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Harmonic Distortion and Filter Design for a 50 MW PV System Connected to a 66 kV

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Abstract

In this study, a 50 MW PV system was designed and integrated with the grid at BaniWalid - Tninai 66 KV substation. The system's performance was simulated using PVSol Expert 6.0, achieving an approximate performance ratio 87% and an annual yield of 1,786.4 $\mathrm{KWh/KW}_p$. The annual system exported, about 99.3 GWh to the grid. ETAP was used to analysis power quality after integration PV system through load flow, short circuit, and harmonic distortion. The integration injected 42.6 MW into the grid, and the load consumed 7 MW. The short circuit current increased from 4.708 KA before integration to 5,245 kA afterwards. Harmonic analysis showed the grid unstable and a voltage increase of 67.18 kV after integration, a total harmonic distortion (THD) producing about 19.01%. The THD was reduced to 0.529% by using harmonic filters for the orders 11th. 13th, 23rd.

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Keywords: Photovoltaic System; Harmonic Distortion; Grid Integration; Power Quality; ETAP Simulation.

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التشوه التوافقي وتصميم المرشحات لمنظومة كهروضوئية بقدرة 50 ميجاوات ومربوطة مع خط 66 كيلوفولت

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1 كلية الطاقات المتجددة – تاجوراء/ ليبيا

2 الشركة العامة لتحلية المياه – بنغازي/ ليبيا

الملخص

في هذه الدراسة، تم تصميم منظومة طاقة شمسية كهروضوئية بقدرة إجمالية 50 ميجا وات ذروة، وربطها مع الشبكة العامة للكهرباء من خلال محطة بني وليد – تنيناي الفرعية وبجهد 66 كيلو فولت. حيث تم محاكاة اداء المنظومة الكهروضوئية باستخدام برنامج PVSol expert 6.0، كان معدل الاداء المنظومة تقريبا 87%، وانتاجية سنوية 1786.4 كيلووات ساعة/ كيلووات ذروة، ومن المتوقع ان تُصدر للشبكة العامة للكهرباء حوالي 99.3 جيجاوات/ساعة. تم ايضا نمذجة المحطة الكهروضوئية وربطها مع الشبكة العامة للكهرباء من خلال محطة تنيناي الفرعية 66 كيلوفولت، وذلك بهدف تحليل جودة القدرة من خلال محاكاة تدفق الاحمال وتيار القصر الكهربائي، بالإضافة الى محاكاة تشوه التوافقيات المتولدة من الربط، وقد لوحظ ان هذا الربط نتج عنه حقن الشبكة بقدرة مقدارها 42.6 ميجاوات منتجة من المنظومة الكهروضوئية، وتم استهلاك 7 ميجاوات مباشرة من الاحمال الكهربائية. ايضا تيار القصر زاد من 4.708 كيلوامبير قبل الربط الى 5.245 بعده. تبين ايضا من تحليل التشوه التوافقي ان الجهد زاد من 66 كيلو فولت قبل الربط الى 67.18 كيلو فولت بعده، مما ادى الى زيادة التشوه التوافقي حيث بلغ 19.01%. وحسب متطلبات IEEE519-2022 تم التقليل من التشوه التوافقي الى 0.529%، وذلك باقتراح مرشحات توافقية صممت للرتب 11،13، 23.

وقد تم عرض هذه الورقة العلمية في جلسات المؤتمر الدولي للطاقة المتجددة والنفط والغاز وتغير المناخ "أيريقو" في الفترة 25-27 ابريل 2026م. طرابلس – ليبيا

الكلمات المفتاحية: المنظومة الكهروضوئية، التشوه التوافقي، الربط مع الشبكة العامة للكهرباء، جودة الكهرباء، ETAP.

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1. Introduction

The electricity production in Libya rose to 40.731 MWh in 2021 from 37.117 MWh in 2017 [1]. Despite this growth, the electrical sector is mostly dependent on fossil fuels. Solar energy contributes very little to electricity production, despite Libya's having a significant geographic location and climatic conditions, where the annual solar irradiation reaches up to 2,200 kWh/m^2 [2]. Therefore, Libya's National Renewable Energy and Energy Efficiency Strategy 2023–2035 aims for a 15% reduction in electricity consumption and 20% penetration of renewable energy so as to facilitate the country's shift to sustainable and reduced emissions.

Large-scale grid-connected photovoltaic (PV) systems have environmental and operational benefits, but they also present technical challenges. The increasing penetration of PV systems can affect load flow, reverse power flow, short-circuit current, and voltage profiles. The power electronic switches within inverters used in PV grid integration are a major cause of harmonic distortions, distorting current and voltage waveforms. The distortions can decrease the quality of the power, increase losses, and damage equipment. Operating multiple inverters on the same feeder, the harmonic will increase. As a result, harmonic reduction is required to maintain grid stability and reliability, according to international standards such as IEEE 519-2022 [3].

The previous studies have evaluated the effect of integrating the large PV system on the power quality. Al-Sharif et al. [4] found that a single tuned filter in a large PV system in Saudi Arabia successfully reduced the total harmonic distortion to less than 8%. Almoktar et al. [5] used ETAP to assess the effect of the PV system penetration at Karabuk University. This study showed that if penetration is greater than 75%, the total harmonic distortion and losses of the system increase significantly, emphasizing a challenge of integrating a large scale of PV. Al- Ansari et al. [6] investigated a 300MW solar power plant using ETAP. The investigation has shown that high penetration of PV systems causes fluctuations and spikes in the voltage, which affects the stability of the system. Inverters were also found to be the primary source of harmonics. Exceeding the limitation of IEEE 519. The study recommended the use of harmonic filters whose capacity is determined

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based on the analysis results and power factor.

Marhil et al. [7] evaluated the impact of integrating a large-scale photovoltaic system with the Bani Walid substation. Their results underlined the need for reliable filtering techniques, as it was found that unexpected harmonic distortions were sometimes above the allowed levels, although the voltage patterns were generally improved. Bashiri et al. [8] analyzed the power quality of a 62.4 kW grid-connected PV system at the Libyan Center for Solar Energy Research, Tajura. The electrical parameters like voltage, current, frequency, active/reactive power, power factor, and harmonic distortion were measured by the Fluke 435-II analyzer at the point of common coupling (PCC) of 380V. The results showed that variation of solar radiation has a significant effect on the power quality.

The current work deals with the design and assessment of a 50 MW grid-connected PV system in the Tninai-Bani Walid area (31.40°N, 13.74°E). PV*SOL software is used to simulate the PV system performance. ETAP is used to study the harmonic distortions caused by PV integration into the 66 kV network to ensure that THD at PCC complies with IEEE 519-2022 limits.

2. Methodology

2.1. Site and Meteorological Data Analysis

The photovoltaic solar system is proposed in Tninai, Bani Walid, Libya (31.40°N, 13.74°E). The site coordinates and land dimensions were obtained using Google Earth, and the plan was designed in SketchUp (Figure 1). Meteorological data, including solar radiation, temperature, and wind, had been obtained from the National Solar Radiation Database (NSRDB) [9]. The data is analyzed by using Excel, a spreadsheet, to determine average annual values, providing essential data for solar system sizing and yield of energy prediction.

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Figure 1. The proposed site for installing PV system

Tilted solar radiation at 30°; orientation to south facing obtained by using Liu- Jordan model [10] to transformed horizontal solar radiation as shown in Figure 2, the horizontal average daily solar radiation was 5.75 KWh/m^2/day, and 6.19 kWh/m^2/day on tilted. The range ambient temperature between ($-8^{\circ}C$ to $43^{\circ}C$), these parameters are essential for sizing and assessing performance of PV system.

2.2. Design and Simulation of Photovoltaic Systems

To size and design a 50 MW$_p$ grid-tied PV system, use PVSol simulation software [11]. The system comprises Jinko 630 Wp modules, Sungrow 1 MW inverters, and Sungrow PVS16MH combiner boxes, grouped into 50 subsystems of 1 MW each.

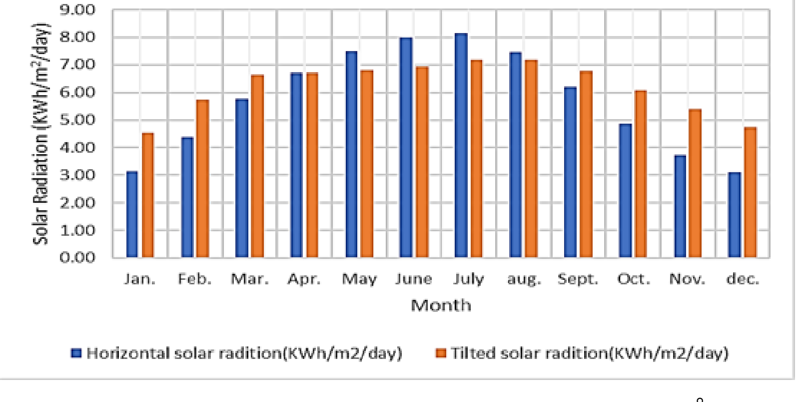

Figure 2. Solar radiation on horizontal and tilted 30°

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System sizing included selecting the series-parallel configuration of solar panels and the overall panel quantity, based on a specified DC to AC ratio of 1.2. The required number of panels has been determined as [12]:

$$N_{panels}=\frac{P_{DC}}{P_{panel}} \qquad (1)$$

Where P_{DC} is the total DC capacity of the PV system (kW_p) and P_{Panel} is the rated power of a single PV panel (W_p).

The number of panels connected in series was determined by considering voltage variations caused by temperature extremes in the region, which range from -8°C to 43.5°C. To accurately determine the solar panel temperature under operational conditions, the solar cell temperature Tcell was computed using the Nominal Operating Cell Temperature (NOCT) model as shown:

$$T_{cell} = T_{air} + G \times \frac{NOCT - 20}{800} \qquad (2)$$

Where NOCT is the nominal operating cell temperature (ºC), G is the solar irradiance incident on the solar module (W/m^2), and T_{air} is the ambient temperature (ºC).

Equation (3) was used to determine the voltage of the solar modules at the coldest and warmest temperatures.

$$V_{pv}(T_{cell})=V_{STC}[1+\beta(T_{cell}-25°C) \qquad (3)$$

Where $V_{pv}(T_{cell})$ is the solar module voltage in volt at cell temperature; V_{STC} is the solar module voltage at STC; β is the temperature coefficient of voltage $(\%/C^{\circ})$; and T_{cell} is the cell temperature(C°).

$$N_{series,max} = \frac{V_{max,inverter}}{V_{PV}(T_{min})} \qquad (4.1)$$

$$N_{series,min} = \frac{V_{start,inverter}}{V_{PV}(T_{max})} \qquad (4.2)$$

Where $N_{series,max}$, and $N_{series,min}$ are the number of minimum and maximum PV modules connected in series, $V_{max,inverter}$ is the

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maximum system voltage, $V_{start,inverter}$ is the minimum voltage of the inverter required for operation, and $V_{pv(T_{min})}$, $V_{pv(T_{max})}$ are the voltages of the PV modules at low and average high cell temperatures respectively.

To determine the maximum number of PV modules that can be connected in parallel based on the inverter's specification, use the equation (5) as follows:

$$N_{parallel/mppt} = \frac{I_{max,mppt}}{I_{sc,panel}} \qquad (5)$$

Where $I_{max,MPPT}$ is the maximum input current/MPPT in A, I_{SC} is the short circuit current of the PV module in A, and MPPT is the number of independent maximum power point trackers in the inverter.

Figure 3, illustrated PVSol, which was used to simulate the configuration of a PV grid-tied system. To assess the system efficiency under the site's conditions and to ensure the design meets the good performance, with critical metrics such as performance ratio and annual energy production were analyzed.

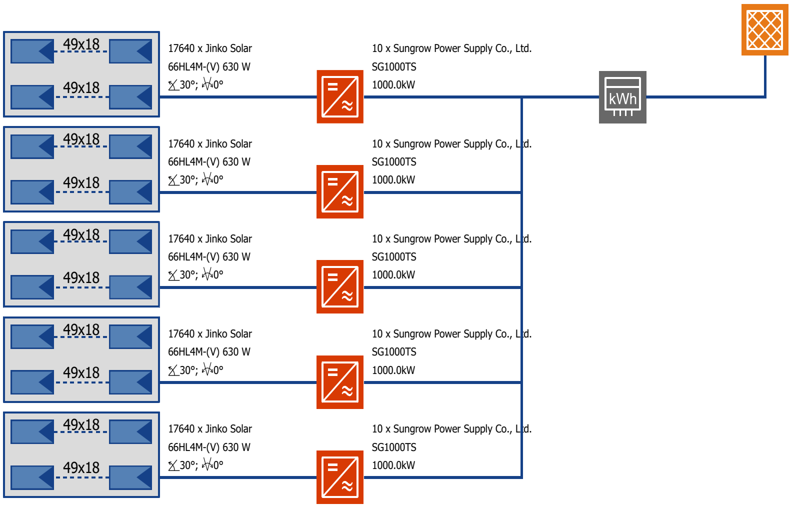

Figure 3. PV system configuration

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2.3.Integrated PV system with grid using ETAP

The Electrical Transient Analyzer Program (ETAP) [13] was used to model and simulate the integration of the 50-MW photovoltaic system with the Tininai 66KV substation. A 10 MVA bus-linked transformer steps down voltage from 66 KV to 11 KV, supplying a total load of 2.77 MVA to Shmaykh, Souf Al-Jin, Souq, and Al-Qasr. A second 66/11 KV transformer supplies three backup transformers and the Maqil region, with 2.70 MVA of overall load capacity. Two other transformers are fed 1.32 MVA and 1.30 MVA throughout the 42 Km distance between the Tininai and Nesma substations via the transmission line between them. The electrical network is modeled using ETAP as shown in Figure 4.

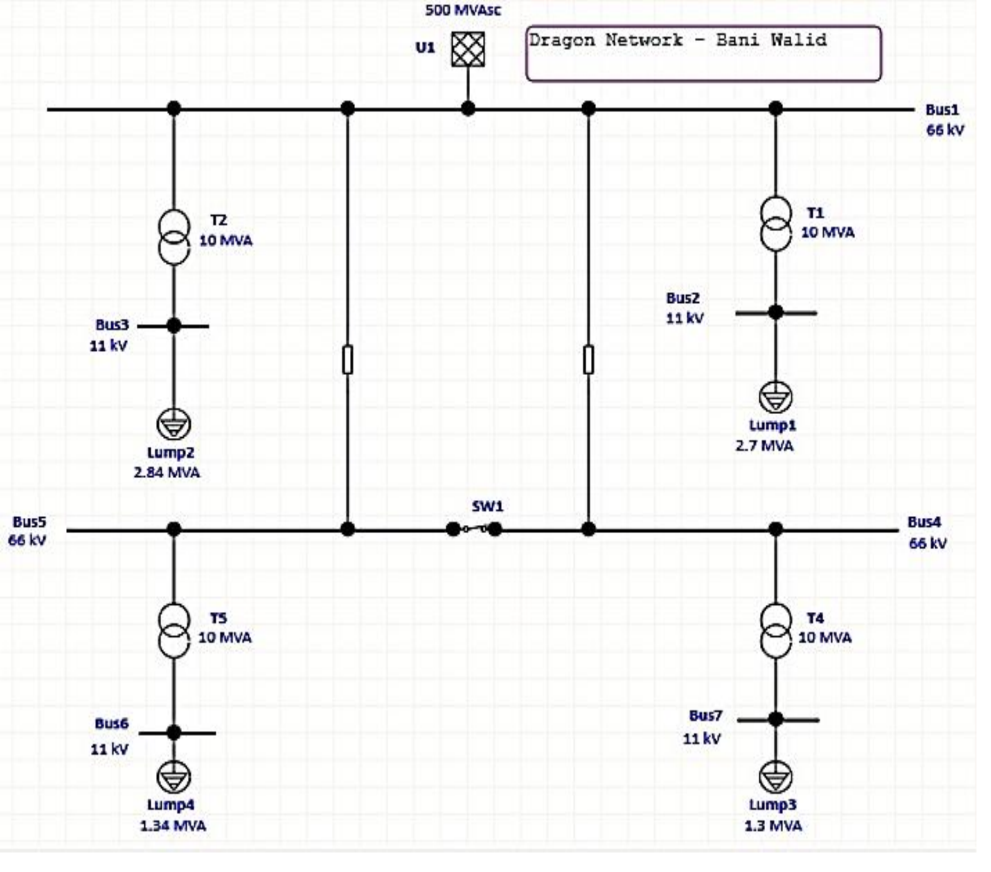

Figure 4. Tninai grid diagram

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After the electrical network was built, the PV system was also modeled and integrated with the grid; the system is divided into 5 groups, each group containing 10 inverters, producing 10 MW, a total 50 MWp capacity. The electricity produced from the PV system was injected into the 63 MW substation at PCC. The photovoltaic system is 1.5 Km away from the PCC of the 11/30 KV step-up transformer. As shown in Figure 5.

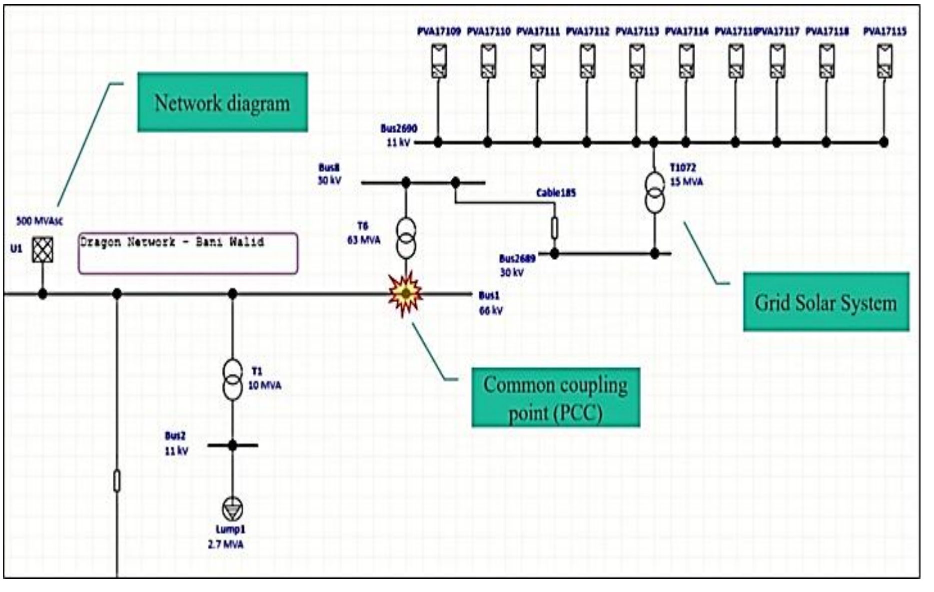

Figure 5. PV system modeled and integrated with grid in ETAP

Power quality tests on the electrical grid were conducted before and after the connected PV system. The main tests performed include:

I. Load flow models:

The effect of integrating the PV system with the national grid was evaluated using load flow tests before and after integration, as shown in figures 6, and 7, respectively. These tests were conducted by determining the bus voltages. branch currents, active and reactive power flow, and power factor for each scenario. Comparing the results in terms of voltage profile, line transformer loading, and power flow direction.

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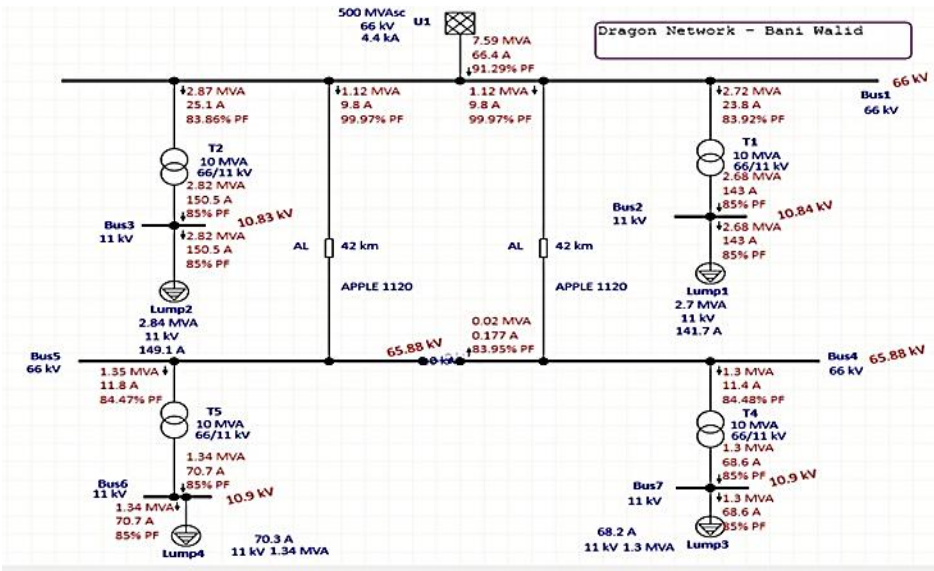

Figure 6. Grid energy Flow before integrating PV system

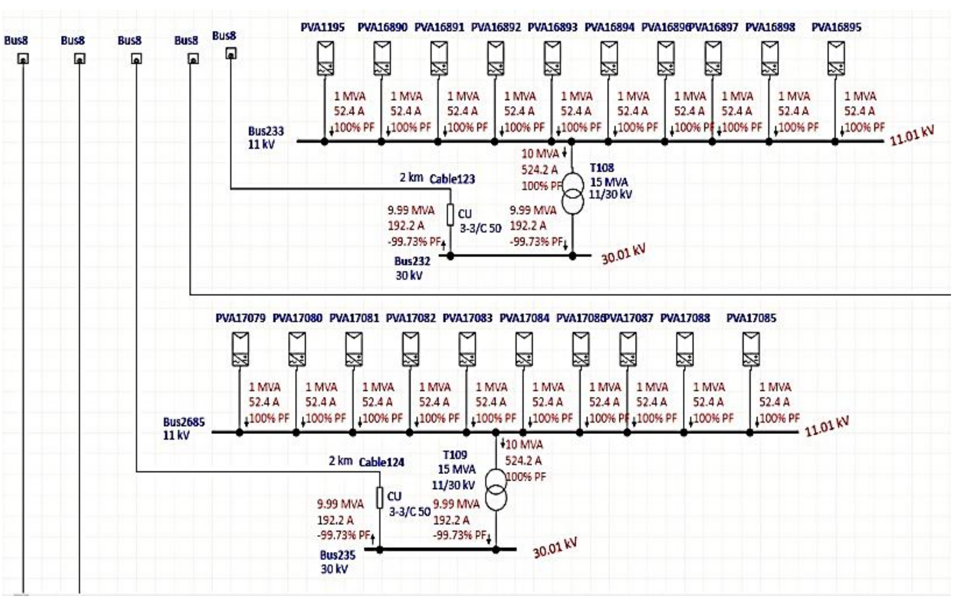

Figure 7. Figure 6 Grid energy Flow before integrating PV system

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II.Short Circuit models:

ETAP carried out a short circuit analysis at PCC in accordance with IEC 60909, to evaluate the impact of the integration of the PV system. The PV system was modeled as a limited current source to reflect the contribution of its inverters during faults. Three-phase bolted faults were simulated at PCC in two cases: before integration, as shown in Figure 8, where the network alone supplies the fault current; and after PV integration, as shown in Figure 9, where the PV system contributes partially to the fault current.

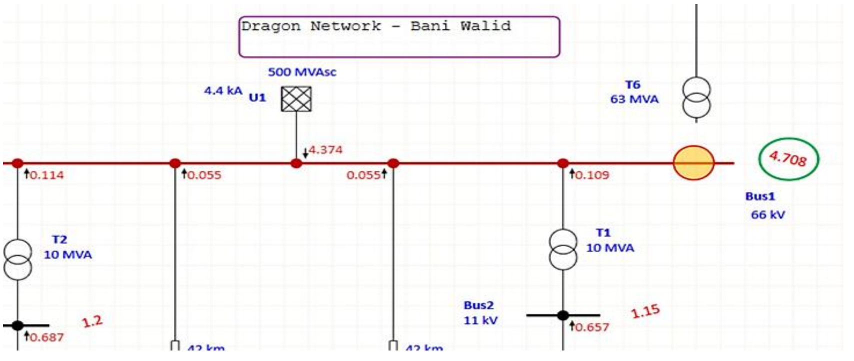

Figure 8 analysis fault currents before integrating PV system

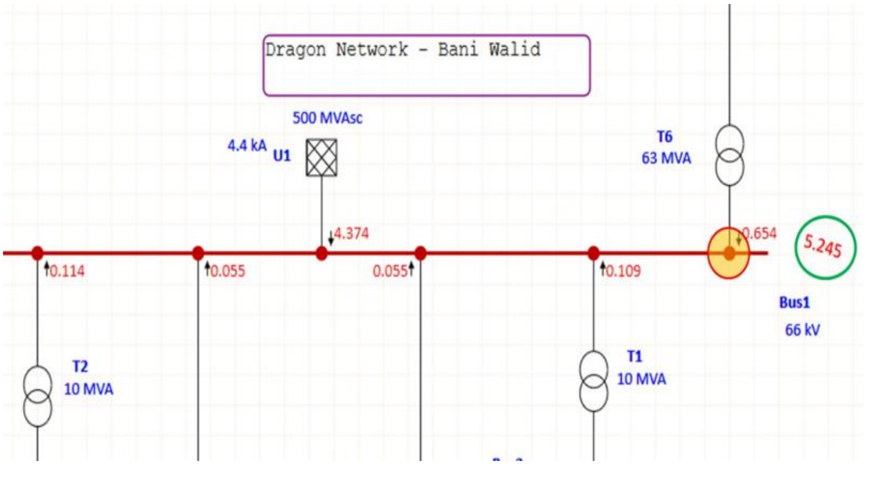

Figure 9 analysis fault currents after integrating PV system

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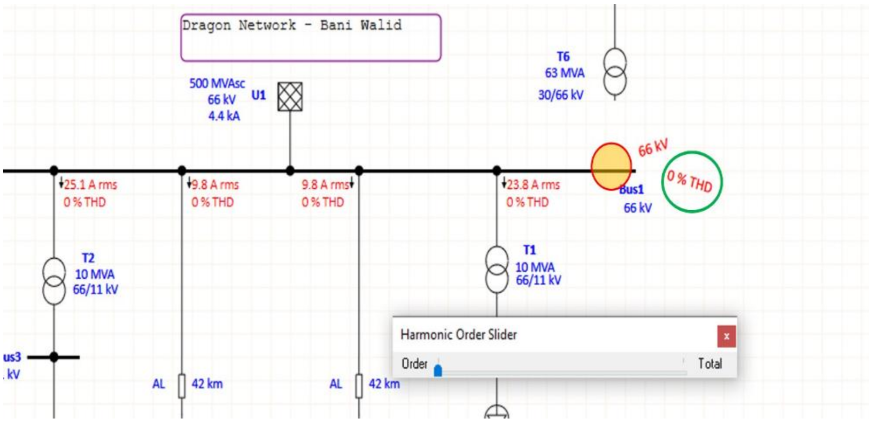
III. Harmonic distortion analysis

To analyze harmonic distortions in the grid caused by the integration of the PV system, harmonics are simulated using ETAP at PCC. The analysis simulates harmonic current and voltage, with the PV inverters treated as a restricted current source (standard IEEE 12 pulse) to indicate their harmonic contribution. Two scenarios were studied before PV integration, as shown in Figure 10, where harmonics came from existing loads, and after PV integration, as shown in Figure 11, where inverter harmonics were added. The IEEE519=2022 standard was used to limit the



harmonic measurements, especially total harmonic distortions (THD) of voltage and current as well as individual components up to 50 orders.

Figure 10 Harmonic distortion analysis before integrating PV system

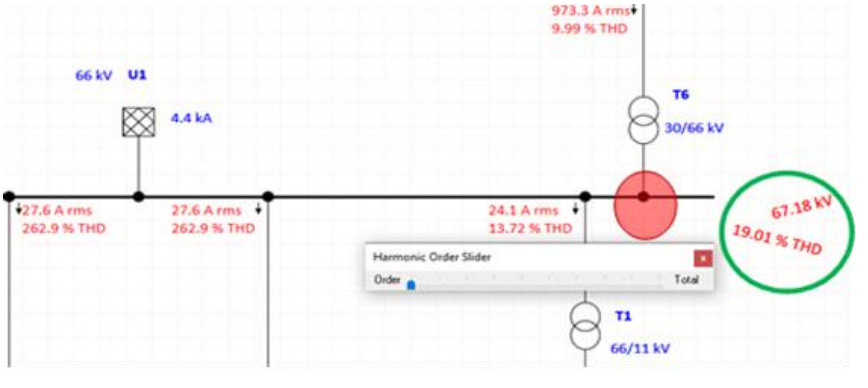


Figure 11 Harmonic distortion analysis after integrating PV system

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IV.Design of Harmonic Filter

Creating a harmonic filter is one of the most important steps in controlling and minimizing harmonic distortions that result from integrating a PV system to the electrical grid. After analyzing harmonic distortion and determining the target order using ETAP, which was higher distortion, determine the frequency for the filter. In this study the 11th (550 Hz), 13th (650 Hz), and 23rd (1150 Hz) were determined, as the X_L and X_C values for a single tuned filter are dependent on these frequencies. The reactive power required for power factor correction is calculated using the following relation [14]:

$$Q = (P)_{MVA} \times PF_0 \times \tan[\cos^{-1}(pf_0) - \cos^{-1}(pF_1)] \qquad (6)$$

Where PF_0 , andPF_1 are the actual and required power factor.

According to this, to determine the filter the capacitive reactance of (X_c) by:

$$X_c = (V)^2/Q \qquad (7)$$

Where V in volt, is the rated voltage of the system.

To find the filter's capacitance, using the following formula;

$$C = {}^{1}/_{[2\pi f X_C]} \qquad (8)$$

Where f is the fundamental frequency (Hz) of the system.

To compute the inductive (X_L) at harmonic order h as follows;

$$X_L = {}^{X_C}/_{h^2} \qquad (9)$$

Where h is the harmonic order.

The single- tuned harmonics filter (RLC) was chosen because it is inexpensive, simple, can detect specific harmonics and also improve power factor. The filter sizing depends on the electrical load (MVA), current, target power factor, and harmonic orders, figure 12 shows harmonic filter editor and harmonic filter sizing for 11 harmonic order.

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Following the creation and implementation of these harmonic filters, a harmonic load flow analysis was carried out to assess their effectiveness in minimizing harmonic distortions and improve overall power quality in the system.

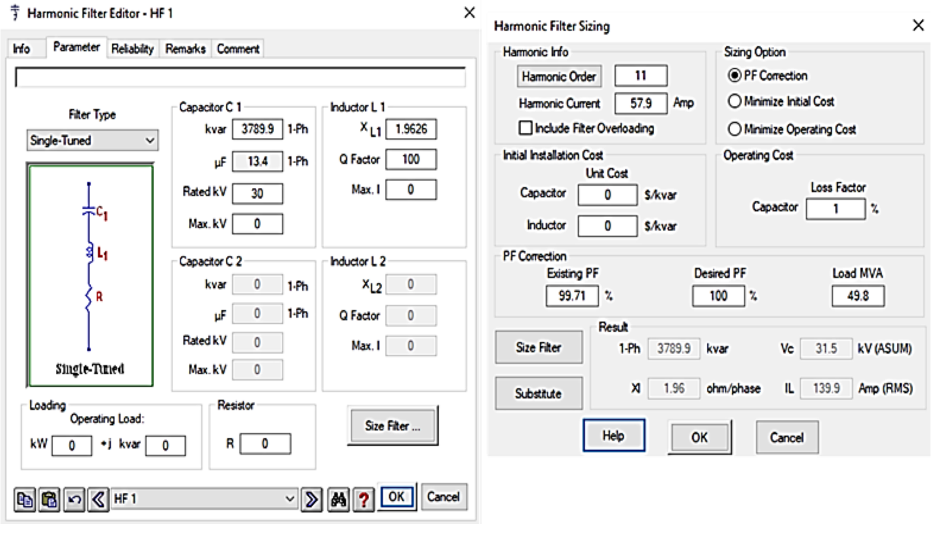

Figure 12 design single tuned filter for 11 order a) harmonic filter editor, b) harmonic filter sizing

3. Results and Discussion

3.1 Technical Analysis of the PV System with PVSol

A 50 MW grid-connected photovoltaic (PV) system had been designed for the Tininai region located in Bani Walid, Libya, to enhance local power supply and reduce reliance on fossil fuels. The plant is expected to cover an area of approximately 75 hectares. Figure 13 shows the system, comprised of 88,200 Jinko Tiger Neo JKM630N-72HL4-V solar panels that have a total surface area of 233,202.6 m² and 50 Sungrow SG1000TS inverters rated at 1 MW. Each inverter was configured with 18 PV modules connected in series, and 49 strings per MPPT. To maximize the solar radiation, the solar PV modules are installed on a ground mounted structure with a 30° tilted, south orientation. The DC/AC ratio is 1.11and then integrated with the national grid through 11KV, 3 - phase.

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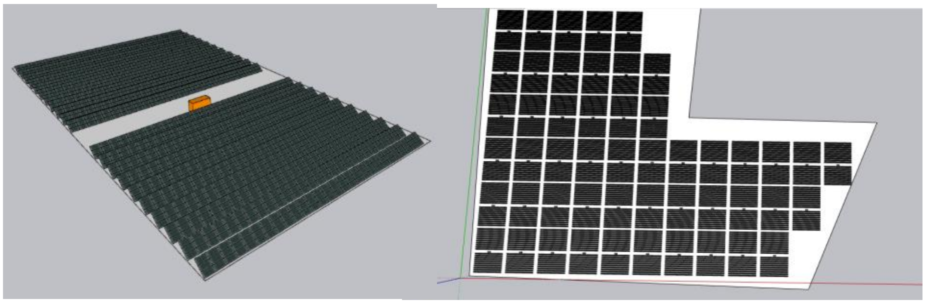

Figure 13a) 3D 1 MW PV system, b) 50MW PV system at Tinani

The photovoltaic system is designed with an installed capacity of 55.66 MWp, with an anticipated annual energy yield of approximately 1,787.82 KWh/KW_p. The performance ratio was calculated to be 86.83%. The expected annual energy production of the plant is shown in Figure 14. The system is expected to export 99,326,184 kWh to the grid annually, which corresponds to a reduction of CO_2 emissions by approximately 46.65 million kg per year.

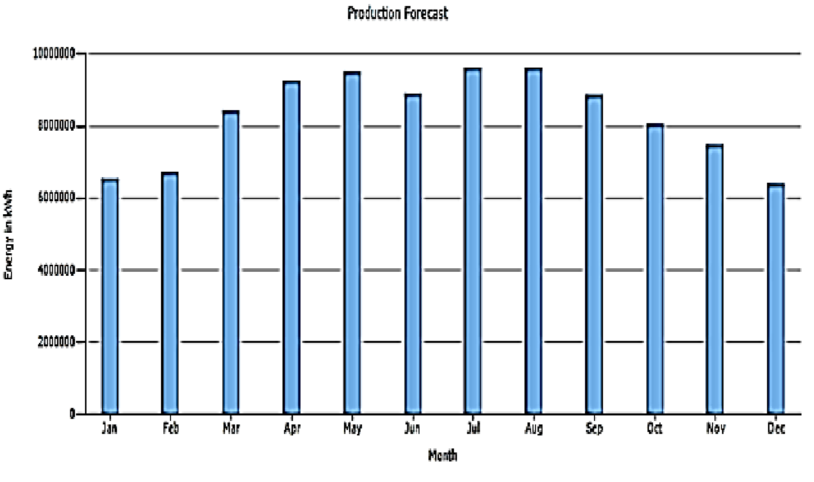

Figure 14 The expected annual energy production

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3.2 Load flow evaluation

A load flow evaluation of the Tinanai-BaniWalid substations was carried out before and after the connected of a 50 MW PV system with the national grid. Before integrating, the overall load was 6.916 MW with 4.286 MVAR of reactive power. The production had been almost the same, at 6.932 MW and 3.099 MVAR. The system losses were relatively small, estimated to be 0.016 MW active and -1.187 MVAR reactive. Bus voltages were approximately constantly equal to 99.8% of the normal range. Transformer loading reached 28.7%, the current averaging about 25 A, as shown in the Figure 6.

After the PV system connected with the grid. The generation increased up to 7.406 MW, and electrical load consumption remained constant, fed from solar system in daily. The reactive power dropped to -7.474 MVAR. That indicates a capacitive injection from PV system. The losses from the system relatively small, with an estimated 0.016 MW active, and 1.187 MVAR reactive. The voltage profiles are improved, reaching a peak about 101.78%.

Transformer load increased to 79.9%, with currents reaching 955 A on T6. Cable currents reached 189 A at 35.8% loading, as shown in figure 7. The conclusion, the connected PV system with national grid was enhanced the volage profile and supplied reactive power, Nevertheless, it is increased the losses of the system and equipment load, which emphasized the need for periodic monitoring and potential system modification.

3.3 Short Circuit Analysis

After integrating the 50 MW solar PV system, short-circuit current measurements at Bus1 rose: symmetrical current from 4.71 kA to 5.25 kA, asymmetrical current from 6.76 kA to 7.53 kA, and peak current from 11.51 kA to 12.83 kA. The multiplying factor (1.436) and X/R ratio (~9.93) remained unchanged. Figures 8 and 9 show the short-circuit test results prior to and following PV system integration, respectively.

3.4 **Harmonic Distortion Analysis**

Before connecting the 50 MW solar PV system, the Bani Walid Tininai

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network exhibited a nearly ideal sinusoidal voltage waveform, as shown in Figure 15a. The base frequency (order 1) was almost 100%, and the higher-order harmonics were very small, as shown in Fig. 15b.This baseline was used as a valid reference to evaluate the impact of integrating the PV system.

After the integration of a 50 MW_p PV, the power quality decreased significantly and rapidly. The waveform of the voltage was strongly distorted as compared to the baseline waveform as shown in figure 16 a. The total harmonic distortions (THD_V) were 19.01%, exceeding the IEEE519-2022 allowed limit by nearly 7 times.

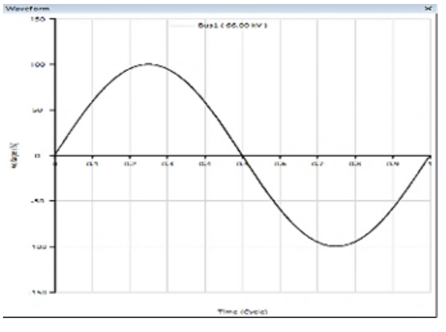

Figure 15a Voltage Waveform of grid before integrating PV system

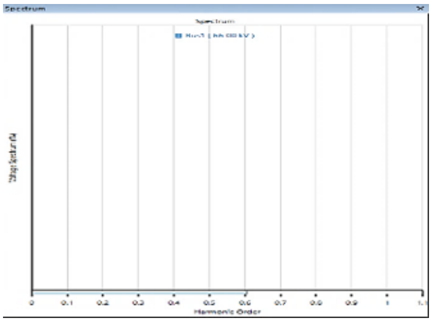

Figure 15b harmonic distortion of grid before integrating PV system

As shown in figure 16b, the harmonic spectrum indicated dominant individual harmonics, especially the 11th (9.35%), 13th (11.06%), 23rd (9.97%), and 25th (6.23%). All of which are above permissible criteria. The results also show that the internal inverter filters were insufficient for minimizing harmonic noise, and operational issues such as equipment overheating and possible system failures.

To mitigate harmonic distortion, tunable passive filters were added in three stages. The first filter reduced the 11th to 0.0069%, while reducing the total harmonic distortion (THD_v) to 9.72%. However, the 13rd, 23th and 25th harmonics remained high (1.93% and 8.1%, and 4.59% respectively). Figures 17a and b illustrates the appropriate voltage waveform and harmonic spectrum at this stage, indicating a partial improvement.

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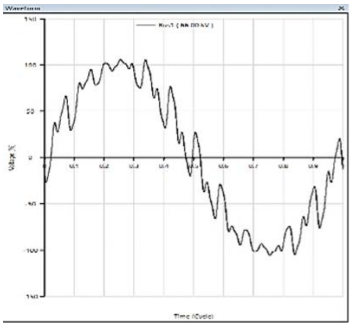

Figure 16a Voltage Waveform of grid after integrating PV system

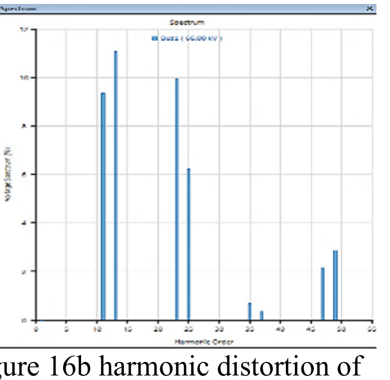

Figure 16b harmonic distortion of grid after integrating PV system

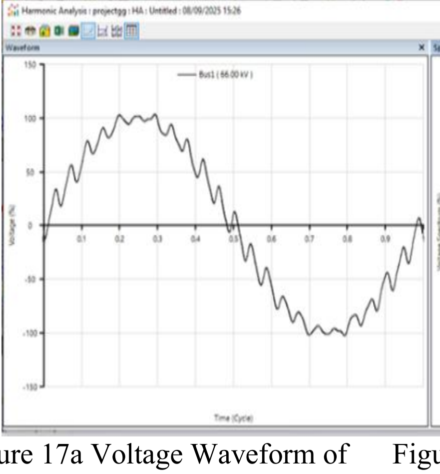

Figure 17a Voltage Waveform of grid after PV system with first filter

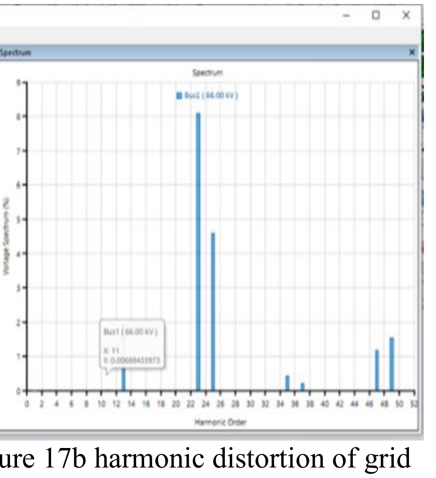

Figure 17b harmonic distortion of grid after integrating PV system with first filter

A second filter was added to reduce the 13rd ,23th and 25th harmonics to 0.043%, 7.74 %, and 4.39 respectively, while also reducing THD_v to 9.1%. Despite this, the network did not fulfill the IEEE 519-2022 standards. Figures 18a and b shows the waveform and harmonic distribution after this stage.

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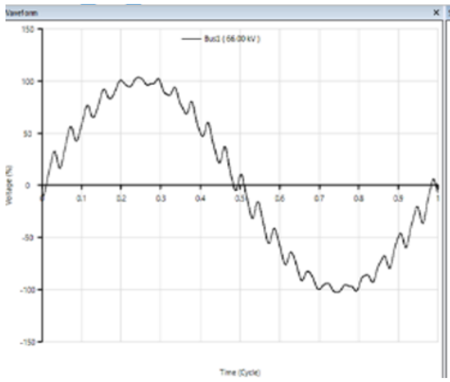

Figure 18a Voltage Waveform of grid after PV system with second filter

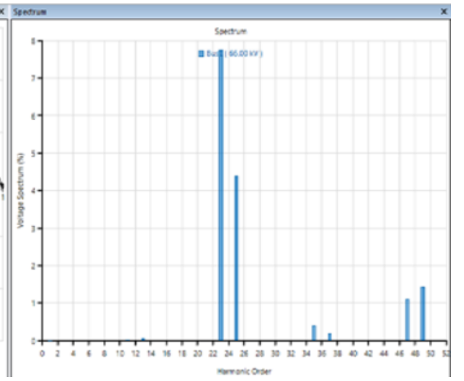

Figure 18b harmonic distortion of grid after integrating PV system with second filter

The third filter considerably reduced the remaining harmonics, dropping the 23rd and 25th to 0.0092% and 1.63%, respectively, and THD_v to 2.01%, close to the limit. Figures 19a and b illustrates the efficacy of the filter's mechanism through the final waveform and harmonic spectrum. These results show the performance of the proposed passive filters to mitigate harmonic distortion as IEEE 519-2022 requirements, thus ensuring reliable network operation and further protecting equipment from harmonic degradation.

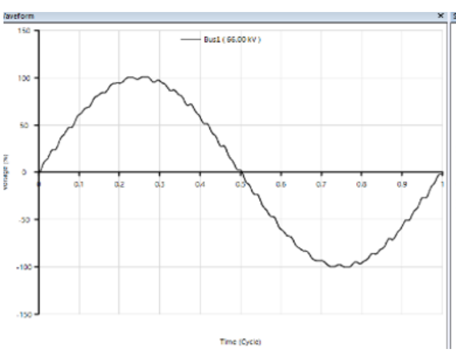

Figure 19a Voltage Waveform of grid after PV system with second filter

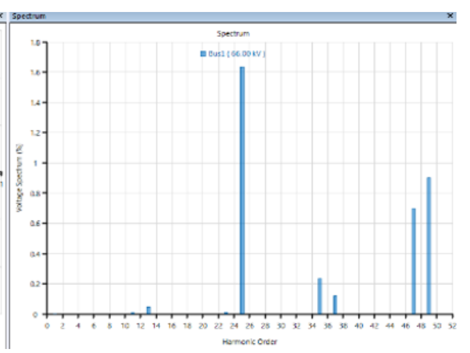

Figure 19b harmonic distortion of grid after integrating PV system with second filter

http://www.doi.org/10.62341/istj-vol38-2-irego08

4. Conclusion

This study includes the design and simulation of a 50 MW grid PV system by using PVSol, integrated with the national grid a 66 KV using ETAP. Evaluate the quality of power though analysis: load flow, short circuit, and harmonic distortion. The results obtained from PVSol simulation of the designed PV system indicate that the performance ratio of almost 87%, an annual energy yield of 1786.41 KWh/KWp, and nearly 42.6MW exported to grid and 7 MW used by load directly. This means that Tininai sit is suitable for installing PV system, as well as it's a wide-open area.

Following the PV system modelled and integrated by ETAP, short - circuit analysis showed an increase in current from 4.708 KA to 5.245 KA, indicating higher network loading. Inverters injecting harmonic currents caused a significant total harmonics distortion is 19.01 % in voltage. This issue has caused an increase in voltage up to 67.18 KV, resulting in network instability.

To mitigate the undesirable harmonic distortion, three tuned passive filters were implemented to eliminate the 11th, 13th,23rd orders, and effectively reduced total harmonic to 0.53as IEEE519-2022 requirements. Thes results illustrate the performance of the proposed mitigation technique for improving power quality and ensuring stable, safe grid operation with PV integrated.

5. References

[1] State of Libya, Ministry of Planning, National Strategy for Renewable Energy and Energy Efficiency 2023–2035, Tripoli, Libya, Mar. 2023.

[2] Teyabeen Alhassan Ali , N.B. Elhatmi, Akram A. Essnid, F. Mohammed, "Estimation of monthly global solar radiation over twelve major cites of Libya", Energy and built Environment, vol 5 (2024), 46-57, http://doi.org/10.1016/j.enbenv.2022.07.006.

[3] IEEE Power and Energy Society, *IEEE Standard for Harmonic Control in Electric Power Systems*, IEEE Std 519™-2022 (Revision of IEEE Std 519-2014), New York, USA: IEEE, 2022.

[4] Sharif, Y. M., Swelem, G. M., Kaoudi, T. A., "Harmonic Analysis

of Large Grid-Connected Solar Energy Systems in Distribution Networks: A Saudi Case Study," International Journal of Solar Energy, vol. 23, PP,12-25,20222, DOI: 10.1201/9781032617305-1.

[5] M. Almaktar, A. Algburi, Z. Rajab, and A. Elbreki, “Power quality assessment of Karabuk University’s grid-connected microgrid under high penetration of PV generation,” in Proc. Int. Symp. On Multidisciplinary Studies and Innovative Technologies (ISMSIT), 2022, 472-477, http://doi.org 10.1109/ISMSIT56059.2022.9932654.

[6] M.Rehmat, A.Ansari, M Rehman, “Modeling and Analysis 300MW Photovoltaic System Using ETAP And Harmonic Filter Design”, in proc. 2023 3rd int. symp. On instrumentation, control, artificial intelligence, and robotics (ICA SYMP), Karachi. Pakistan, 2023, pp.140-149. Doi: 10.1109/ICASYMP563482023.10044936.

[7] O. G. Mrehel, A. M. O. Alkeesh, and K. A. S. Albgar, "Effect of Large-scale PV system on Load Flow short circuit and harmonics in Libyan Electrical Network," in Proc. 2021 IEEE 1st Int. Maghreb Meeting of the Conf. on Sciences and Techniques of Automatic Control and Computer Engineering (MISTA), Tripoli, Libya, 2021, pp. 412–419, doi: 10.1109/MI-STA52233.2021.9464463.

[8] A. Elbaz, M. Bashiri, A. Almorabet, N. B. Elhatmi, F. Zreeq, and T. Elbouashi, "Evaluation of Power Quality in a 62.4 kW PV Grid-Connected System in Libya," Solar Energy and Sustainable Development, vol. 14, no. 1, pp. 540–549, Jun. 2025, doi: 10.51646/jsesd.v14i1.297.

[9] National Centers for Environmental Information (NCEI), "National Solar Radiation Database," [Online]. Available: https://www.ncei.noaa.gov/products/land-basedstation/national-solar-radiation-database.

[10] R. Mubarak, M. Hofmann, S. Riechelmann, and G. Seckmeyer, "Comparison of Modeled and Measured Tilted Solar Irradiance in Different Weather Conditions," *Energies*, vol. 10, no. 1688,

pp. 1–18, 2017.

[11] Valentin Software, "PVSOL – Photovoltaic Software," [Online]. Available: https://pvsol.software/en/

[12] R. A. Messenger and J. Ventre, *Photovoltaic Systems Engineering*, 3rd ed. Boca Raton, FL, USA: CRC Press, Taylor & Francis Group, 2010.

[13] Operation Technology Inc., "ETAP – Electrical Power System Analysis Software," [Online]. Available: https://etap.com/

[14] S. T. Y. Alfalahi, M. B. Mansor, A. Nouh, S. I. Abdrabba, and F. Mohamed, “Sizing passive filters for mitigation of harmonics in a low voltage network containing solar PV units,” Franklin Open, vol. 10, p. 100220, Mar. 2025, doi: 10.1016/j.fraope.2025.100220