homogeneously on the surface of the conductor due to the frequency, and the tendency of the current to pass through the parts close to the outer surface of the conductor as the frequency increases, is defined as the "skin effect". As the level of harmonic components increases, the frequency value increases at the same rate. As the frequency increases, the current tends to flow from areas close to the outer surface of the conductor. The resistance of the conductor in alternating current is greater than its resistance in direct current increases with harmonics.

The basic component ohmic resistance value (R1) in the sinusoidal current of the conductor is added to the (RH) resistance that occurs due to harmonics in case of nonsinusoidal current flow. Thus, the ohmic resistance value shown to the harmonic current becomes R = R1+RH. While most of the analyzes ignore the additional resistance (RH) from harmonic components, its effect is also included in academic and more detailed analyses. The increase in conductor resistance due to the skin effect is calculated by various empirical formulas based on experimental studies and practical applications. One of them is the following equation 2.

$$x = 1{,}585.10^{-4}ç\sqrt{\frac{f}{R_0}} \quad (2)$$

Table 3 shows the power parameters measurements made in 10 transformer centers in Batman province for a week and whether the transformer systems qualities are suitable according to TS EN

50160:2011 standards as a result of these measurements. Among the standard values given in the measurement results, the transformer center quality has successfully passed the tests in the measurements made. If the measurements are not within the given standard value ranges, they are considered unsuccessful in the tests [20].

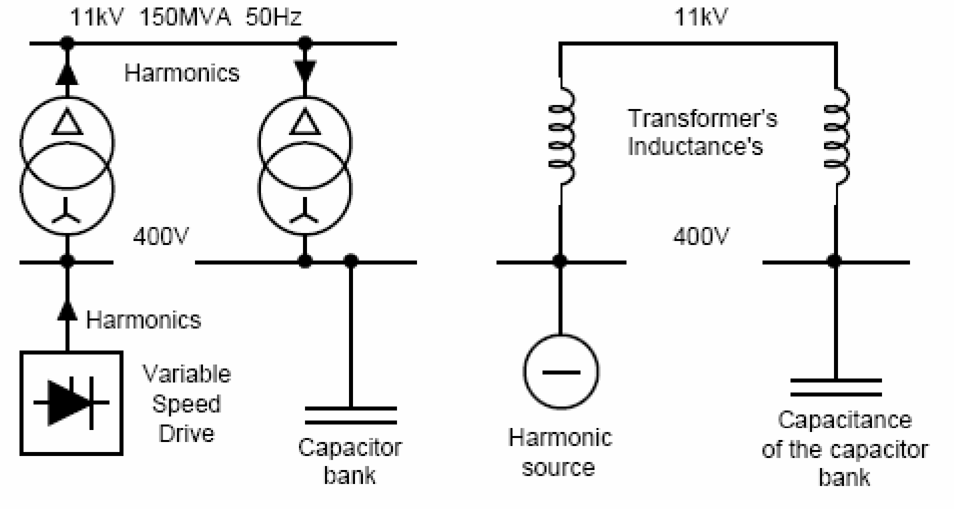


Figure 2 The formation of series resonance in the energy system due to harmonics and its equivalent circuit

Harmonic currents have two important effects on electrical circuits. Since harmonic currents increase the effective value of the total current, power losses will occur in the transmission medium. In addition to power transmission lines, machines and transformers also get hot due to harmonic currents. In addition, while the depreciation windings of the generators act to reduce and eliminate the harmonics that occur in one-phase or two-phase short circuits, they also get very hot and cause additional losses in the generators.

Another effect of harmonic current is to create harmonic voltage drops on circuit impedances. In other words, high impedance systems cause greater voltage disturbance effects than low impedance systems. Since the frequencies of the harmonic currents are equal to multiples of the normal network frequency of 50 Hz, the voltage drops that occur on the generator, transformer and line reactances against these currents increase in proportion to the harmonic frequencies, and as a result, the waveform of the voltage is distorted [21-24].

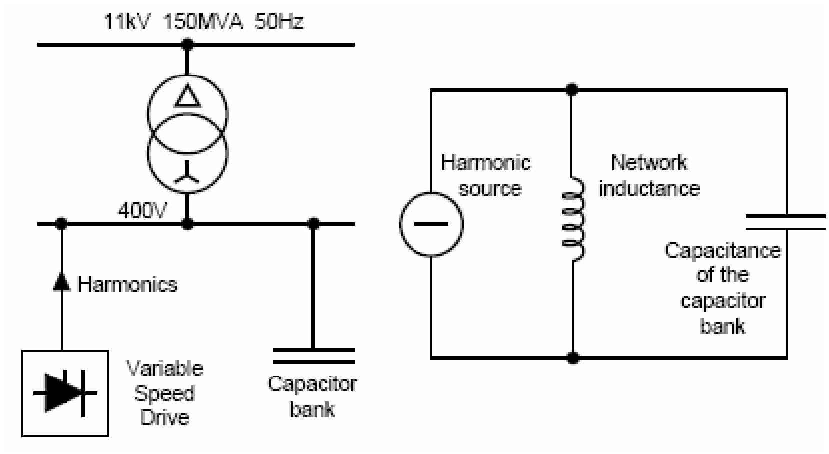


Figure 3. Parallel resonance formation and equivalent circuit in electrical installations

Table 3. 1-week measurements and evaluation results at Batman Transformer Centers

Transformer Center	Hour-Date	Voltage Change	Voltage Imbalance	Total Harmonic Distortion	Harmonic Voltage	Long Time Flicker	Voltage Slump
Batman DM13	16.10.2021	Passed	Passed	Passed	Passed	Not Passed	25
Batman DM22	16.10.2021	Passed	Passed	Passed	Passed	Not Passed	15
Batman DM3	16.10.2021	Passed	Passed	Passed	Passed	Not Passed	18
Batman DM42	16.10.2021	Passed	Passed	Passed	Passed	Not Passed	21
Batman DM53	16.10.2021	Passed	Passed	Passed	Passed	Passed	0
Beşiri DM8	16.10.2021	Passed	Passed	Passed	Passed	Not Passed	32
Hasankeyf DM6	16.10.2021	Passed	Passed	Passed	Passed	Not Passed	24
Batman DM30	16.10.2021	Passed	Passed	Passed	Passed	Passed	8
Batman DM17	16.10.2021	Passed	Passed	Passed	Passed	Passed	14
Batman DM18	16.10.2021	Passed	Passed	Passed	Passed	Not Passed	17

- Transformer substations are among the standard values given in voltage variation, voltage imbalance and total harmonic values and have passed all tests successfully.
- Considering the voltage harmonics, it is seen that the BATMAN DM42 transformer substation measurement values are not suitable because of the nonlinear loads (six-pulse rectifiers and other converters). By using the necessary filtering circuits, the power quality problem can be eliminated by damping the harmonics.
- It has been observed that the measurements of 6 transformer centers in voltage flicker are above the standard values. It has been observed that the high power motors in the industrial facilities connected to these transformer centers are in the majority.

4. Conclusion

Power quality problems are increasing day by day and we encounter power losses. Measuring parameters related to power quality is important to eliminate the problem. Nonlinear loads connected to power systems, arc furnaces, high power motors used in industrial plants and control systems are the factors that cause power quality problems with the increase. By using appropriate filtering circuits, making compensation in the facilities where high power motors are used, and performing maintenance and repair works in the facilities increase the power quality. Thus, quality energy is provided to the consumer by keeping the power quality parameters in accordance with TS EN 50160:2011 standards.

When we examine the power quality parameters measurements made in Batman Transformer Centers, we obtain the following results.

- In the power quality measurements, it is seen that flicker values and voltage events in Batman Substations sometimes exceed the limit value allowed in the standards. It was observed that a large number of power quality events occurred in the measurements lasting 24 weeks, which started in April 2021. The loads that produce harmonics on power systems are increasing day by day. Therefore, it indicates that power quality problems will increase in the future. Considering this situation, necessary precautions should be taken.
- When the measurements made at Batman Distribution Substations are examined, it is seen that the long-term flicker intensities in the 3 substations do not exceed the standard value in the voltage measurements at the measurement points, while the remaining transformer centers exceed the standard value. When voltage harmonics were examined, it was determined that they did not exceed their standard values. At the same time, voltage imbalance was observed twice

in a substation. In order to eliminate the voltage imbalance, necessary maintenance work should be carried out at the substation.

References

[1] Reid, E. W., ' Power Quality Issues-Standards and Guidelines', *IEEE Trans on IA, Vol 32*(1996), No 1, May/June.

[2] Eklas H., Mehmet Rida T., Sanjeevikumar P., Selim A., Imtiaj K., Analysis and Mitigation of Power Quality Issues in Distributed Generation Systems Using Custom Power Devices, *IEEE Access*, Volume: 6, (2018)

[3] Roger C. Dugan, Mark F. McGranaghan, H. Wayne Beaty, Electrical Power System Quality, Mc Graw-Hill, (1996).

[4] Guides and Standards for Surge Protection, IEEE Standard C62.,

[5] Elektrik Şebeke Yönetmeliği, 6. Versiyon, Değişiklik tarihi: 26/11/2017. 28/5/2014 Tarihli ve 29013 sayılı mükerrer Resmi Gazete.

[6] Arrilaga, J. N. Watson, R. Chen, S. Power System Quality Assessment, *WILEY C. Sankaran, (2002), Power Quality*, CRC Pres (2001)

[7] Tur, M.R. and Bayindir, R., A Review of Active Power and Frequency Control in Smart Grid, *2019 1st Global Power, Energy and Communication Conference (IEEE GPECOM2019)*, June 12-15, 2019, Cappadocia, Turkey

[8] C. Kocatepe, N. Umurkan, F. Atar, R. Yumurtacı, M. Uzunoğlu, A. Karakaş, O. Arıkan, M. Baysal, Enerji Kalitesi ve Harmonikler, *EMO Yayın* No. EG/2006/1, (Ocak 2006),

[9] M.R. Tur, S. Ay, A. Shobole, M. Wadi, Güç Sistemlerinde ünite tahsisi için döner rezerv gereksinimi optimal değerinin kayıp parametrelerin dikkate alınarak hesaplanması, *Journal of the Faculty of Engineering & Architecture of Gazi University* . Vol. (2018) Issue 18, Part 2, p1-20. 20p.

[10] Muğdeşem Tanrıöven- Yrd.Doç.Dr. (Yıldız Teknik Üniversitesi), Rıza İnce- Elektrik Tesisleri Anabilimdalı Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü, İstanbul

[11] C. Kocatepe, M. Uzunoğlu, R. Yumurtacı, A. Karakaş, O. Arıkan, Elektrik Tesislerinde Harmonikler, *Birsen Yayınevi*, (Kasım 2003)

[12] M.R. Tür, Solution Methods and Recommendations for Power Quality Analysis in Power Systems, *Journal of Engineering and Technology* 2;2 (2018) 1-9

[13] Ferracci, P., Teknik Kılavuz No. 199, Güç Kalitesi, *Schneider Electric*

[14] HB Teknik Proje ve Dan.Ltd.Şti., Elektrik Güç Sisteminin Kalitesini Bozan Faktörlerin İncelenmesi .www.etmd.org.tr-Teknik Yazılar.

[15] Tur, M.R., Wadi, M., Shobole, A. and Ay S., Load Frequency Control of Two Area Interconnected Power System Using Fuzzy Logic Control and PID Controller, *IEEE ICRERA* 14-17 Oct. 2018, France

[16] Collombet, C. Lupin, J.M. Schonek, J. Teknik Kılavuz No. 152, Şebekelerde Harmonik Bozulmalar ve İyileştirilmesi, *Schneider Electric*

[17] IEEE Recomended Practices and Requirements for Harmonic Control in Electrical Power Systems, ANSI/IEEE Standard 519, 1992.

[18] Massey, G. W., Estimation Methods for Power System Harmonic on Power Distribution Transformer, *IEEE Trans on IA*, Vol 30 No 2, Marc/April 1994.

[19] CENELEC, EN50160 EN50160 *Voltage characteristics of electricity supplied by public distribution networks*, 2007.

[20] Apay F. T., Güç Kalitesi Parametrelerinin Ölçülmesi Ve Değerlendirilmesi, *F.B.E. Elektrik Mühendisliği Anabilim Dalı Elektrik Tesisleri*, İSTANBUL, 2008

[21] G. Ye, Power quality in distribution networks: estimation and measurement of harmonic distortion and voltage dips, *Ph.D. dissertation, Dept. Elect. Eng., Tech. Univ. Eindhoven*, Eindhoven,

[22] Tür, R, Yenilenebilir Enerji Kaynaklarına Dayalı Bir Sistemde Güç Kalitesinin İncelenmesi, *Gazi Üniversitesi Fen Bilimleri Dergisi Part C: Tasarim Ve Teknoloji 8* (2020),(3), 572-587,

[23] E. F. Fuchs, M. A. S. Masoum, Power Quality in Power Systems and Electrical Machines, *Elsevier Academic Press*, 2008.

[24] M. R Tür, F. Yaprdakdal, Yenilenebilir Enerji Kaynaklarına Dayalı Bir Sistemde Güç Kalitesi Analizi, Kontrolü ve İzlemesi, *Gazi Üniversitesi Fen Bilimleri Dergisi Part C: Tasarım ve Teknoloji, 8* (2020), Sayı 3, 572-587.