Impacts of distributed photovoltaic generation on Jenin distribution network: voltage level, power losses, power factor and power quality

Maher Jalal Khammash and Marwan Mahmoud
Electrical Engineering Department, An-Najah National University
Nablus, Palestine
maherkh@najah.edu, marwanma@najah.edu

Ibrahim Anwar Ibrahim and Ihsan Omareyh
Electrical Engineering Department, An-Najah National University
Nablus, Palestine
ibrahim.a.ibrahim@hotmail.com, eeng.ihsan@gmail.com

Abstract—**This Study presents the schematic diagram of a complete PV generator with control system (design with detailed specifications) to be connected safely with the electric network of Jenin. The effects of connecting the PV generator to the grid with respect to voltage level, power losses, power factor, reactive power and harmonics distortion were thoroughly investigated in this paper. The effects of this work were that voltage profile has been increased by around 2.15%, the total losses have been decreased by about 0.87%, and total harmonic distortion has been decreased for voltage and current signals at the medium voltage level side.**

Keywords- PV-Power System; DG; PSO Algorithm; THD.

I. INTRODUCTION

Due to the global trend toward the clean energy resources, it is very important to make our projects and researches related with it. Moreover, we need to find the best solutions for improving our power networks taking into consideration the best possible price which is represented in the almost free sources such as solar energy, especially that Palestine is under occupation and we don't have control on our networks or the electricity generation.

Accordingly, the renewable energy resources can only be tapped into distributed system through integration by means of distribution generation (DG) [1].

Distributed Generation (DG) is defined as electrical power generator that consists of distributed resources that are located on the distributed networks or on the customer side. [2].

Governments all around the world try to support the using of renewable energy sources and combined heat and power (CHP) to enhance fuel diversity and to limit the climate-change challenge. Fig.1 shows the annual renewable sources capacity around the word from year 2009 up to 2015 [1].

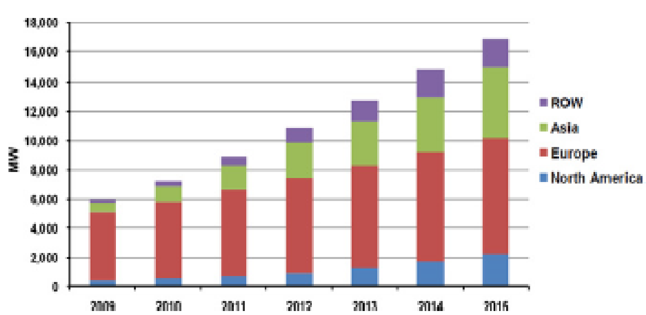

Fig. 1 Annual renewable distributed generation capacity, 2009 to 2015 [1].

Many studies were done to minimize the power losses and increase the voltage level in the system. These studies used the mathematical models like; optimum load flow with second order algorithm method, Hereford Ranch algorithm and genetic algorithm to find the optimal location and sizing as: Fuzzy-GA method, 2/3 rule, which is often used to study the capacitor placement algorithm to determine the near optimum location. Each methodology has its features and potential for applicability of adding PV DG in the power system [2].

II. METHODOLOGY

The methodology used in this study contains two parts, the first part is finding the optimum placement and sizing of DG that can be added to the network in order to reduce the total power losses and maintain the bus voltages in an acceptable range, the second part is studying the effects on the power quality and harmonics in the system after adding DG, then comparing the results with the previous studies to give recommendations about the best locations and sizes of PV DG that can be added to the system.

A. Artificial intelligent optimization technique for distributed renewable generation placement-PSO Techniqe.

From the previous studies it is found that the most suitable methodology to find the optimal location and sizing of the photovoltaic distributed generators to be added to the system is one of Artificial Intelligent techniques called "Particle Swarm Optimization (PSO)" because it is fast and accurate .The selected system was one part of Jenin's distribution network that contains 25 buses of the same voltage level which was used to study the effects of DG PV on the power quality and harmonics in the system [3] ,[4]. The methodology used in this study consists of the following steps:

Step 1: Input the system parameters (line parameters, transformers parameters, and bus voltage limits).

Step 2: Use MATLAB program to run the load flow calculations to find the results in maximum and minimum load conditions. (Bus voltages, voltage drops, power losses, and P.Fs).

Step 3: Add DG from 0% to 15% of total power load in steps of 0.5% to each bus separately at each iteration.

Step 4: Use MATLAB program to calculate the total power losses and check if the bus voltages become within the acceptable range.

Step 5: Use PSO method to find the optimum location and sizing of DG according to the minimum total power losses in the network and to maintain the bus voltages within the acceptable range.

B. The effects of adding PV DG to the system

After finding the optimal location and sizing of DG to be added to the system, the effects of adding PV DG to the system have been studied. These effects are: related to: the voltage level, total power losses, power losses in the branches, P.F, bus voltages and harmonics. The harmonics distortion in the network shouldn't exceed 3% for the total voltage and 5% for the total current [3], [5].

III. Results And Analysis

A. Optimum sizing for PV added:

The solar radiation and the temperature change during the year in Jenin City, and the energy generated from the PV array depend on these terms. So in order to have the maximum efficiency of the PV generator we will use tracking solar system algorithm used by Maximum Power Point Tracker (MPPT) device to change the tilt angle 12 times per year [7].

In this system we used PV array that feeds the feeder at 400 V and unity power factor. Due to fluctuation into solar radiation during each day, we used DC/DC booster converter to have a constant 400 V that will be the input to the inverter [5], [11], [12].

The maximum demand for Jenin system in the months (April., May., Jun., Jul., Aug. and Sep.) is **10.076 MW** and the maximum demand in the months (Jan., Feb., Mar., Oct., Nov. and Dec.) is **1.878 MW**. So if the DG will be 15% of the total load, it will be clear that the PV power needed in (April., May., Jun., Jul., Aug. and Sep.) is 1.5 MW and the PV power needed in (Jan., Feb., Mar., Oct., Nov. and Dec.) is 0.2817 MW.

B. Optimum location for PV added:

When the optimum sizing of DG that will be added to Ayash Feeder shown in Fig. 2 has been found, it is required to find the optimum location for this PV DG by using PSO algorithm. Firstly, we implement this size in all buses in the feeder.

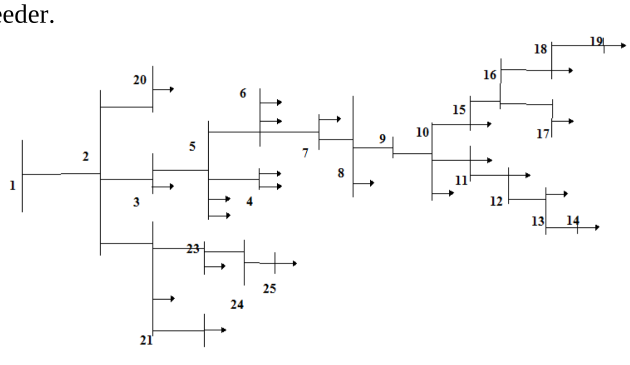

Fig. 2 The system that contains 25 bus at the same Voltage levels.

The PSO algorithm uses for each bus the initial values like: voltage profile, power factor, total real power losses and total reactive power losses to find the optimum location.

The results of using PSO algorithm indicate that **bus #12** is the optimum location for DG PV in the minimum and maximum load states.

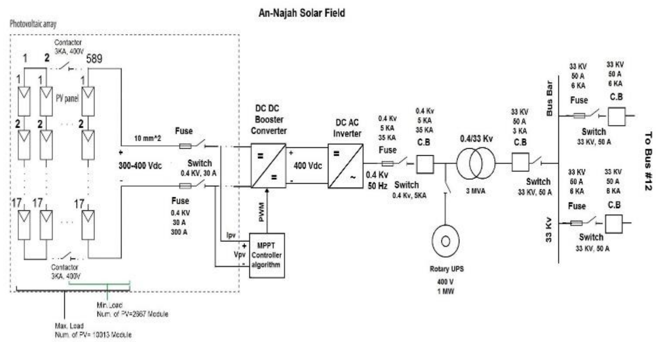

Fig. 3 An-Najah Solar Field

Fig. 3 shows the one line diagram of the solar field that will be used to generate the electrical power needed to feed **bus #12** in the minimum and maximum load states in the grid during the year as mentioned above. This field contains PV modules so that each module generates 300 W DC in STC (1000 W/m², 25ºC, 1.5 m/sec) . Since the monthly average solar radiation in Palestine was 400 W/m² the number of modules required to cover the needed power in the maximum load state was calculated to be 10013 modules and in the minimum load sate it was 2667 modules. In addition fig.3 shows the power electronics devices used to convert the power from DC to AC to feed the AC loads in the grid. Nevertheless the field will contain some devices for protection as C.Bs. To increase the reliability of the system rotary UPS was used, that will feed the load at the maximum load state when the energy generated becomes less than the energy consumed when the solar radiation becomes less than 400 W/m²[8], [11], [12], [13].

C. Imapct of PV DG added to the system:

The total real power fed to the main feeder (Ayash Feeder) after adding DG PV is shown in fig. 4:

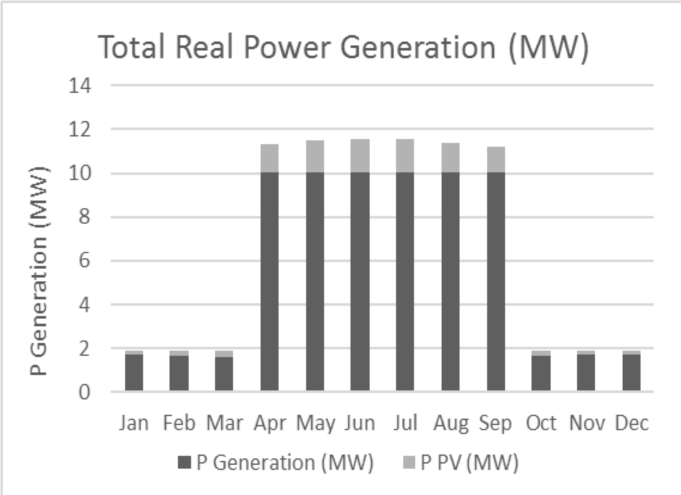

Fig. 4 The total real power fed after adding DG PV on bus 12

The total real power and reactive power losses in the main feeder (Ayash Feeder) after adding DG PV are shown in fig. 5:

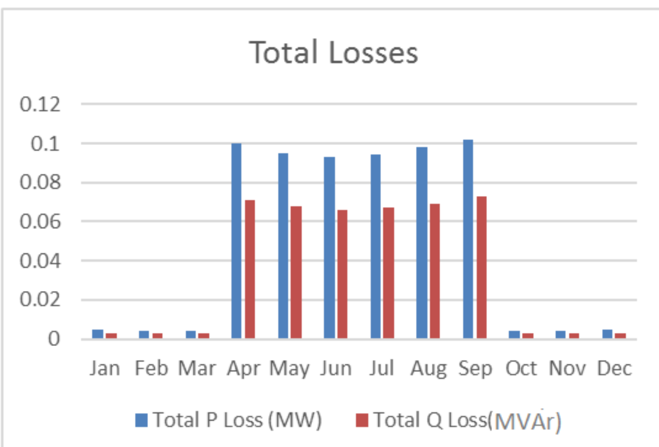

Fig. 5 The total real power and reactive power loss in the main feeder after adding DG PV on bus 12

We can notice from the previous results that:

- The power factor at the main feeder sharply decreases
- The voltage profile at the main feeder gradually increases.
- The reactive power generation remains constant.
- The real power supplied by the main connection point steady decreases.
- The total real and reactive power losses within the system decrease.

The following figures show the effect of adding DG PV to bus #12 on different parameters of the system at each bus.

The affects of adding DG PV to bus #12 on the power factor at each bus is shown in Fig. 6:

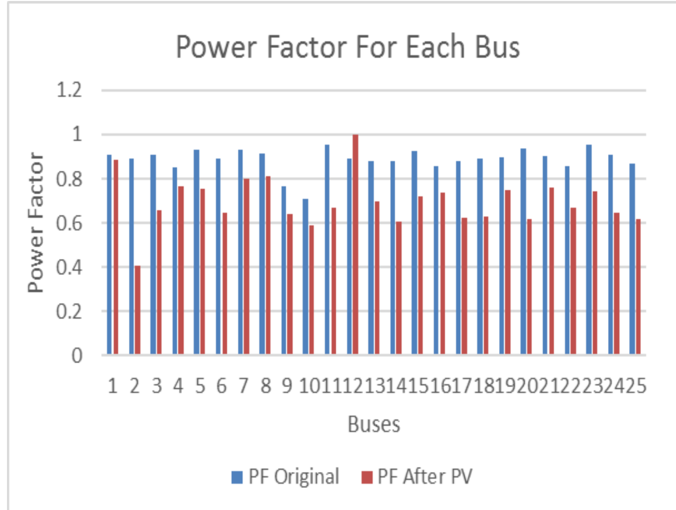

Fig. 6 The affects of adding DG PV to bus #12 on the power factor at each bus

The effects of adding DG PV to bus #12 on the voltage profile for each bus is shown in Fig. 7.

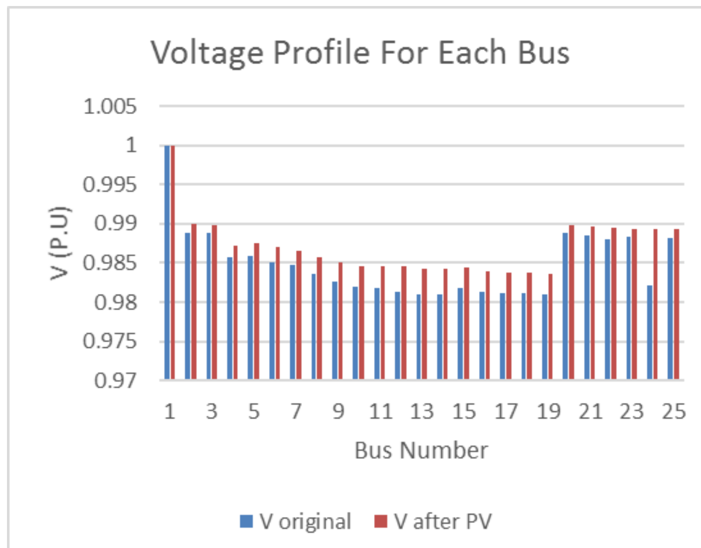

Fig. 7 The affects for adding DG PV to bus #12 on the voltage profile for each bus

The Voltage Harmonic emission in the network after adding DG PV to bus #12 and how it affects the total harmonic distortion (THD) is shown in Fig. 8:

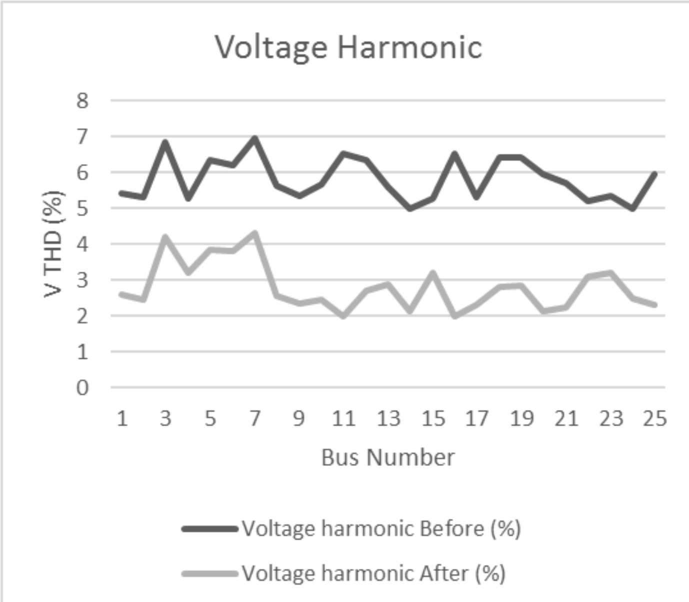

Fig. 8 The Voltage Harmonic emission in the network after adding DG PV to bus #12

The Current Harmonic emission in the network after adding DG PV to bus #12 and how it affects the THD is shown in Fig. 9:

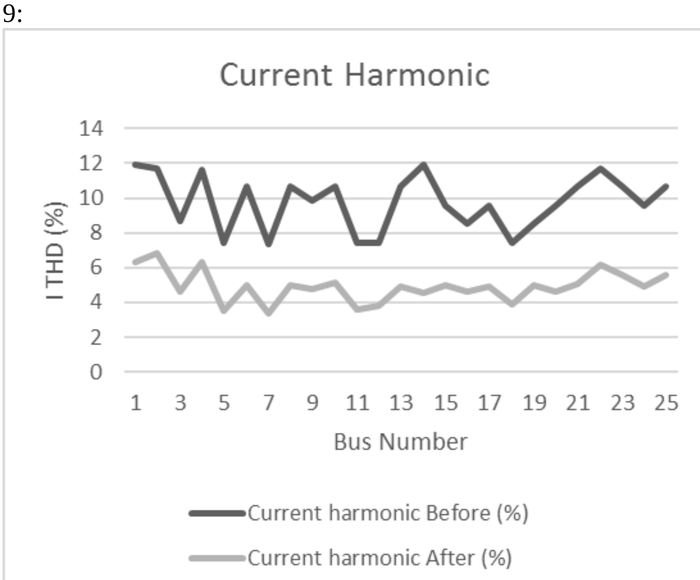

Fig. 9 The Current Harmonic emission in the network after adding DG PV to bus #12.

We can notice from the previous results that:

- The power factor at each bus sharply decrease(Fig 6)
- The Voltage at each bus increases (Fig 7).
- The total power losses decrease.
- The THD decreases for voltage and current signals (Fig8 and Fig 9).

IV. *Conclusions and Recommendations.*

In general, we can conclude that this study is a good solution for this problem due to the improvement that was obtained after adding DG PV to bus # 12 of Jenin Distribution Network.

The effects of adding DG PV on the system can be summarized as follows:

- The voltage profile has been improved so that all the bus voltages become within the range ($0.95 \leq V \leq 1.05$ p.u). This will increase the efficiency of the supply as the currents in the system will decrease and hence the total power losses will decrease, so the total bill will decrease.
  On the other hand increasing the voltage profile allows to add new loads to the same feeder with all voltages remaining within the acceptable range.
- The total harmonic distortion in the system has been decreased. It was found that only the 12th, 15th, 18th, 21st and 24th harmonics exceeded the threshold limits. However, the total voltage harmonics distortion for all of the studied cases was within the Australian regulatory standard limit as stated in AS 4777 [10].
- The total real and reactive power losses decrease sharply. This is due to the increase of the voltage profile and decrease of the currents in the system.
- The total saving in the total bill will be about 24 Million $ for the next 16.5 years, while the life cycle is 20 years for the PVs. [6], [8], [13].
- The only bad effect of this solution was the decrease in the power factor in the system which will cause huge penalties [9], [10],so it is recommended to use capacitor banks to increase the power factor to be equal or more than 92%.

References

[1] Wen-Shan Tan, Mohammad Yusri Hassan, Md Shan Majid, Hasimah Abdul Rahman, Optimal distributed renewable generation planning: A review of different approaches. ELSEVIER 2013; 626-645.

[2] Tuba GÖZEL, M.Hakan HOCAOGLU, Ulas EMINOGLU, Abdulkadir BALICKCI, Optimal Placement and Sizing of Distributed Generation on Radial Feeder with Different Static Load Models. In International Conference on Future Power System 2005.

[3] Krischonme Bhumkittipich, Weerachai Phuangpornpitak, Optimal Placement and Sizing of Distributed Generation for Power Loss Reduction using Particle swarm Optimization. ELSEVIER 2013; 307-317.

[4] William Rosehart, Ed Nowicki, Optimal Placement of Distributed Generation. In: 14th PSCC, Sevilla 2002; 11(2):1-5.

[5] Gilbert M.Masters, RENEWABLE AND EFFICIENT ELECTRIC POWER SYSTEMS. WILY‑INTERSCIENCE 2004; 445-592.

[6] North Electricity Distribution Company, Nablus-Palestine 2013.

[7] Energy Research Center, An-Najah National University-Nablus-Palestine 2013.

[8] SUNTECH Solar Technology AG, 2013, [Online Available]: http://www.suntech-power.com

[9] Standards Australia, AS 4777 Grid connection of energy systems via inverters, Sydney, 2005, [Online Available]: http://www.saiglobal.com

[10] Standards Australia, AS/NZS 61000.3.2: Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase), Sydney, 2007, [Online Available]: http://www.saiglobal.com

[11] SMA Solar Technology AG, 2014, [Online Available]: http://www.smaaustralia.com.au/en_AU/products/solarinverters/ sunny-boy/sunny-boy-1200-1700-2500-3000.html

[12] ABB Automation and Power Technologies, 2014, [Online Available]: http://www.abb.com

[13] Schneider-Electric Com., 2014, [Online Available]: http://www.schneider-electric.com