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Achieving simulation as REBIANA Village Case Study of Photovoltaics System-Based Residential Distribution Grid

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Abstract—The growing demand for photovoltaic (PV)-based buildings and increasing utilization of DC electronic loads, along with decreasing DC appliances prices, have resulted in attraction of DC networks for residential consumers. The main aim of this paper is to present an economic study of a PV system-based DC residential distribution network. This includes designing and simulation of the system that is based on DC residential distribution network. Electrical Transient Analyzer Program (ETAP) software can be used for designing and modelling of the PV system components for a single house and for the distribution grid. The process starts with the PV module, DC/DC converter, battery, and the load. It takes into account all the ratings of the specific components for the whole system. Subsequently, the system efficiency has been evaluated for a common DC home at 24V, 48V, and 110V DC, and compared to the 220V AC through the simulation.

Power losses will be through the conversion and distribution. Based on the obtained results using American Wire Gauge AWG-6 for a single house, it is found that the efficiency of a 48V DC system is higher than that of 220V AC system. It is also found that the usage of 48V DC leads to better efficiency compared with that of other system. This states that the efficiency of the system will increase with increasing of the main bus voltage. At the rest of the paper, the installed capacity for a single house is evaluated at 10 KW per house and this is results in a 2 MWp total installed PV system for 200 houses. This installed capacity can produce 4344 GWh per year. The installed PV system could improve the Libyan grid by reducing losses. Moreover, the installed PV capacity saves around 592,956,000 LD yearly and prevents emission of 328.82 million kg, 5,408,890 million kg and, 4963617743 million kg from gas, heavy fuel, and light fuel respectively.

Keywords—Photovoltaic; Residential Loads; System Efficiency; Economic Evaluation; ETAP Software

I. Introduction

Libya is located in the Mid-North of Africa., with most of the region occupied by the Libyan Desert, northern and eastern Sahara. Libya has six boundaries, which are with Algeria, Chad, Egypt, Niger, Tunisia, and Sudan. It falls in between latitudes 19º and 34º N, and longitudes 9º and 26º E. Libya is considered one of the first oil producers in the world. It has been reported that Libya has the highest oil reserve holder. In addition, in the future, this country will face the challenge of increasing energy consumption[1] [2].

Libya's electricity is based on fossil fuel (Oil and Gas), which are old centralized power plants. While the economy revenue of Libya is depends on fossil fuel resources, Libyan production is about 1.6 mbb/day, which is adequate for less than 30 years [3]. Therefore, Libya requires an efficient plan to convert its electricity system to more renewable, economic, clean and environmentally sustainable system. Based on recent studies, it was reported that the usage of the PV system is the best method to provide an economical source of the electricity in Libya [3-10]. Solar PV or solar energy system is a renewable power network that transforms sunlight into electricity using photovoltaic modules. The generated electricity may be directly stored or used, added to the grid, or combined with one or more other power generators or renewable sources. Solar PV is an efficient renewable power source that can be used for a wide variety of applications, such as for home, manufacturing, farming, livestock etc.

The implementation of AC current took place in the later part of the 19th century as a transmission and distribution network. AC distribution (110V, 60Hz or 220V, 50Hz) is now the standard due to the following reasons: (a) practical conversion with the use of transformers and (b) the electrical machines consisting of a poly-phase AC electrical system. However, DC current has found its mode after the appearance of renewable energy resource and with the DC appliances invention. The renewable energy sources consist of solar and wind energy, fuel cell and biogas. The main advantages of these resources is installation near the load, which in turn reduces the losses from the lines and the overall cross section area of the conductors [11].

Load flow analysis has been conducted in the reported work [11]. It also studied the effect of various voltage stages on the distribution losses and residential load in the system. In addition, the system efficiency for a single house at the same voltage levels has been evaluated and compared with the DC voltages at 220V AC. The results indicate that the 48 V DC is higher efficiency than the other levels. In [12] a load flow study was implemented in a DC network configuration: Radial and Ring. The system efficiency remains the same, but the ring configuration is more reliable. Also, the ring type is low cost since wire size is minimized and a lower system current in turn results in lower losses.

The other parts of this paper is focused on description of the electricity situation, the application of solar energy and the component and station design of the system for Libya. The economic study and the simulation and load flow analysis are given in section seven and eight respectively. Finally, the conclusion remarks are made.

II. Situation of electricity in Libya

Libya is one of main oil and gas exporting nations, economically dependent on these conventional sources and domestically using them for electricity generation. Libya's General Electric Company (GECOL) is fully run by the government and is responsible for most of the electricity generation in the region. GECOL has built many of the power plants in Libya since its establishment in 1984. Fig. 1 indicates the planned nuclear power plants are situated in Libya. The network's generation power is estimated at 8.347 GW while the actual production performance is 6.357GW [13]. The per capita use of electricity grew from 2227kWh in 2000 to 3871kWh in 2007 [13]. Most people are linked to national power grid. The power grid is partially concentrated in eastern and western Libya where the bulk of residents live. Soft coal, hard coal, and natural gas are the fuels types employed by such power plants to satisfy electricity requirements. Our figures are respectively 44%, 31%, and 25%. It had been expected to increase in years following the peak demand for the load.

Nonetheless, the nation has not been legally or economically secure since 2011, and it has impacted many infrastructure sectors, including GECOL. Some had to deal with fraud, and some were lost, leading to severe restrictions in power generation efficiency, causing blackouts especially during peak hours of demand. While GECOL has roughly 26 power stations, as shown in Fig.1, 85 generation systems of different sizes, ages, and inventions are operating around the globe. At least 19 of these 85 systems have reached their redundant cap and will be decommissioned. If such systems are not replaced the total sum would be 9.755GW.

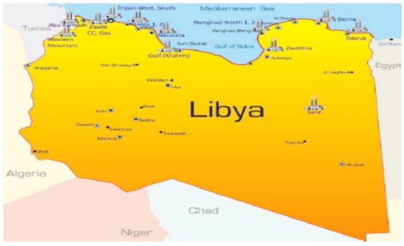

Fig. 1. Position of group plants of GECOL

III. Application of Solar Energy in Libya

Solar energy in Libya is the cleanest and best source compared with others due to the high solar radiation. Solar Power application in Libya, the initial aim for installation of solar in, country was to provide cathodic protection for oil pipelines. Later in 1980s solar systems were used by the telecommunication sector for providing power to microwave repeater station at Zalla. 120 communication stations have been using solar power till 2006. Water pumping stations were running by solar power of 120kWh by year 2012. Rural electrification system using solar system was introduced in 2003, by end of year 2006, total remote systems installed by GECOL reached 440 and installed power reached 405kWh. At end of 2012 the total rural electrification reached 725kWh [14]. Solar power also has been studied in Benghazi for solar water heater project of 5000 homes over time span of 20 years. Also, in Almarj city, which located 74km east from Benghazi, has implemented solar power to give power to LED street lightning at beginning of 2017. Furthermore, not only small scales solar power in Libya have studied but also implied for large scale application including, concentrating solar power system CPS applications and centralized solar stations have studied recently [14].

IV. Case Study: Rebiana Village

Rebiana is located in southern Libya, approximately 2000 km from Tripoli city and 1000 km from Benghazi city [11]. Coordinates are 24° 30'0 "N" and 21° 0'0"E in DMS, or 24.5 and 21 (decimal). The average temperature in Rabiana is about 39.8°C per week in season, and the mean northern radiation is between 7 kWh /m2 and 8kWh / m2 in the far southern regions, including around 3500 hours of sunshine [3]. Fig.2 illustrates the monthly average solar radiation in Rebiana city from satellite software application.

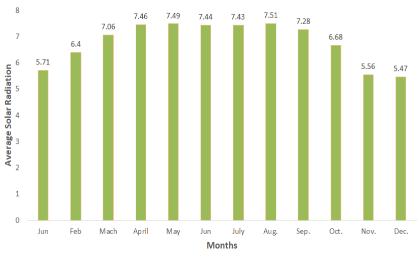

Fig. 2. Average monthly solar radiation kWh/m2/day in in Raibana city.

The major problem in Rebiana residents are suffering deeply from is lack of electricity, with residents of Rebiana living without electricity more than a year, although there are many alternatives solutions such as renewable energy, that includes wind energy and solar PV energy. Until at moment Rebiana has not connected with the grid yet. Rebiana has been supplied electricity by Diesel generator capacity 3MW since 1980 which are four decades, but the generators are broken down continually and replaced more thousand times due to the rising of the temperatures.

Fig. 3. The existing electricity state in Rabiana

V. System Design

Table 1 shows the optimized DC loads. Where the average appliance consumption considering the desired system efficiency.

TABLE I. Average power consumption of DC house [14].

Device	Rated Power (Watt)
LED Lighting	9 W
TV	100
Refrigerator	50
Personal Computer	80
Washing Machine	100
Mobil Charger	20

The optimum angle of the solar panel inclination in Libya is approximately the latitude angle [5]. Rechargeable battery, solar panels, and the loads is what the solar powered DC house systems consist of. Additionally, the system requires cables, cable joins and screw bolts. The total energy of a DC house daily and during night are presented in table II and table III respectively.

TABLE II. Total Energy consumption and the Rated power of DC house loads.

Device	Rated Power Watt	N^0 of Devices	Total power Watt	Average Operation Hours	Energy Consumption
LEDLights	9	10	90	12	1080
TV	100	1	100	5	500
Fridge	50	1	50	24	1200
Computer	80	1	80	1.5	120
Washing Machine	100	1	100	1	100
Mobil Charger	20	1	20	3	60
Total			**490**		**2960**

TABLE III. Total Energy consumption during the night-time loads

Device	Rated Power Watt	N^0 of Devices	Total power Watt	Average Operation hours	Energy Consumption
LED Lights	9	5	45	12	540
TV	100	1	100	1	100
Fridge	50	1	50	24	1200
Total			**195**		**1840**

$$C_R = \frac{L_d \cdot d_a}{\eta \cdot DOD} \quad (1)$$

Where Ld refers to the daily load in Ah i. The d_a presents the days of autonomy, η is charging efficiency.DOD is battery depth-of-discharge. The number of days is 3 in autonomy, efficiency of the charging is 0.9 and the DOD is 60%. The battery size required is then 150 Ah, the nearest standard is 150 Ah. It should be noted that over sizing the battery means increasing the system cost while under sizing the battery means that the system may not meet the energy demands.

PV Panel Sizing: From table III, the average solar radiation of 7kWh/m2. To fulfil the load requirements, array size should be [5]:

$$P_{PV} = \frac{P_{peak}}{R_{lowest} \cdot \eta_d} \quad (2)$$

Where, Ppeak is the load peak power, R_{lowest} is the sunshine hours of the month with the lowest radiation, and ηd is the dust accumulation factor, the PV panel rating is 422.86 W. The nearest standard is two 250 W or two 235 W panels.

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VI. PV POWER PLANT DESIGN

The design of PV for the plant system is subjected to the total obtained power from the system. It was found that the essential components are important for designing the large scale of PV systems. 25 years is around the lifetime of the plant system. The PV panel, DC/DC converter, distribution panel, and the cables are essential parts of the plant systems. These components are discussed in detail in the following sections.

A. PV Panels

The Specific of PV module using in this paper is shown in table IV below. The maximum power at standard condition is 235 Wp.?

TABLE IV. PV PANEL PARAMETERS

Model	Cyocera Power 235
Rated Power (Pmax)¹	235 W
Maximum Power Voltage (Vpm)	30.13 V
Maximum Power Current (Ipm)	7.7 A
Open Circuit Voltage (Voc)	36.56 V
Short Circuit Current (Isc)	8.48 A
Temperature Coefficient (Pmax)	-0.587 % / °C
Temperature Coefficient (Voc)	-0.046 V / °C
Temperature Coefficient (Isc)	2 .01 mA / °C
Cell Efficiency	15.5%
Module Efficiency	17.2%
Series Fuse Rating	15 A
STC: Cell Temp. 25°C, AM1.5, 1000W/m²	

B. DC/DCConverter

A DC/DC Converter is one of the main components in the system. They regulate DC output of PV system, the DC/DC converter is important, and the parameters of the converter used are presented in table V.

TABLE V. DC/DC PARAMETERS

Rated power (KW)	50
Input Voltage	110
output voltage (V)	48
Efficiency	90%

C. The Battery

A battery is a crucial part in the standalone PV system. The batteries are charging during the daytime and discharge in night. The battery used has a capacity of 200 Ah and the battery specification are as shown in table VI

TABLE VI. THE BATTERY SPECIFICATION

Capacity	200 Ah
Open-Circuit Voltage per Cell	2.06
Resistance per positive plate in ohms	0.0015
Battery rated discharge time in hours	8
Rated / Base Temperature in degrees Celsius.	25

VII. PLANT DESIGN CALCULATIONS

The design of a 2MW PV is given in this section. The component parameters are given in the previous tables. The total number of PV modules, which will be connected, can be calculated based on the presented parameters by dividing one MWp into five 200KWp [7].

The number of PV modules per 200Wp = 200KWp/ PV module capacity= 200KW/235W=851 module

The total number of the PV modules per 1MWp = 851×5 = 4255 PV module. The total number of modules in 2 MWp are 8510.

Number of modules per 200Wp in series = Bus voltage-rated /Voc module=110/30.13 = 4 modules. Number of modules per 200Wp in parallel=851/4=213.

Therefore, four modules connected in series and around 213 models connected in parallel were used to obtain 200KW. By using the same method of 1 MWp and 2MWp, it was used to conduct the number of series and parallel units. The system has 200 house each one need DC/Dc converter. Therefore, the total number of converters is 200. Also, the house needs two batteries. The total number of storage units are 400.

TABLE VII. 2 MWP SYSTEM SPECIFICATION

Item	Rating	Quantity
PV Panels	235 KWp	8510
DC/DC Converter	20 KW	200
Battery	200 Ah	400

Regarding the cost of 1MW is around 1.33 Million /MW [12] and about 2.66 million is the total cost of 2MW. PV mduels represents 42%, Converters 13%, Cables 4%, Security 1%, Frame 17%, Project managment 6%, and the grid 15%. The total cost of 2MW is shown in table VIII.

TABLE VIII. THE COMPONENT PRICE

Components	Price $/MW
PV modules	1,117,200
Converters	345,800
Cables	106,400
Security	26,600
Grid	399,000

Frame	452,200
Project Management	159,600
Total cost	**2.66 million dollar**

A. Operation And Maintains Costs

The Operation and Maintenance (O&M) costs are very low compared to other resources. There are many factors that (O&M) costs depends on for example, the project location and the surrounding environment. (O&M) costs represents about 8% $/ mega watt [7,10]. Then the total (O&M) costs for 2 MW equal $212,800 million.

VIII. Economic Evaluation

It requiries a 2 MWp PV system to produce the electricity needs of a 400-house in Rebiana-Libya town. In order to have critical loads seen in the first table 5KWp / house, the total capacity can be installed. Table IX compares costs of the electricity generated from the conventional way and a PV system.

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Total cost	**2.66 million dollar**

The life expectancy of the PV system is roughly 20 years. About 592,956,000 LD will be preserved for 20 years. In addition, the PV system would save 10,392million bbl when the loss of grid is ignored. Libya's grid losses are about 30% [5]. The power generators would need to generate about 5647.2GWh, causing an annual burn of about 13,510 million bbl which increases their CO_2 emissions. Table 5.19 shows CO_2 pollution factors in Libya.

The largest cause of CO_2 emissions is fossil fuel. Table X notes that the CO_2 emission level depends on the fuel type. In Libya a small volume of fuel oil produces 418 kWh, while 500 kWh is provided by a hard fuel oil barrel and 3,1722kWh by a cubic meter.

To generate5647.2GWheither 13,510 million bbbarrel of light oil, 11,294.4 million bbbarrels of heavy oil, or 1777.4 million m3of natural gas burning required.In most of the feasibility studies, the CO2 emission cost is not counted. CO_2 can in many ways affect the economy by reducing agricultural production and impacting the health of humans and animals. According to a new report by scientists at Stanford, the cost of CO_2 is called "social impact" and is measured at $220 per ton of CO_2. Table X below lists the social costs of various forms of petrol.

TABLE X. AMERICAN WIRE GAUGE TO

Fuel type	Gas	Light fuel oil	Heavy fuel oil
Conversion Factor	0.185 Kg CO_2/KWh	2.518 KgCO2/liter	2. 764 Kg CO_2/liter
Fuel Amount	1777.4 million m3	13,510 millionbb	11,294.4 million bb
CO_2 emission	328.82 million Kg	5,408,890.620 million Kg	4,963,617.734 million Kg
CO_2 social cost	72,340,400 LD	1,189,955.936 million LD	4,963,617 million LD

IX. Simulation and Result

ETAP will be used to estimate the efficiency of the DC Power-house, which is able to model PV resources and other factors such as the static loads, DC/DC converters, and used wire cables. The test for the system will involve 3 steps that are related to static load, DC/DC converters and wire cables. After that, the power flow study will be used to record the efficiency. By using various AWG, the efficiency will be studied [15-16].

X. Test Results of System Integration

XI. Study and Analysis of Load Flow

To estimate the load flow analysis, the ETAP software was applied based on the bus voltages, flow of current and power and branches loss. The load flow analysis in ETAP will support to have an idea regards the behavior of the power system in different conditions. This will also supports for effectively designing systems before the real operation.

A. Results of Efficiency

The first stage of optimize bus voltage is testing the AWG efficiency. In this case, the copper loss in the wire will be determined. Where, the highest voltage drop is due to highest wire resistance, based on $P = I^2R$. Fig. 4 and 5.

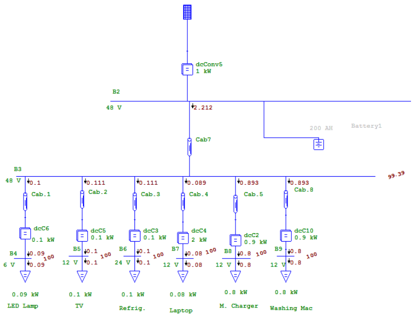

Fig. 4. Load flow Simulation During Daily Time

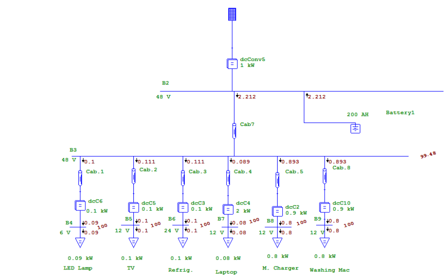

Fig. 5. Load flow Simulation During Night-time

For varying AWG values in the main bus voltage system, for each wire gage, the test of the system was measured. It can be said that there is a proportional relation between the AWG No and the main bus voltage drop. Based on this, the system efficiency is optimized.

TABLE XI. AMERICAN WIRE GAUGE TO THE AREA (MM2) AND DIAMETER (MM) CONVERSION.

American wire Gauge	Diameter (mm)	Area (mm2)
12	2.0525	3.3088
10	2.5882	5.2612
8	3.2636	8.3656
6	4.1154	13.3018
4	5.1894	21.1506
2	6.5437	33.6308

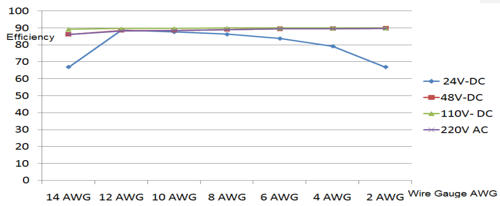

Fig. 6. Comparison of system efficiency for AC 220 V DC (24,48, and110) with different wire gauge.

Efficiency comparison of AC 220 V DC (24,48, and110) at various wire gauge.

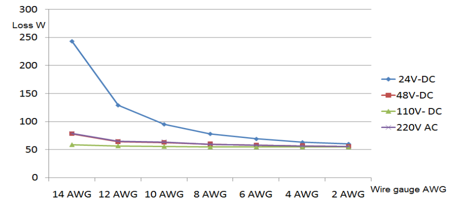

Fig. 7. Losses comparison of AC220V and DC (24,48, and110) at various wire gauge

XII. SYSTEM MODELING FOR 200 HOUSE

This section discusses the implementation of 200 DC houses with the 100kWp PV plant. Firstly, the system is divided in 4 groups each contents 50 house the fifty houses is divided in five streets represented in networks 2, 3, 4 and 5. For each network, the load flow results is displayed in Fig. 8. Then the system is divided into four subsystem each has 5 streets each street 10 houses the total is 200 house this the project target as presents in Fig. 8below.

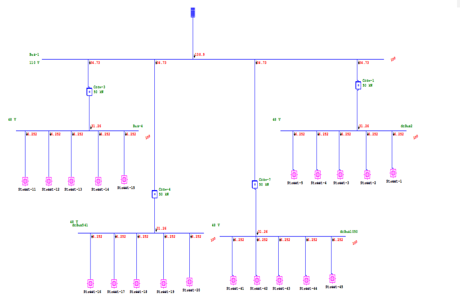

Fig. 8. Load flow simulation with 200 DC house

XIII. CONCLUSION

Economic evaluation, design and simulation of a DC network-based PV system is illustrated in this work. The paper shows a complete ETAP model in order to carry out the load flow analysis, optimize the main bus voltage, obtaining the highest system efficiency. The test was based on AWG efficiency, bus voltage percentage, and the efficiency of DC/DC converter, refrigerator, laptop, washing machine, charger, and TV. The system is tested under two scenarios: The first scenario the impact of various voltages 24V, 48V, 110Vand 220 V AC on residential system is analyzed. Also, the losses due to the conversion and distribution were reduced. The PV plant system is designed for 2 MW to feed the whole system. The installed capacity costs 2.66 million dollar and can generate 4344 GWh per year. It was also found that the reduction of losses led to an improvement in the electricity of PV system. Besides, around 784 million bbl per year will be saved by using PV, along with obtaining a friendly and sustainable environment.

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