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# Effect of Photovoltaic Generator on Electric System at Al Jaghbub Oasis

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**Abstract** This paper propose 17MW photovoltaic (PV) power plant in the Al Jaghbub Oasis that located in south of Libya where solar energy is available. This Oasis is connected to Libyan network through medium voltage transmission line and its local load is small. This transmission line experiences a voltage rise, which increases in magnitude of voltage. This project explain how to take advantage of the implementation of solar energy to cover domestic load and export excess power to the grid as well as to reduce the voltage in 66 kV network. Thus application of PV generators has an effect on voltage profile. Also the design of PV power plant and the control system to control active power and power factor are described in this paper. The controlled PV power plant connected to 66KV network has been successfully modeled, implemented and tested using a power system simulation program PSCAD.

**Keywords**: Solar energy in Libya, Al Jaghbub**,** Photovoltaic, Voltage Rise, Ferranti effect.

# تأثير المولدات الكهروضوئية على المنظومه الكهربائيه في واحة الجغبوب

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***الملخص*** تقترح هذه الورقة انشاء محطة للطاقه الشمسيه بقدره 17 ميجاوات بواحة الجغبوب التي تقع في جنوب شرق ليبيا والمتوفره بها الطاقه الشمسيه طوال العام. هذه الواحة متصله بالشبكة العامه من خلال خط نقل من نوع الجهد المتوسط وحملها المحلي صغير، لهذه الاسباب هذا الخط يعاني من مشكلة ارتفاع الجهد. توضح هذه الورقه كيفية الاستفادة من استحدام الطاقة الشمسية لتغطية الحمل المحلي في الاماكن البعيده من محطات التوليد وتصدير الطاقة الزائدة إلى الشبكة العامه وكذلك للمساهمه في معالجة مشكلة ارتفاع الجهد في شبكة 66 كيلو فولت.كما تقدم هذه الورقه تصميم لمنظومة الخلايا الشمسية المزوده بنظام تحكم في القدره الفعاله ومعامل القدره. وقد تم بنجاح تمثيل واختباركيفية عمل شبكة 66 كيلو فولت بدون وجود لمنظومة الخلايا الشمسية وفي حالة وجودها وماهو تأثير استخدام الخلايا الشمسية على الجهد والحمل بالشبكه وذللك باستخدام برنامج محاكاة نظام القدره PSCAD .

**الكلمات المفتاحية:** الطاقه الشمسيه في ليبيا،الجغبوب، ارتفاع الجهد. ظهارة فرنتي.

## Introduction

Current oil prices and the declining costs of renewable power generation technologies have made renewable energy the default option for energy generation [1]. Also renewable energy sources provide a stand-alone power option for areas where transmission and distribution infrastructure does not exist or is too expensive to build. Using of renewable energy sources for the generation of electricity is one of the important ways of reducing carbon dioxide emissions. The solar power (photovoltaic, concentrated) are among the most efficient and cost-effective of renewable power generation types currently available [2-3]. In addition to these benefits, this paper shows the impact of integration of PV systems on power system operation issues in medium transmission line. One of this issues that is focused on in this paper is voltage rise that defined as the receiving end voltage is more than the sending end voltage. An example of voltage rise is "Ferranti effect" phenomena; which is due to the line capacitor and the light loading condition. Thus this voltage rise can be found in the medium transmission line (66 -120 KV) that represented by R and L, with the shunt admittance, usually pure capacitance (the circuit is called a nominal п) [4].

Currently, the everyday load shedding in Libyan network and voltage rise in medium transmission lines between the power stations and the towns located far away from these stations lead the researcher to looking for a solution that could contribute to solve these problems. Solar energy is among the available renewable energy technologies in Libya, has been chosen as a solution to these problems. The case study that used to assess the effect of using PVs on the voltage rise is Al Jaghbub Oasis in Libya. Al Jaghbub has been chosen because the solar energy is available and the Al Jaghbub 66KV transmission line is facing the voltage rise problem. Moreover there is no need of infrastructure in this project because of the 66KV network connected Al Jaghbub to the national grid and other switchgear are already available in 66KV/11KV Al Jaghbub substation, so that will reduce the cost of the project. The proposed project has been tested using Power Systems Computer Aided Design simulation software (PSCAD).

**The Research Goals**: According to the records of the General Electricity Company of Libya (GECOL) the voltage at receiving end at the Al Jaghbub Oasis (69KV) is more than the voltage at the sending end at Tobruk power station (66KV). Due to that this work has been done to achieve these goals:

1)-To solve the voltage rise in the Al Jaghbub network to avoid the voltage instability.

This case is considered as Ferranti effect phenomena; where due to the transmission line between Al Jaghbub and Tobruk is a medium transmission line (66KV) where the capacitance is high. Also due to light loading condition, where the load demand by customers in Al Jaghbub is 2MW. These reasons lead to that the voltage at receiving end (Al Jaghbub) is more than sending end (Tobruk).

2)-To produce the active power to contribute in load energy demand in the Libyan grid.

Recent cases in Libyan network of voltage collapse and similar power system instabilities have been linked to imbalances between the load demand and power supply. So the primary responsibility of utilities is to supply sufficient real and reactive power to the loads [5]. Therefore this work introduces solar energy in Al Jaghbub connected to 66KV Libyan network to trying to cover the load demand in the east southern region of Tobruk.

**Project Description**

The goal of this project is that to use Photovoltaic system (PV) to generate 10.5MW, which can provide the local load in Al Jaghbub and the residual can be transmitted to the Libyan grid through 66KV transmission line connecting Al Jaghbub and Tobruk.

**1. Solar Energy in Al Jaghbub Oasis**

Al Jaghbub is located (29° 45' 0" North, 24° 31' 0" East) to the East south part of Libyan Desert in the south of Tobruk city at a distance of 280 km. 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/m$^2$.day in the southern region; this results in 3000-3500 hours of solar irradiance annually [6–8]. Based on data of Solar-Med-Atlas shown in Fig.1 the average annual sum of the global horizontal irradiation data (GHI) in Al Jaghbub Oasis site is above 2300 kWh/m$^2$/year [9]. Therefore, the utilization of solar energy in Al Jaghbub is reliable during the whole seasons. Due to that the renewable generation type chosen in this project is solar energy

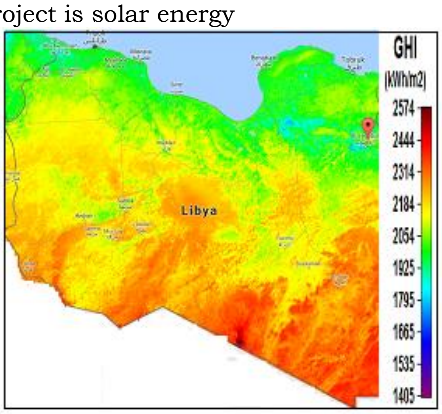


**Fig.1:** Annual sum of GHI on tilted surface for Al Jaghbub site [9].

**2. The Al Jaghbub 11KV/66KV Substation**

Fig.2 show the 66/11KV Al Jaghbub substation that consists of transformers feeders, cables and other switchgear. The local low voltage network 0.4/11KV consists of ten feeders connected to 150 KVA transformers. The two 10MVA power transformers connect the Al Jaghbub substation to Tobruk power station through 66KV network.

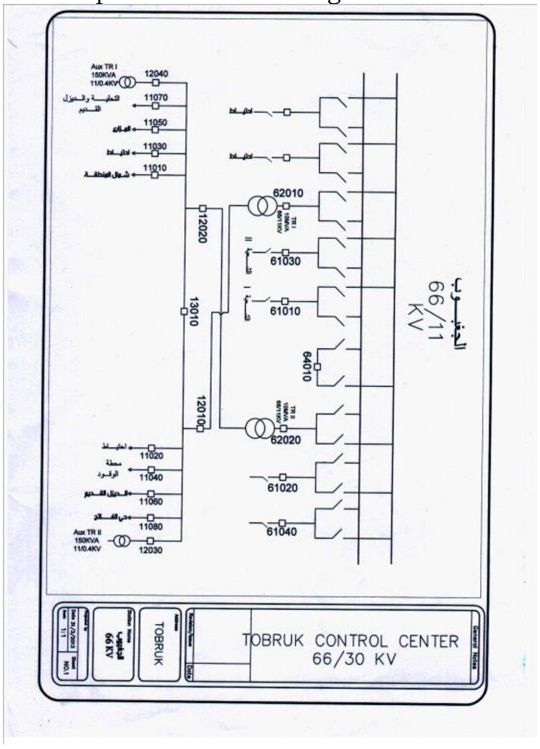


**Fig. 2:** Al Jaghbub 66/11 KV Substation.

***3. The Al Jaghbub PV Power Plant***

Photovoltaic (PV) units, with the help of solar cells, convert the sun light directly into electrical energy. As shown in Fig.3 Photovoltaic (PV) system consists of a PV generator, maximum power point tracker (MPPT), energy storage (for example a battery) and a power conditioning system. A PV generator can contain several PV arrays. Each array is comprised of several modules and each module is built up of several solar cells. The MPPT is used to assure that the PV Array generates the maximum power for all irradiance and temperature values. The battery bank stores energy when the power supplied by the PV modules exceeds load demand and releases it back to the system when the PV supply is insufficient. The power conditioning system contains a DC to DC converter and DC/AC inverter, isolation transformer and filter. Its function is to provide an interface between all the elements of a PV system and the grid, as well as to protect and control the system [10][11].

In this project, Al Jaghbub solar PV power plant consists of several smaller sub-systems or arrangements with 1 MWp (megawatt peak) each. Poly-crystalline modules with capacity of 230 W are chosen in this works. PV modules are connected in series and parallel to get the desired power level (17MW).Thus the photovoltaic generator will require a total of about 73,914 modules divided to 17 modules in series and 4348 strings in parallel. The connection of the PV system to the grid is through power electronic inverter. The inverter converts the DC power produced by the PV generator into AC power with frequency 50Hz. If this system divided to 34 units the required solar panel capacity is 500KW. However in this work the size of each inverter is 400V AC and rating 600KVA is chosen to be capable of absorbing certain amount of reactive power (at power factor 0.85 leading) even at nominal active power output. Therefore, the number of inverters required for the whole system is equal to 34 units with total apparent power of 20.4MVA. The output from the inverters is collected in 11KV distribution network through step-up transformers (400V/11kV). This output energy supply the local load in Al Jaghbub and the residual feed into the national grid through two 10MVA 11/66KVpower transformers that already available in the system. Moreover the other switchgear and protection system are already available in the Al Jaghbub substation. Fig.4 shows PV modules with inverters and transformers connection to the grid.

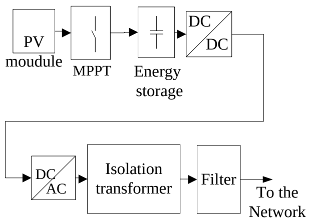


**Fig. 3:** PV modules schematic diagram

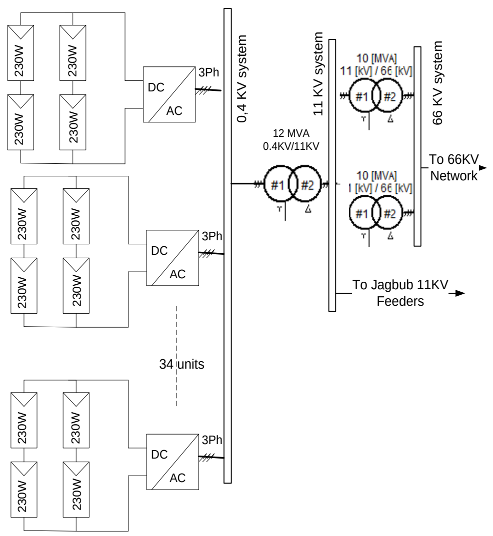


**Fig. 4:** PV Modules connection to the grid

### 3.1 The Al Jaghbub PV Power Plant Control System

The function of the control system is to control the output power, voltage and frequency of the PV power plant before the connection to the grid. The type of the controllers are chosen in this work is active power and power factor controller. Due to the active power must be within the capacity of the PV system and the power factor must be higher than 0.75 (leading or lagging) as specified by the manufacturer [12]. As shown in Fig.5 the basic structure of the active power and power factor control system is a combination of the active power and power factor controllers generating the proper values for voltage angle $\delta_p$ and magnitude V.

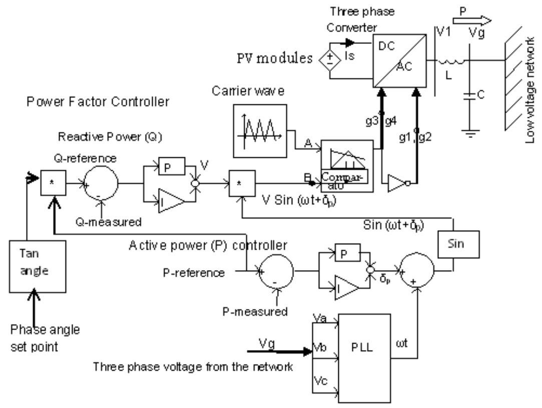


***Fig. 5:*** Active power controller considering constant power factor.

*A) Basic structure of the Active Power (P)-Controller*

The function of the active power (P) controller is to control the active power flow by adjusting the power angle $\delta_p$ according to the following equations:

$$P = \frac{V_0 V_1 \sin\delta_p}{X} \qquad (1)$$

$$Q = \frac{\left(V_1^2 - V_0 V_1 \cos\delta_p\right)}{X} \qquad (2)$$

$$P_{meas} = I_0 . V_0 \cos\phi \qquad (3)$$

Where:

$P$ : active power; $Q$ : reactive power

$V_1$ : grid bus voltage; $V_0$ : converter terminal AC voltage

$\delta_p$ : power angle diference ($\delta_1 - \delta_0$) ,where $\delta_1$ :power angle of $V_1$ ; $\delta_0$ :power angle of $V_0$

$X$ : interconnecting reactance; $\delta_p$ : angle difference between $V_0$ and $V_1$

$I_0$ : Converter output current

$\phi$ : Phase angle between $V_0$ and $I_0$

As shown in Figure .5, the PI controller would suffice to control the flow of active power by generating the proper values for $\delta_p$, based on the instantaneous values of current and voltage taken from the converter output terminal.

The transfer function of the PI controller is:

$$\delta_p(s) = K_{p\delta}\left[1 + \frac{1}{\tau_{i\delta} S}\right].E_P(s) \qquad (4)$$

Where $E_P(s) = \left[P_{ref}(s) - P_{meas}(s)\right]$ (5)

$K_{p\delta}$ : Proportional gain of the PI controller,

$\tau_{i\delta}$: Integral time constant of the PI controller equal to $\frac{K_{p\delta}}{K_{i\delta}}$ where $K_{i\delta}$ is the integral gain. All the PI controllers in this work were tuned using the Ziegler –Nichols Rules [13].

*B ) Power Factor Controller*

The PV system can be controlled to be operated at constant power factor. As shown in the Figure.4, the function of the PI controller is to control the flow of the reactive power (Q) by generating the proper values of the voltage magnitude (V), based on the reference power factor. The reference value of power factor (PF) is defined by the phase angle setpoint where is the power factor is $PF = Cos\phi$.

The reactive power is determined by the magnitudes of $V_0$ and $V_1$ as described in equation (2). If $V_0 = V_1$ then the reactive power flow is zero.

Also $Q_{meas} = I_0.V_0 \sin\phi$ (6)

The value of reactive power that the source can inject or absorb to or from the grid is given by:

$$Q_{ref} = P_{ref} \tan\phi \quad (7)$$

$$Q_{ref} = \sqrt{\left(S_{rated}^2 - (I_s V_s)^2\right)} \quad (8)$$

$$I_s V_s = P \quad (9)$$

The transfer function of the PI controller is:

$$V_{ref}(s) = K_{PV}\left[1 + \frac{1}{\tau_{iV} S}\right].E_Q(s) \quad (10)$$

Where $E_Q(s) = \left[Q_{ref}(s) - Q_{meas}(s)\right]$ (11)

$K_{pV}$ : Proportional gain of the PI controller

$\tau_{iV}$ : Integral time constant of the PI controller which equals $\frac{K_{pV}}{K_{iV}}$ where $K_{iV}$ is the integral gain, $Q_{meas}$ : measured reactive power. In order to detect the angular positions (ωt) of the voltages waveform, the measured three-phase voltages of the low voltage network are fed to a three-phase PI-controlled Phase Locked Loop (PLL). Then this (ωt) is added to the load angle ($\delta_p$) generated by the active power controller. Then the sin of (ωt +$\delta_p$) is taken and multiplied by the output of the power factor controller (V) to obtain three phase sinusoidal voltage waveforms as described below [14]:

$$v_a = V_1 \sin(\omega t + \delta_a) \quad (12)$$

$$v_b = V_1 \sin(\omega t + \delta_b - 2\pi/3) \quad (13)$$

$$v_c = V_1 \sin(\omega t + \delta_c + 2\pi/3) \quad (14)$$

These voltages are the input of the PWM unit to generate the gate signals for the converter.

**Project Implementation in PSCAD**

***1 PSCAD Software***

Power Systems Computer Aided Design (PSCAD) is a power systems simulator that allows for the design and verification of all types of power systems and power electronic controls [15]. PSCAD has been chosen in this work for the testing the performance of the Al Jaghbub PV power plant because already has a very comprehensive library of models and components available. Using PSCAD the Al Jaghbub PV power plant, 66KVelectrical network and Al Jaghbub substation are modeled, implemented and tested.

***2 The Al Jaghbub PV Power Plant connected to Electrical Network***

The photovoltaic project in Al Jaghbub connected to the 66KV network has been successfully implemented and tested using PSCAD/EMTDC. In this work the models of the PV power plant system is simplified to controlled voltage source as a central inverter to control the active and reactive power output. Fig.6 show the connection of Al Jaghbub local network with the 66KV Libyan grid .This network has been modeled to evaluate the performance of the grid with photovoltaic panels that proposed in this work. It includes a 3-phase AC ideal voltage source as (infinite bus) represent the main system connected to 66kV double circuit transmission line. PI Sections models are used to model mutually coupled transmission line systems. Transformer and load represent Alshaba substation connected to the 66KV network .Transformers and loads represent the Al Jaghbub 11KV local network connected to system through 66/11 KV substation.

**Project Simulation Results**

In order to investigate the system voltage and power transmitted behavior with and without PVs connected to the grid at Al Jaghbub. Two types of simulation test have been done, the first is the network without PVs and the other test is with PVs.

***1 Al Jaghbub Network without PV***

The first test carried out without connection with photovoltaic unites and main purpose of that is to investigate and shows the problems of voltage rise that mentioned by GECOL. Fig.7 show the results of the sending end voltage at Tobruk power station is 66KV, the voltage at Alshaba substation is 67.5KV and the voltage at the receiving end at Al Jaghbub substation is 69KV.Thus the results ensured that there is a voltage rise problem at the receiving end.

However the results as shown in Fig.8 explain the, active power output from Tobruk power station toward Al Jaghbub 66KV network is 2.3MW,the active power at Al Jaghbub is 2MW and the active power consumed by Al Shaba is 0.185MW,because of Al Shaba is very small village. The difference between the sending end power and the receiving end powers is the loss in transmission line.

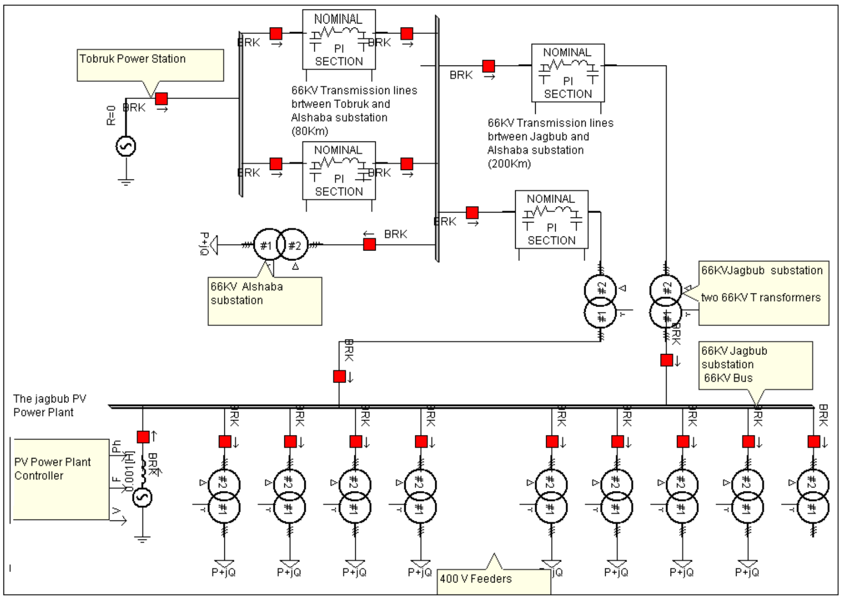


**Fig. 6:** Grid from Tobruk to Al Jaghbub

## 2 Al Jaghbub Network with PV

In this test the PV power plant is connected to Al Jaghbub 11/ 66KV substation shown in Fig.6 and operated at 17 MW at power factor 0.85 leading. The function of the central inverter is to control the injection of active power generated by the PV power plant and absorbing the reactive power. The simulation results show the implementation of PV Generator in the electric system and reduction in voltage rise. As shown in Fig.9 connection of PVs reduce the voltage at Al Jaghbub substation to 68.33KV and at Alshaba substation is 67.3KV. However the results in Fig.10 show the active power produced by PV units toward 66KV network is around 17MW. Also the active power toward Tobruk power station 14.78 this is negative because the direction of power from receiving ends to sending end. Finally Fig.11 show the reactive power absorbed from the system by PV power plant is around 10.5 MVar that means the system is operated at 0.85 leading power factor.

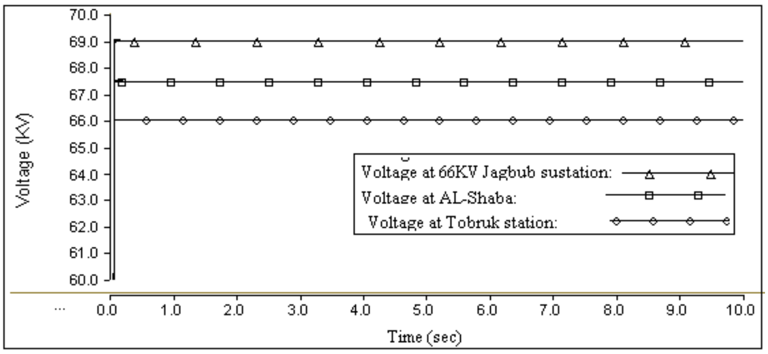


**Fig. 7:** The Network Voltages without PV system.

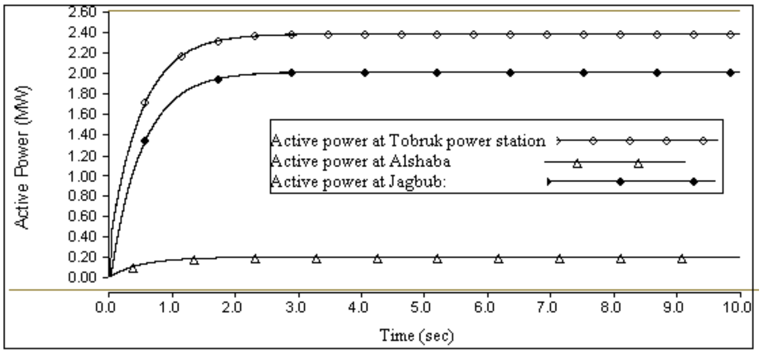


**Fig. 8:** Active Power in the Network without PV system

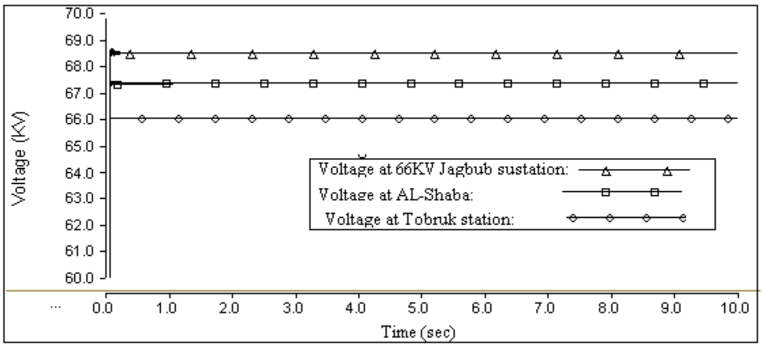


**Fig. 9**: The Network Voltages withPV system

**Conclusions**

This paper explained the problem of the voltage rise issue in medium transmission line and how can the solar energy that available in south of Libya at receiving end contribute to reduce this voltage rise. PV power plant with active power and power factor controllers is presented in the paper. PV power plant connected to 66KV network was modeled and simulated in PSCAD/EMTDC. Different operating conditions of the Al Jaghbub network were carried out when the network with and without PVs. The results showed that the connection of the PVs to the network improving the voltage regulation of the electrical system. Also the generated power by PVs cover the requirement the local loads and contribute in the load demand in Libyan network. Thus it is very useful to implement PV Genrators in the electric systems for loss reducing and improving the voltage profile.

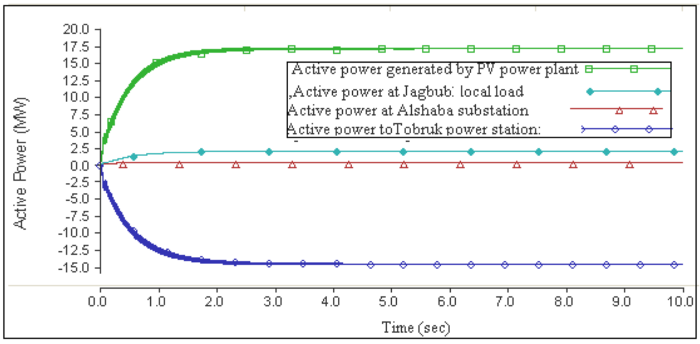


**Fig. 10:** The active power in the network

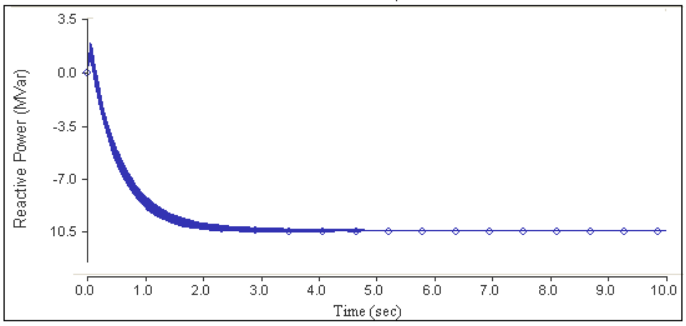


**Fig. 11:** Reactive power absorbing by PV power plant.

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