Techno-Economic Impact of Electrification Rural Areas in Palestine using Micro-Grid Solar Energy “Al-Mkahel& Saeed Villages – Case Study”

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ABSTRACT:
Palestine has a large number of remote small communities with no electricity services and the probability of connecting them with local grid in the near future is very poor, because of political and financial issues. This paper will illustrate the techno-economic impact of electrification small communities using micro-grid photovoltaic systems, and also the CO2 emission that will be reduced in comparison of using diesel generator which pollutes the environment. The implementation of two micro-grid PV-systems for electrification of two communities in Palestine will cover the electricity needs of households and street lighting, and can replace candles, kerosene and traditional unsustainable biomass and diesel generators. Beside economic and social benefits, micro-grid PV systems also have positive impacts on people’s health and on the environment due to the reduction of smoke and toxic waste.

KEYWORDS: Energy Poverty, Rural Electrification, Micro-grid, Off-grid PV System, Sustainable Development.

1. INTRODUCTION
Palestinian Territories suffer from severe shortage of energy supply as well as the fluctuations of energy prices. The Palestinian authority has no control on borders so all energy products are bought from Israeli companies [1].

Large number of villages and small communities still are utilizing small diesel generators to cover their electrical energy demand in Palestinian territories, as most of them are isolated and far away from the electric grid. Normally the working hours of the diesel generators in those localities are limited to small periods of time. Moreover, the price of diesel fuel is high and keeps increasing in additional to frequent faults which require continuous maintenance. High percentage of air pollution is released from the exhausts of the diesel generators. Therefore, the use of diesel generators is ineffective option for rural electrification.

Palestinian Energy Authority (PEA) is paying great attention to exploit the photovoltaic energy to mitigate the energy crisis of the isolated villages and localities. Palestine is granted high solar radiation potential and high sunshine hours throughout the year in which the horizontal yearly average daily solar radiation is about 5.4 kWh/m2/day with about 3000 sunshine hours. [2]

The PV electrification could be using the decentralized stand alone and centralized systems depending to the nature of the load and the distribution of houses.

Photovoltaic electrification is limitedly used in different rural areas in Palestine mainly for schools, clinics, Bedouins communities, agricultural and animal farms, and private homes.

2. CASE STUDY: REMOTE VILLAGES AL-MKAHEL & SAEED-IN YABAD-JENIN.

Khirbat Al-Mkahal is in the south west of Jenin district, the nearest city is Yabad which is 5 km away, the location coordinates for Al-Mkahal village are as follows: 32º 25’ 15, 85”N and 35º 07’ 33, 94”E.

Depending on a comprehensive assessment on non-electrified villages in the West Bank, Al-Mkahal was found to be one of the most appropriate villages to be subject to a socio-techno-economic impact study of electrification by mini off grid Centralized PV system [4].
Al-Mkahal village inhabitants work mainly in farming and cattle breeding and some of young people are working as construction workers. Their number amount to about 70 individuals, 10 families. Drinking water is obtained from artesian wells in the village area. Some people were using candles and gas cylinders for lighting, cooking and pumping water and sometimes they operated old generator for 2 hours at maximum due to costly and high fuel consumption, so the cost of energy consumption will be over 50 US$ /month for some families, including the cost of transportation.

Al-Saeed Village is in the southwest of the province of Jenin. The closest urban center is the city of Y’aabad which is 3 km away. The village is located at bottom of mountain where the settlement was built on top. The location coordinates are 32° 25’ 23”N and 35° 10’ 56”E.

People were also using candles, batteries and gas cylinders for lighting, cooking and pumping water, this sources is costly due to transportation and they have high dependency on them because there are no other power resources, so the cost of energy consumption was higher than 50 US$/month for some families.

3. DESIGN OF PV SYSTEMS

3.1. Measuring Solar Radiation (Solar Energy)

The availability of solar radiation will affect the power output of PV modules, as the generated energy will decrease in rainy and cloudy day. The readings indicate that the annual average solar radiation rate is 5.4 kWh/m2/day for both sites, and the maximum value was 8.19 & 7.56 kWh/m2/day in June for Saeed and Mkahel, respectively, while the minimum solar irradiation was in December of 2.7 & 3.13 kWh/m2/day.

So according to the result collected using weather station sensors in area, we can easily analyze the performance of PV system.

![Irradiation - Khirbat Saeed.](image)

Fig. 3. Irradiation - Khirbat Saeed.

![Irradiation - Khirbat Saeed.](image)

Fig. 4. Irradiation - Khirbat Saeed.

3.2. Selection Elements of System Design

3.2.1. Electrical load

An estimation of family user daily consumption has been realized based on the information in questionnaire and the beneficiaries needs regarding the electricity.

The estimated daily demand and all the appliances which will/may be used in communities are shown in Table 1.

| Applications          | # quantity | Power (Watt) | H/day | W.h/day |
|-----------------------|------------|--------------|-------|---------|
| PL lamp               | 2          | 11           | 4     | 88      |
| TV                    | 1          | 120          | 5     | 600     |
| Radio                 | 1          | 20           | 5     | 100     |
| Mobile charger        | 1          | 10           | 1     | 10      |
| Small refrigerator    | 1          | 200          | 5     | 1000    |
| High efficient washing machine | 1 | 180 | 2 | 360 |
|                       |            |              |       | Total= 2158 |

Using high efficient appliances in this kind of project, the total loads in the village will be around 21, 58 kWh/day.
### 3.2.2. Electrical load

In selecting a suitable PV module when designing PV solar system to cover average load energy demand of (21580 Wh/day), PV array size can be determined, using the following equation [4].

\[ \text{PPV-array} = \text{EL} \times \text{Sf} \times \eta_v \times \eta_R \times \text{PSH} \]  

(1)

- **EL**: Estimated average daily load energy consumption in Wh/day (21580 Wh/day)
- **PSH**: Peak Sun Hours (5.4 h) [5]
- **\( \eta_v \)**: Efficiency of inverter (95%)
- **\( \eta_R \)**: Efficiency of wire losses (97%)
- **Sf**: Safety factor (1.15)

\[ \text{PPV-array} = 4987 \text{ watt} \]

The PV module of type 135 Wp Canadian solar is installed in this project, so number of modules in system (Nm) is determined in following equation:

\[ \text{Nm} = \frac{\text{PPV-array}}{\text{Pselected module}} \]  

(2)

\[ \text{Nm} = 36.9 \approx 36 \text{ module} \]

### 3.2.3. System Voltage Selection

Selecting the operating DC voltage of standalone PV system is based on system requirements, so the selected system voltage is 48 Vdc.

According to system voltage, the number of modules in series (Nms) is calculated according to the following equation:

\[ \text{Nms} = \frac{\text{Vsystem}}{\text{Vmodule}} \]  

(3)

\[ = \frac{48}{17.6} = 2.72 \approx 3 \text{ module in series} \]

The PV array is composed of 36 PV modules on galvanized steel metallic support and distributed by three sub-array of 4 string and each string has 3 modules (3 modules * 4 string * 3 sub-array=36 modules), the array capacity is 4.86 KWp of 135Wp PV module, and also with approximated area of 38.88 m².

So, the modules of system were installed in series, and as a result:

- **V Oc.array**: 22 × 3 = 66 V
- **I Sc.array**: 8.19 × 4 = 32.76 A

### 3.2.4. Sizing of Battery Bank

Battery is the most important part in stand-alone PV system, so we consider that the battery will cover the needs of beneficiaries at night and cloudy day which required high efficient battery. The capacity of battery(CA-H) is measured in Amper-hours, As in the following formula;

\[ \text{CA-H} = \text{Nc} \times \text{EL} \times \frac{\text{VB} \times \text{DOD} \times \eta_v \times \eta_R}{\text{Nc}} \]  

(4)

- **Nc**: Numbers of days of autonomy (1.5 - 3 days)
- **VB**: Operating voltage for system (48 V)
- **DOD**: Maximum depth of discharge (0.6-0.75)

\[ \text{CA-H} = 1045 \text{ A.H} \]

### Table 2. Characteristics of installed batteries.

| Battery Module Type | AGM LEAD ACID RITAR 2 V |
|---------------------|--------------------------|
| No. of Battery Bank | 24                       |
| Capacity (100)      | 1000 Ah                  |
| days of autonomy    | 1.5                      |

\[ \text{CWH} = \text{CA-H} \times \text{VB} \]  

(5)

CWH = 1000 Ah \times 48 V = 48 Kwh

### 3.2.5. Sizing of Charge controller

The basic function of charge controller is to extract as energy as possible from PV array in order to maintain a high state of charge of the battery and avoid its complete discharge, so it controls the cycle of charge and discharge avoiding over charge and deep discharge.

After selecting the charge controller, it was considered that the unit has the following characteristics:

- High efficient charge controller with low self-consumption
- Maximum Power Point Tracker (MPPT) to get the maximum power of PV array
- Possibility to maintain the batteries at floating voltage to compensate the losses in case of full charge
- Advanced algorithm of charge and discharge control

The size of the charge controller will be selected according to following equation:

\[ \text{P} = \text{VB} \times \text{I} \]  

(6)

\[ 4860 = 48 \times I \times 1.15 \]

\[ I = 88 \text{ A} \times \text{Sf}^2 \]

\[ I = 110 \text{ A} \]

\[ \text{Sf}^2 \text{ Safety factor (1.25); in special conditions, the panel produces more power from its normal rated (about 25% - 30%). For example, sun light reflects from snow, water.} \]

So, the MPPT- 150 A and peak efficiency of 97.5% were used,
For selecting the inverter which will be used in project; the system voltage, output voltage 230V/50Hz, low self-consumption with efficiency, max charge current > 15A and as well as, the input of inverter have to be matched with the battery bank voltage as in electric grid as follow [6]:

\[ \text{Rating inverter} = \text{PV rating} = 135 \text{ Wp} \times 36 = 4860 \text{ W} \]

\[ \text{The input energy of inverter} = \text{PV rating} \times \text{PSH} \times \eta_R = 4860 \times 5.4 \times 0.97 = 25,456 \text{ Wh} \]

The output energy of inverter = input energy of inverter \times \eta_V = 25456 \times 0.95 = 22974 \text{ Wh}.

The inverter with high efficient sinusoidal bidirectional generator with self-consumption less than 10 W was used, the working voltage is 48Vdc and the output voltage is 220V/50Hz, with capacity of 5 kW.

### 3.3. Total Energy Generated by PV Power Plant

The system was monitored using data logger and the data was collected and stored each hour, so the total produced energy on monthly and annually basis can be obtained, using the following equation:

\[ E_t = \text{sum (Em1+Em2 \ldots \ldots \ldots Em12)} , \text{where} \ m1 = \text{January}, \ldots, \ m12= \text{December} \]

\[ E_m: \text{Actual energy production by plant in month (KWh)} \]
\[ E_t: \text{Annual energy production by plant (KWh)} \]

The estimated energy generated by PV plant: In order to inspect the performance of PV power plant in reference to global and technical factor, the estimated energy that may be produced using this PV plant have to be calculated, using the following equation:

\[ E_e = H \times A \times \eta \]

\[ E_e: \text{Estimated energy generated by PV plant (KWh)} \]
\[ H: \text{Irradiation (KWh/m2)} \]
\[ A: \text{Net plant area (m2)} \]
\[ \eta: \text{Efficiency of photovoltaic module in operating condition} \]

The following figure shows the actual vs. estimated Energy output and the load consumption in both villages.

#### 4. TECHNICAL IMPACT OF RURAL ELECTRIFICATION IN AL-MKAHAL AND SAEED VILLAGES

**4.1. Performance Ratio (PR) of PV systems**

This impact factor is called also quality factor because it measures the actual energy ratio to estimated energy and shows the losses effect on yield due geographical and season factors which affect the PR value to fall to 40% to 90%, and for well-designed system PR ratio range is 70-90% [3, 5]

\[ \text{PR} = \frac{E_t}{E_e} \text{ (for annual PR)} \]
\[ \text{PR} = \frac{E_m}{E_e} \text{ (for monthly PR)} \]
The annual average of PR is 71%, and the maximum value of PR is 93% in August, 2015 and the minimum value of PR is 43% in February, 2017.

The annual average PR is 77%, and the maximum value of PR is 90% in July, 2016 and the minimum value of PR is 54% in April, 2016.

4.2. Capacity Utilization Factor
This factor measures the actual energy to output if the system operates at nominal power during the specific period, using the following equation [3]:

\[ CUF = \frac{E_t}{(H \times P)} \times 100\% \]  ..... (10)

P: Installed capacity of plant (Wp)
H: Number of hours in one year/month/day

The annual average CUF is 23%, and the maximum value of CUF is 32% in October, 2017 and the minimum value of CUF is 15% in May, 2015.

CUF value refers to the period of time during a year when the PV system is generating energy at its full power energy, so for Saeed and Mkahel area is about 84 days in a year.

4.3. Performance of Battery Charging and Discharging
In both sites, the monitoring system checks each day using the sensor and installed data logger the following parameters:
- Battery temperature
- Ambient temperature
- Charging and discharging state of battery

These values help the analyzer to ensure that the system works without problem, and to solve any issues that may affect the operation of system in future.

The figures below are a sample from both sites:
5. ECONOMIC AND SOCIAL IMPACT OF RURAL ELECTRIFICATION IN AL-MKAHAL AND SAEEED VILLAGE

5.1. Capacity Utilization Factor

Economics is the basis of most engineering decisions so, this section presents an economic analysis of the proposed stand-alone PV system estimated using the life cycle cost method. The LCC of an item consists of the total costs of operating and owning it over its lifetime. The costs of this system items include buying cost expressed in today’s price, operating cost, maintenance and replacement cost.

Table 3. Economic Aspects.

|                      | Saeed  | Al-Mkahal |
|----------------------|--------|-----------|
| Energy output (Kwh)  | 19446.9 | 17945.1 |
| Monthly bill from PV system (US$/family) | 15 | 15 |
| Monthly energy expenses before PV installation ($/family) | 50$ | 50$ |
| Monthly saving ($/family) | 35 | 35 |
| Yearly total saving $ | 12x35x9 = 3780 | 12x35x10 = 4200 |
| PV installation cost $ | 22000 | 22000 |
| S.P. B.P (year) | 5.82 | 5.3 |

Economic and social impacts of rural electrification at the household level are multidimensional; both tangible and intangible. The multifaceted impacts and benefits are either direct or indirect. Rural areas in Palestine consume above 65 percent of supplied electricity in household level. The direct impacts are mostly economic, and reflected in enhanced income, and employment, and optimized expenditure pattern, surpluses, savings, and asset building. Most indirect impacts are related to the social and cultural aspects of life, which include, among others, such areas as education, health, women’s status, modernization etc. These direct and indirect benefits together produce synergy in economic growth, poverty reduction, and human development.

6. ENVIRONMENTAL IMPACT OF RURAL ELECTRIFICATION IN AL-MKAHAL AND SAEEED VILLAGE

Recently, environmental benefits may be one of important reasons for using PV systems in rural areas. The annual reduction of CO2 for Al-Saeed and Al-Mkahal villages is shown in table 4.

Table 4. Co2 emission Production.

| #  | System  | CO2 emission reduction (Kg.CO2) |
|----|---------|---------------------------------|
| 1  | Khirbat Saeed | 13612.851                      |
| 2  | Khirbat Emkahel | 2561.57                        |

7. CONCLUSION

The design, and results analysis of the implemented systems, and technological configuration of electrification of Saeed and Al-Mkahal villages with micro grid system generation have been performed in this study very well. The electricity dispenser and training on load management are keys for no blackouts, battery in good health and minimum startups of the generator set. From this pilot project, it is clear that, utilizing PV-hybrid system is more economic feasible for electrification of remote villages of geographic, climate and load conditions similar to these communities in Palestine. In addition, the PV-system do not pollute the environment as the case of using diesel generator.

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