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Impact of PV Generation on Voltage Profile and MW Losses inSouth-West LibyanDistribution Network

S.A.Tajeldinr, *I.S.Naser, Mohamad Hossin, M.N.Hussin
Renewable Energy Engineering Department, Faculty of Energy and Mining/University of Sebha, Libya
Corresponding author: ibr.naser@sebhau.edu.ly

Abstract Recently, the photovoltaic (PV) has been dramatic development throughout the World especially, connected to the distribution networks. The connection of PV energy resources challenges the planning and operation of the grid. This paper aims to study and provide understanding on the impact of PV generation on voltage profile and MW losses in the south-west Libyan distribution network. For this purpose a 27-bus Takarkibah distribution network has been modelled in Power World Simulator. Finally, the results did show an improvement in the voltage profile and MW losses of the network for both the higher penetration level and multiple locations of the PV.
Keywords: Renewable energy, Photovoltaic, Distribution network, Voltage Magnitude MW losses.

تأثير التوليد الكهروضوئي على الجهد وفقد القدرة في شبكة التوزيع الكهربائية للجنوب الغربي الليبي

صالح عبدالكريم محمد تاج الدين و *ابراهيم سليمان نصر و محمد عبد الله حسين و محمد نوري احمد حسين
قسم هندسة الطاقة المتجددة–كلية الطاقة والتعدين–جامعة سبها، ليبيا
للمراسلة:ibr.naser@sebhau.edu.ly

ملخص حديثا أصبح هناك تطور مثير في تولد الطاقة الكهربائية بإ ستخدام محطات الألواح الشمسية أو مايعرف بالأنظمة الكهروضوئية خاصة الموصلة بشبكات التوزيع الكهربائية. توصيل محطات التوليد الكهروضوئي بالشبكة المحلية يعد تحديا لتشغيل وتخطيط الشبكة الكهربائية. الغرض من هذه الورقة دراسة وفهم تأثير توليد المحطات الكهروضوئية على الجهد وفقد القدرة الكهربائية في شبكة التوزيع في الجنوب الغربي الليبي. لهذا الغرض أجريت محاكاة بواسطة برنامج على شبكة توزيع كهربائية ذات 27- قضيب توزيع بقرية تكركيبة بالجنوب الغربي الليبي. أظهرت النتائج المتحصل عليهاPower World Simulator تحسن ملحوظ في الجهد وانخفاض في فقد القدرة لشبكة التوزيع خاصة في الكميات العالية المتولدة من الخلية الكهروضوئية وتعدد مواقع توصيلها في الشبكة.
الكلمات المفتاحية: الطاقة المتجددة، الكهروضوئي، شبكة التوزيع، مقدار الجهد، فقد القدرة.

1.Introduction

Recently, many counties are encouraging the use of renewable clean energy sources such as solar celland wind power due to environmental concern.The photovoltaic is among the most efficient and cost-effective of renewable power generation types currently available [1-2]. By the end of 2018, global cumulative installed photovoltaic(PV)generation capacity reached about 509 GW and this represented a growthof 27% from 2017[3].Integration of PV can reduce overall operating costs for the entire Libyan grid as well as decrease CO_2 emissions. Moreover, international electricity trade is advantageous for Libya due to its location and extent of available solar energy. The daily average of global solar irradiance in the north region of Libya on horizontal surfaces is between 5 and 7 kWh/m2.day and 8.1 kWh/m2.day in the southern region; this results in 3000-3500 hours of solar irradiance annually [4-5].At the present photovoltaic (PV) is connected to low-voltage grid, with power rating ranging from several kilowatts to multi-megawatts. This influences the operation of the power system networks, i.e. the power flow become more diverse and power generation at that levels makes them more active [6-7].Normally, distribution system uses medium and low-voltage levels for electric power transmission over short distances. The distribution system connects the customer load with the transmission line which is connected to supply centres. Originally, distribution system was designed as passive network with no generators were connected to it. Today distribution systems are no longer passive as number of renewable power plants such as wind power, and photovoltaic are being connected directly it [8]. PV generation has its own characteristics, such as randomness. Unlike conventional generation, the power output produced by a PV is not constant, but depends on the solar radiation condition. Due to this nature, may resulting fluctuations in power flow, frequency fluctuation, voltage fluctuation due to the intermittent nature of solar radiation can increase the complexity of system operation [9-10].The impact of PV generation on the distribution network can be positive or negative depending on network characteristics, penetration level, fluctuation output, and location of PV connection.This paper aims to study and provide understanding on the impact of PV generation on voltage profile and MW losses in the south-west Libyandistribution network taking into consideration the penetration level and location of

PV. For this purpose a 27-bus ofTakarkibahdistribution network has been modelled in Power World Simulator. The PV is connected at different locations of the network, and the level of PV penetration is varied from 10% to 20%in steps of 10% to assess the impact on voltage profile and MW losses.

1.1 PV Generation

The Photovoltaic (PV) generation is the .direct conversion of sunlight to electricity using the PV cell. PV systems are designed around the photovoltaic cell and the PV cell is a specially designed 'pn' junction [11]. Cells must be connected in series-parallel configurations to produce enough power for high-power applications.

1.2 PV Module

The PV module consists of PV cells connected in series in order to obtain suitable output voltage. Since PV systems are commonly operated at multiples of 12 volts, the modules are typically designed for optimal operation in these systems. Figure 1 shows an equivalent circuit diagram of the PV cell, where R_s is the very small series resistance and R_{sh} is the quite large shunt resistance. I_p is expressed as the photo current source generated proportionally by the surface temperature and in solation. V_{pv} and I_{pv} represent the output voltage and output current of the PV cell [12].

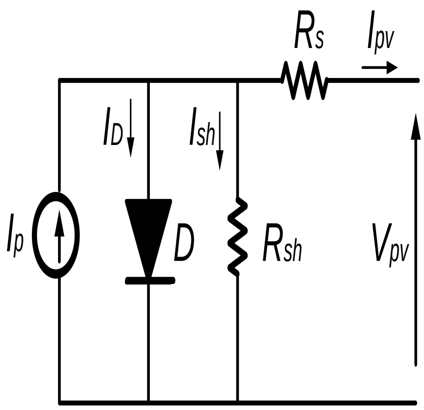

Fig. 1: Single-diode photovoltaic equivalent circuit model

The I-V characteristics of a PV cell are a function of the illumination levels incident on the cell. In the ideal case, the I-V characteristic equation (1); is given by:

$$I_{pv} = I_p - I_0 \left[e^{\frac{qV_{oc}}{nkT}} - 1 \right] \quad (1)$$

Where $I_0$is the Saturation current, V_{oc} is the open circuit voltage, q is the electron charge, k is the Boltzmann constant, T is the junction temperature. The operating point of a PV array is determined under constant cell temperature and irradiance, by the intersection of the photo current, terminal voltage cell characteristic and the load characteristic. As shown in Figure 2, the system operating point moves along the I_{pv}-V_{pv} characteristic curve of the PV panel from point (a) to point (b) as the load resistance increase from zero to infinity. Position (b) is the maximum power operating point. At this point, the area under the I_{pv}-V_{pv} characteristic curve, which is equivalent to the output power is maximum.

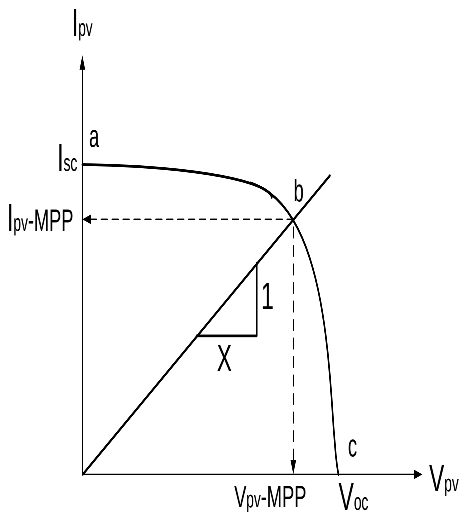

Fig. 2:PV cell operating points.

2.Test System

A single line diagram of a 27-bus Takarkibah distribution network is shown in figure 3. Takarkibah is a small town in the south-west of Libya.The 27-bus Takarkibah distribution networkwas modified by connecting PV generation to the system at different buses, with different connection scenarios at different PV penetration levels. The test system was modelled using the Power World Simulator. The modified test system was analyzed using an AC Optimal Power Flow (OPF). The test system supply power to 25 loads through 66/11 kV Alfajij substation and the peak load is 2.2 MW. The PV generation is assumed to be a PQ bus and operated a unit power factor, and the PV generation outputs are shown in Table 1.

Table1: The PV generation output scenarios

PV Penetration level	10% PV	20% PV
PV output (kW)	220 kW	440 kW

In this study, results for two PV connection scenarios are considered and compared to the base case when no PV generator is connected to the system. One PV generator is located at bus 21 in the first connection scenario. In the second connection scenario, the PV generator is connected to buses 15 and bus 22 simultaneously with a combination PV penetration level. Table 2, shows the combinations of penetration levels and locations connected at buses 15 and 22.

Table2: Different PV penetration level and different locations.

% Of Combination (PV bus15- PV bus22)	% of Total Combination
5 %(110kW) -5 %(110kW)	10% (220kW)
10 %(220kW) - 10 %(220kW)	20% (440kW)

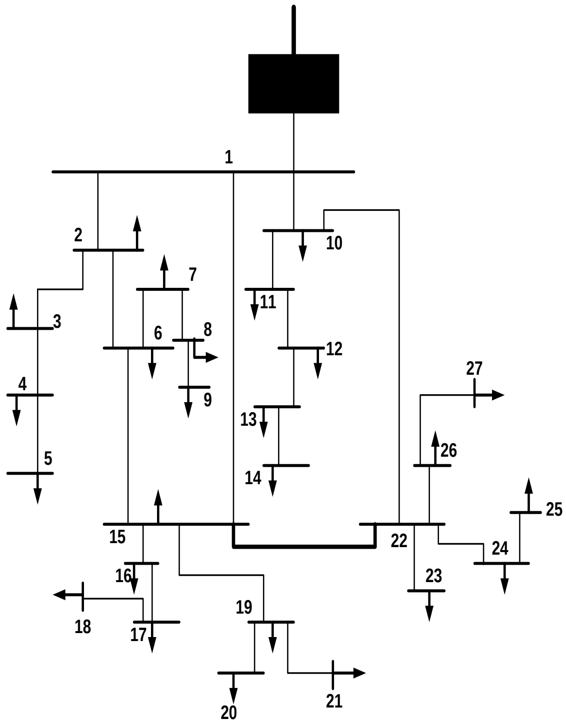

Fig. 3: The single-line diagram of the 27- bus Takarkibah distribution network

3.Simulation Results and Discussion

In this study, only two connection scenarios of PV generation are considered a bus 21 as single location and multiple location scenarios, PV is connected to buses 15 and 22 simultaneously. For each connection scenario, two PV penetration levels scenarios (10% and 20%) were considered to evaluate the effect of PV penetration level and PV location on voltage profile and MW losses in in the 27-bus Takarkibah distribution network. The simulation was carried out using the Time Step Option of the Power World Simulator, whereby both the load and PV generation inputs are varied for each connection scenario and parameters of interest are recorded like the bus voltages, and MW losses in the network. The same load is used for all PV penetration levels and location, to enable us compare the results.

3.1 Voltage Profile

In the section, the voltage magnitudes at each of the buses are recorded. Figure 4, shows the voltage profile of the Takarkibah distribution network as base case (No PV).As we have noted, the voltage value of some buses decrease as the distance from the distribution transformer increases and may become lower than the minimum voltage allowed by the utility, especially for buses 18 to 21 and (25, 27).

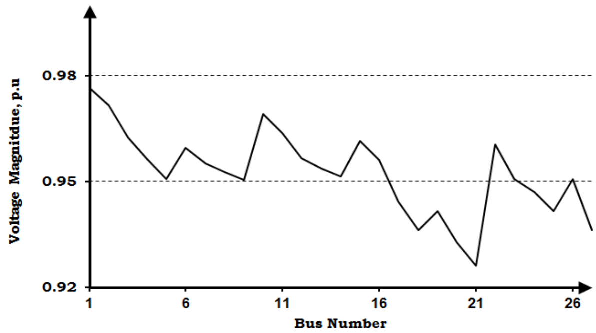

Fig. 4: Voltage profile value of the Takarkibah distribution network as base case (No PV)

In order to investigate the impact of PV Penetration Level on voltage profile, only second connection scenario is considered in this section, PV generation is connected to bus 15 and bus 22 as multiple locations at different combination PV penetration levels from 10% to 20%. The PV unit is assumed to be a PQ bus operating at maximum generation point with a unit power factor. A comparison of the results of voltage profiles are given in figure 5.The voltage value is increased with 10% and 20% PV penetration level due to reverse power flow and all the bus voltages are within the acceptable operating limit. The system voltage profile with PV generation is improved compare to the base case when (No PV) is connected to the network, and the system voltage profile with 20% PV penetration level was much better compared to 10% PV penetration as shown in Figure 5.

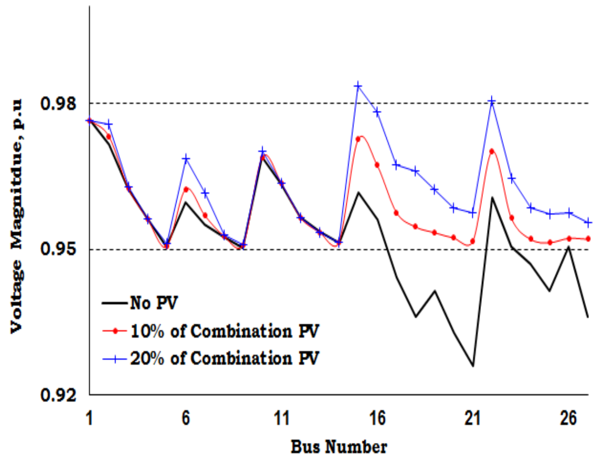

Fig. 5: Voltage profile with 10% and 20% combination PV penetration levels, when the PV generation is connected to buses 15 and 22.

The reason for connecting the PV Generation at different buses is to show the effect of PV location on voltage profile from different areas in the network, and also to choose a suitable connection point bus for the PV Generation which can improve the system voltage profile. Two PV connection scenarios are used to investigate the impact and compared to the base case when no PV generation is connected to the network, in the first scenario PV generation is connected to a bus 21 as a single location and, the second scenario PV generation is connected to a bus 15 and bus

22 as multiple locations with combination penetration levels. The simulation will be processed under 20% penetration level of PV generation. Compared to the base case no PV is connected to the network, the voltage profile is improved when PV generation is connected to a bus 15 and bus 22(multiple location) as shown in figure 6, and all the bus voltages are within the acceptable operating limit. It can be seen from the figure 6 that the voltage magnitude is slightly increased and the voltage value on some buses is below the acceptable value of 0.95p.u when PV generation is connected to a bus 21 as single location. This low voltage problem can be solved by introducing adequate reactive power compensation in the network. The figure also indicates that the voltage profile is better with PV generation at bus 15 and bus 22 (multiple locations) compared to voltage profile when PV is connected to the bus 21 as a single location.

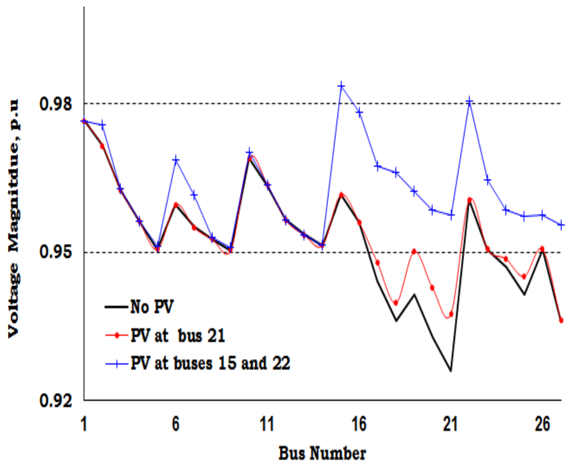

Fig. 6: Voltage profile with 20% PV, when the PV generation is connected to a network at different connection scenarios.

3.2Power Losses

Typical energy losses in distribution network are 10-11% of the energy sold. This section investigates the effects of both penetration level and the location of PV on MW losses in Takarkibah distribution network. The analysis concentrates when the PV generation is operating at maximum generation point.

In order to show the impact of PV generation on real power losses, the simulation results of all penetration level scenarios are compared to the base case (No PV).In this section,Only second connection scenarios is considered. PV generation is connected to bus 15 and bus 22 at different PV combination penetration levels from 10% to 20%. It can be seen from table 3, the value of MW losses decreases with the connection of PV generation from 0.1804 MW in the base case (No PV) to 0.1506 MW for 10% PV and 0.1252 MW for 20% PV combination penetration level. This means that the good effect on decreasing the MW losses especially when the PV penetration is higher.

Table3: System MW losses with PV generation connected to bus 15 and bus 22.

PV Scenarios	load [MW]	Losses [MW]	Losses [%]
No PV	2.2	0.180	8.2%
10% PV	2.2	0.148	6.7%
20% PV	2.2	0.119	5.4 %

Two PV connection scenarios are used, the MW losses are analysed for only 20% PV penetration level. As shown in Table 4, the MW losses are reduced significantly for both PV connection scenarios compared to the base case (No PV). From losses point of view, a PV being connected to multiple locations with combination penetration levels is a better option and will reduce the MW losses more than a single location.

Table4: System MW losses with PV generation for different connection scenarios.

PVfor Different Location	load [MW]	Losses [MW]	Losses [%]
No PV	2.2	0.180	8.2%
(bus 15, bus 22)	2.2	0.119	5.4%
bus 21	2.2	0.167	7.6 %

Conclusion

This paper has investigated the impact of PV and its penetration levels and location on Takarkibah distribution network. This includes the impact on voltage profile and MW losses. The PV generation was integrated into the system and it's modelled as a PQ bus and operated a unit power factor. Different penetration level and connection scenarios were considered. The analyzed concentrates when the PV generation is operating at maximum generation point. The results show that using the PV generation, the voltage profile and real power losses are improved and this improved depends on the production and connection point of the PV generation. From the results presented in this paper, it can be concluded that the improvement shows a direct correlation to both the higher penetration level and multiple locations of the PV. Developers and system operators can decide on the location and penetration levels of new PV generation to be connected to existing systems based on the result presented here.

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