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Authors: Fouad Zaro, Ibrahim Kiriakos

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DESIGN AND IMPLEMENTATION OF A SOLAR PV MICROGRID: A CASE STUDY OF PALESTINE

Fouad Zaro[1*], Ibrahim Kiriakos [1]

[1]Palestine Polytechnic University, College of Engineering, Electrical Engineering Department, Hebron, Palestine.

[*]Corresponding Author: fzaro@ppu.edu

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ABSTRACT: Microgrid is a power subsystem consist of small generators, storages and local loads. The attention to renewable resources and local generation is increasing for three important reasons: economics benefits, environmental matters and limits of fossil fuels. However, development of renewable resources in electrical power systems has been grown rapidly. Microgrid has the ability to support high power quality and sustainability with elimination of load shedding. This paper presents design and implementation of a real microgrid as per the recommended microgrid topology and dispatch methodology real Photovoltaic (PV) station with a local load using real data collected using different monitoring systems, the suggested microgrid is implemented and tested using MATLAB simulation tool, assuring power quality and sustainability, electrical and financial results are reported supporting this design. This study showed that implementing this sort of project can provide clean, economical, and continuous electricity production in countries with daily blackouts.

Keywords: Microgrid, PV System, Power quality, load shedding.

1. INTRODUCTION

Energy demand worldwide is increasing dramatically. CO_2 emissions is increasing with the electricity generation causing serious impact on environment. Intergovernmental panel on climate change (IPCC) and international energy agency (IEA) had put regulations to decrease CO_2 emissions, and the penetration of renewable resources start to increase annually [1].

Stability of power system requires the supply equals the demand, in conventional power system the supply can be controlled, while renewable energy cannot be controlled because it depends on climate changes and other aspects. At higher renewable penetration levels, the supply may exceed the demand, in this case the excess energy can be stored by using energy storage system (ESS), this energy can be used during on-peak times or as an emergency when the main grid is off [2].

Microgrid system which is a cluster of interconnected distributed generators (DG), loads and ESS that co-operate with each other to be collectively treated by the grid as a controllable load or generator. The Microgrid can operate in the islanded mode or the grid-connected mode. The microgrid system in the grid-connected mode either supply energy to the main grid or consume energy from it. The microgrid system must be able to separate or island itself from the main grid and supply the local load effectively when the power from the main grid is off or when the power quality of the main power source is poor. Many countries in the world encourage applying the microgrid systems by assigning certain policies and in corporation with research institutes, universities and private sectors. However, there are two main standards for microgrids issues: IEC 61850-7-420 titled by "communications standard for distributed energy resources", and IEEE Std 1547.4™-2011 which is titled by " IEEE guide for design, operation, and integration of distributed resource island systems with electric power systems" [3-6].

The microgrid system of the university of California-San Diego (UcsD) is one of the famous practical experience implantations has a 42MW microgrid that self-generates 92% of its annual electricity load and 95% of its heating and cooling load, saves more than $800,000 (USD) per month by using the generation on its microgrid comparing with being a direct consumer from the grid. Furthermore, it has the ability to supply the loads during the shading time with the aid of battery containers and microgrid controllers [7]. The new energy and industrial technology development organization (NEDO) in Japan had developed many microgrid projects connected with the national grid, to solve the effect of high penetration of renewable resources and to increase power quality [8].

Researchers and developers that are interested in microgrid systems focus their researches in the following fields:

- *Control strategies* is the main part of microgrid system, it controls the operation of microgrid components based on measurements. It classified according to the capacity of microgrid, load sharing, dynamic response, and grid complexity. Many methodologies implemented in this field from SCADA systems connected to local controller to one control unit for small scale microgrid (nano-grid) [9].
- *Effective energy storage systems* play an important role in restoring balance between supply and demand, has very fast dynamic response and encountered rapid developments. There are many types of storage systems which can be used in accordance with the scale of microgrid and operation response such as pumped hydropower storage, compressed air energy storage (CAES), flywheel, electrochemical batteries (lead-acid, NaS, Liion and Ni-Cd), flow batteries (vanadium –redox), superconducting magnetic energy storage, super capacitors, and hydro energy storage (power gas technologies) [10].
- *Power conversion* due to the fast development of semiconductor materials and decreasing of its cost with increasing its efficiency, power conversion has encountered rapid development [11].
- *Power quality and integration with the grid*: microgrid can improve power quality of the loads especially commercial industrial loads and maximize the profit of these loads [12].
- *DC microgrid systems* are more efficient comparing to AC systems, because there are no conversion losses, and less thermal losses comparing to AC microgrid [13].
- *Economic dispatch:* electricity prices are expensive because it depends on many factors such as running cost of generators and grid and other economic aspects, so supply the load with own generated power will be more feasible [14].

This paper presents a real case study for designing a real microgrid system based on real collected data for a part of Jerusalem District Electricity Company (JDECO) system, the details of the presented case study are as follow: JDECO has a PV station consists of 13 inverters of 60kW each, with 2360 panels occupied with 10000m^2 land, tilt angle of 15^o, Latitude 32 1'17.83" N, Longitude 35° 26' 26.23" E. The station is connected to the 33kV medium voltage grid. The main objective of this study is converting the established PV station with the interconnected critical load part to a microgrid system with minimum cost, sustainability and good power quality as well.

The organization of the rest of the paper is as follows: section 2 provides the methods, adopted scenarios, data, the assessments of the proposed scenarios, cases of work strategies, and how the data have been collected. In section 3, the simulation results and discussion of different scenarios are presented. The economic dispatch of the proposed system is explained in section 4. Finally, the conclusions are depicted in section 5.

2. METHODS AND DATA

This paper proposed a real microgrid system for the residential load of a transformer 250kVA allocated about 5km from the PV station through the medium voltage line, and this paper studies the PV energy profile as well. Figure 1 presents the general scheme of the interconnection between PV station and the selected distribution transformer that will be the load of the proposed microgrid.

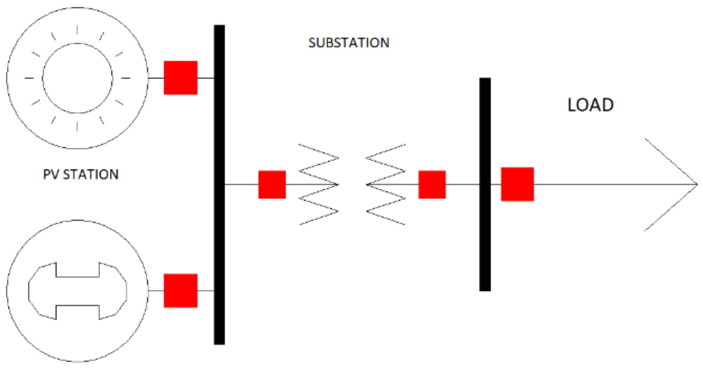

Figure 1. Interconnection between PV station and distribution transformer.

Three different feasible scenarios have been proposed to modify the PV station from on grid station to a microgrid station supplying the target load 24 hours 365 days and the optimum scenario will be implemented, in all scenarios the controller will connect and discount circuit breakers managing the operation of PV and ESS and LOAD and GRID as shown in Figure 2.

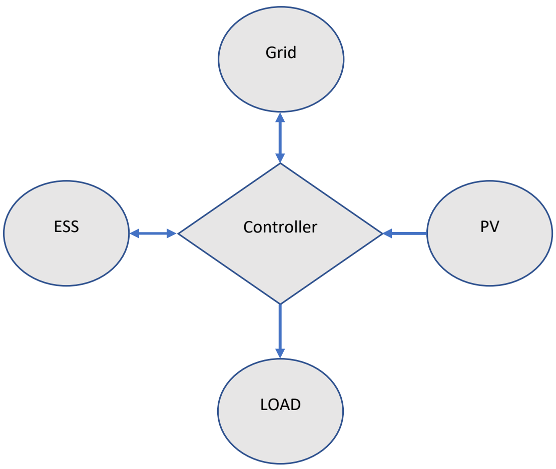

Figure 2. Block Diagram of the Proposed Microgrid System.

The presented three scenarios:

- **Scenario 1**

Dividing the existing PV station into two stations; ON grid station and OFF grid station with same panels ,by adding ESS working with main controller connected to MV Circuit breakers and adding OFF Grid inverters with power of 300kW peak to the existing PV station , and DC circuit breakers connected to the strings , when the power is on the station will work as ON grid station , when the power is off the controller will disconnect the MV circuit breakers and DC circuit breakers connected to On grid inverters ,after that will connect the DC circuit breakers connected to OFF grid inverters and the station will work as OFF Grid station, the ESS system in this case is the main supply of power , the topology of the system is shown in Figure 3.

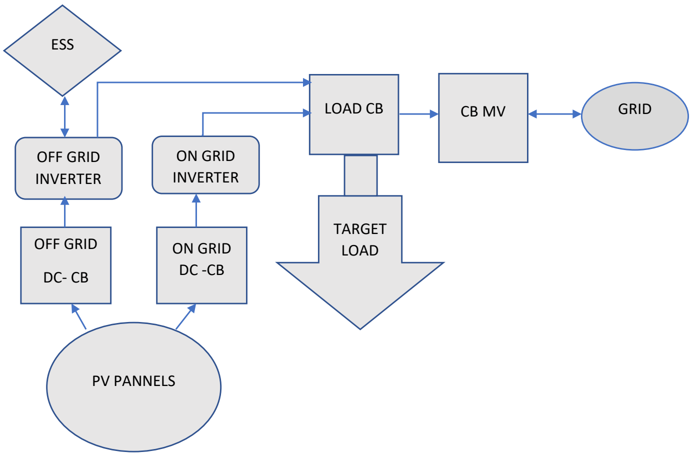

Figure 3. Scenario 1.

• **Scenario 2**

Dividing the existing PV station into two station; ON grid station and Microgrid station with same panels by adding ESS working with main controller connected to MV Circuit breakers and adding Microgrid inverters with power of 300kW peak to the existing PV station, and DC circuit breakers connected to the strings , when the power is on the station will work as ON grid station, when the power is off the controller will disconnect the MV circuit breakers and DC circuit breakers connected to on grid inverters ,after that will connect the DC circuit breakers connected to Microgrid inverters, ESS will share the supply of power with PV, the topology of the system is shown in Figure 4.

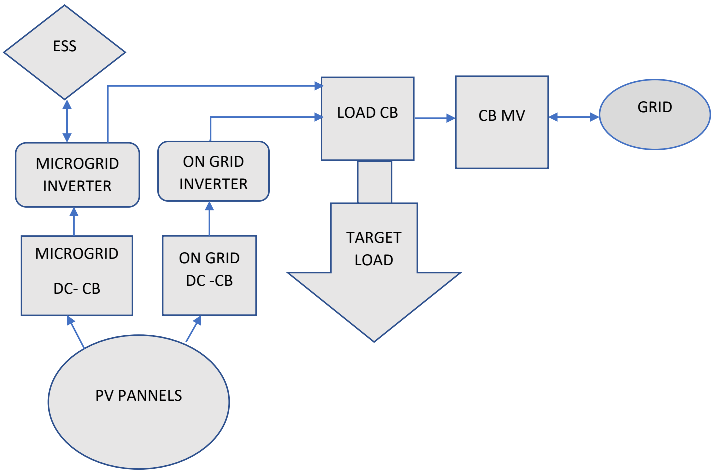

Figure 4. Scenario 2.

• **Scenario 3**

Modifying the existing PV station into two station , On grid station and Microgrid station with same panels, by adding ESS System working with main controller connected to MV Circuit breakers and changing 5 On-Grid inverters to Microgrid inverters , when the power is On the station will work as On grid station, when the grid is off the controller will disconnect the circuit breakers connected to MV circuit breakers and AC circuit breaker connected to the inverters that already exist in the station , the topology of the system is shown in Figure 5.

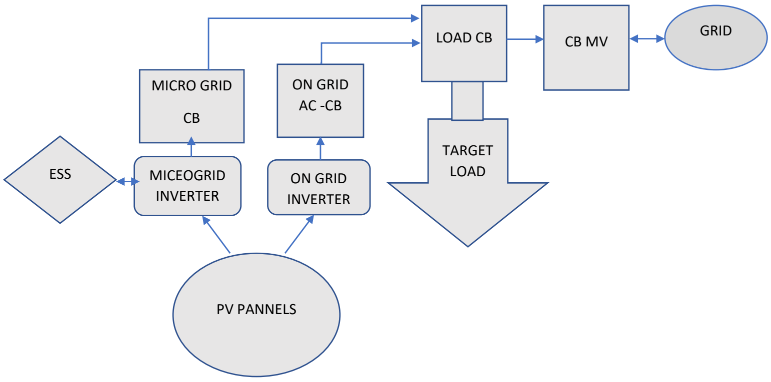

Figure 5. scenario 3.

The storage system has the major cost, it is not economically feasible to use ESS as the main supply to the load. It is more desirable to supply the load from PV system and the shortage covered from ESS system or to cover the whole load during emergency time, thus the scenarios 1and 2 are not economically feasible. On the other hand, the scenario 3 is economically feasible and applicable just by changing 5 inverters with 300 kW peak and controlling the ac circuit breakers only.

Data are collected using POWERCOM monitoring system for demand and GREENPOWER monitoring system for PV station, these data were not organized on hourly basis, effort were done to reorganize this data on hourly basis for 24 hours and 365 days.

The maximum recorded load for the selected transformer is 200 kW for 1 hour, while the average load is around 100 kW, for the proposed microgrid system no need to use all the battery power, in worst case with no sunshine and no grid a 300 kW battery power is efficient and safe, the depth of discharge in worst case is 67% with average load and 34% with maximum load.

There are 3 variable inputs: demand, PV power and grid power; the demand is dynamically changing over the day, while PV power changes based on weather conditions and the amount of dust over PV panels and temperature and radiation, however, sometimes the grid power is off because of the faults that occur suddenly on the grid or scheduled maintenance of medium voltage stations and lines.

There are 4 calculated outputs which are as follow:

1. Calculating the amount of energy bought from IEC
   - If Demand + Bat charge > PV power and the Grid is ON, the amount of electricity bought = demand -PV + Bat charge (This statement give priority to charge the batteries from PV).
   - If Demand < PV power and the Grid is ON, the amount of electricity bought = ZERO
   - If Demand < PV power OR Demand > PV power and the Grid is OFF, the amount of electricity bought = ZERO

2. Calculating the amount of energy sold to consumers
   - If Demand > PV power and the Grid is ON, the amount of electricity sold = ZERO
   - If Demand+ Bat charge < PV power and the Grid is ON, the amount of electricity sold = PV -demand – Bat charge (This statement give priority to charge the batteries from PV).
   - If Demand < PV power OR Demand > PV power and the Grid is OFF, the amount of electricity sold= ZERO
3. Battery discharging
   - If the Grid is Off and PV < Demand, the amount of discharged power = demand -PV
   - If the Grid is Off and PV > Demand, the amount of discharged power = Zero
   - If the Grid is ON and PV > Demand, PV < Demand, the amount of discharged power = Zero
4. Battery charging

   If battery is discharged and the Grid is ON, Battery charging = Battery discharging

The logic statement chart is shown in Figure 6.

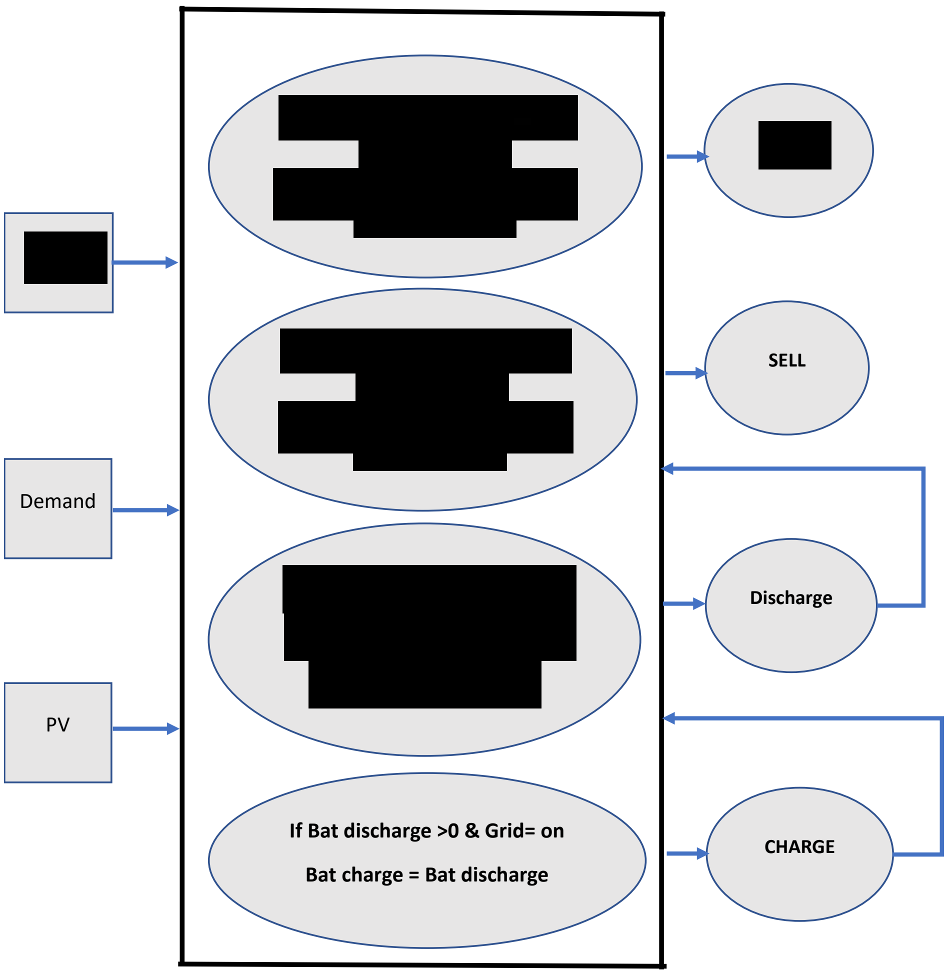

Figure 6. Logic statement chart.

There are three different cases for the proposed system as follows:

Case 1: If the Demand equal 50kW and PV energy equal 100kW and the grid is On,
- Energy sold =50 kWh

- Energy bought = ZERO
- Battery discharged = ZERO
- Battery charged = ZERO

Case 2: If the Demand equal 50kW and PV energy equal 100kW and the grid is Off

- Energy sold =ZERO
- Energy bought = ZERO
- Battery discharged = ZERO
- Battery charged = ZERO

The load is totally supplied by PV energy

Case 3: If the Demand equal 50kW and PV energy equal 40kW and the grid is Off

- Energy sold =ZERO
- Energy bought = ZERO
- Battery discharged = 10kWh
- Battery charged = ZERO

The load is supplied by PV energy and batteries

3. SIMULATION RESULTS

The main block diagram of the proposed model is shown in Figure 7, the PV system is divided into two systems PV microgrid system connected to CB-MG (circuit breaker microgrid) and PV On Grid system connected to CB-OG (circuit breaker on grid), CB1 (circuit breaker 1) is used to island the target load from the grid.

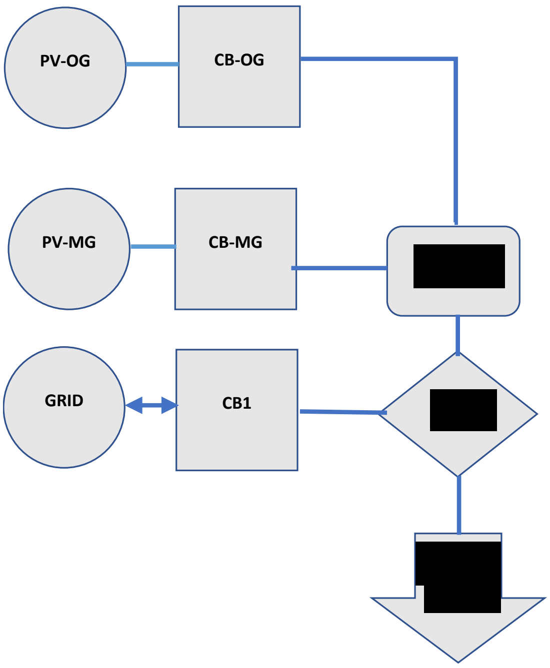

Figure 7. Main block diagram of the proposed model.

This microgrid has two operation modes, depending upon the measurement of RMS current and THD, the added controller has input from measurement unit and based on this measurement the controller will operate according to the flowchart shown in Figure 8.

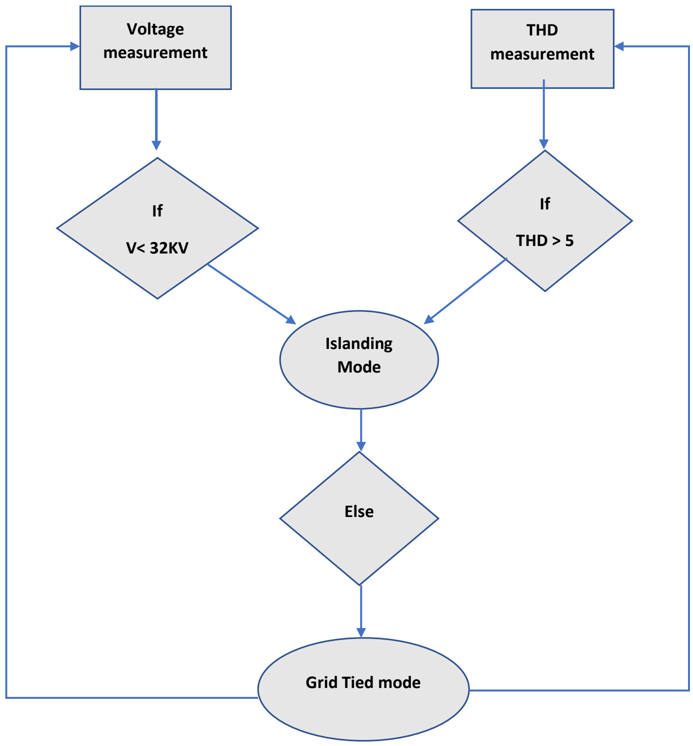

Figure 8. Controller operation flow chart.

The modes of operation are described as follow:

- **Grid tied mode**: In this mode, the controller is just monitoring the grid and THD of the target load, all the circuit breakers are on.
- **Islanding mode**: The microgrid will go to islanding mode when the grid is off or when THD larger than 5%.
- **Islanding mode, grid off**: when the grid is off, the controller will open CB1 and CB-OG which are shown in figure 7, then supplying the power to the target load using the microgrid. The current from the grid is shown in Figure 9 over 10 seconds of simulation time, the target load voltage before improving the system is shown in Figure 10, after improving the system the target load is shown in Figure 11.

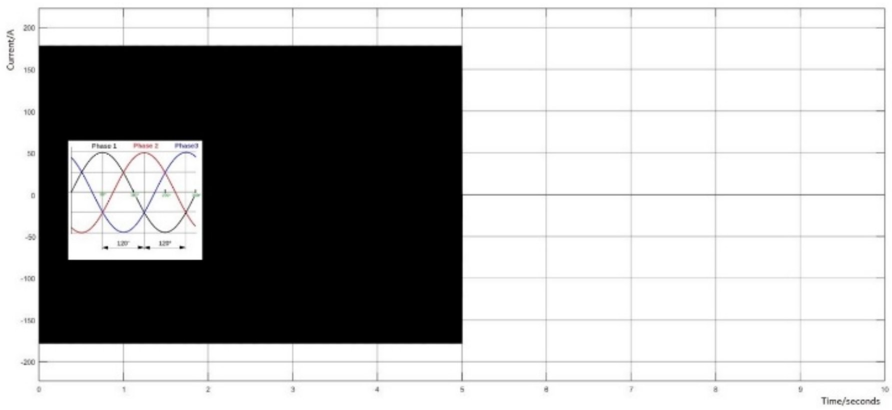

Figure 9. The current of the main grid.

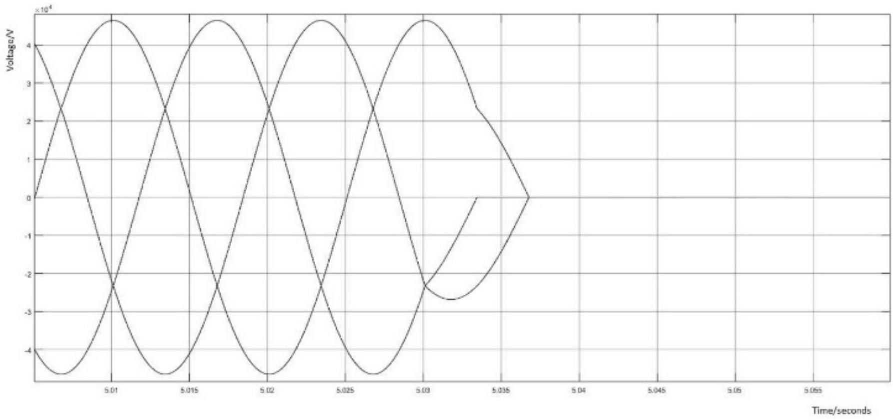

Figure 10. Load voltage without microgrid operation.

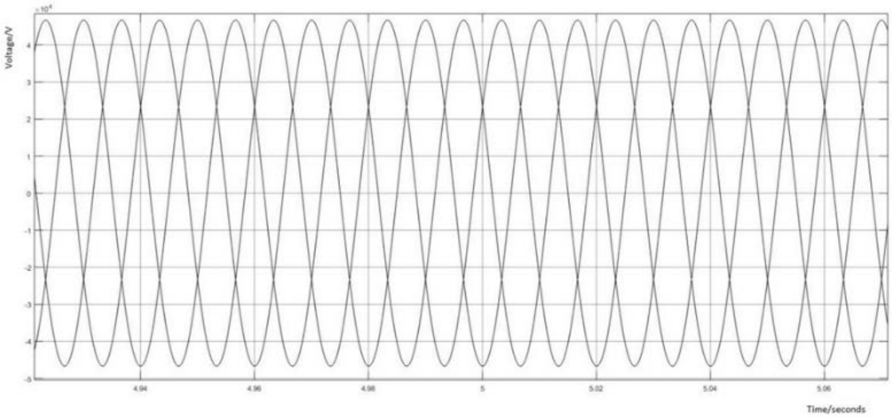

Figure 11. Load voltage with microgrid operation.

As shown in Figure 9 the grid is off after 5 seconds, without operating the system, the load also will be off as shown in Figure 10, operating microgrid system will keep supplying the load with energy as shown in Figure 11.

- **Islanding mode improving THD**: In this mode if the THD is greater than 5% the controller will open CB1 and CB-OG which are shown in figure 7, thus supplying the target load using microgrid system, where the THD of the grid is shown in Figure12, and the THD of the load is shown in Figure 13.

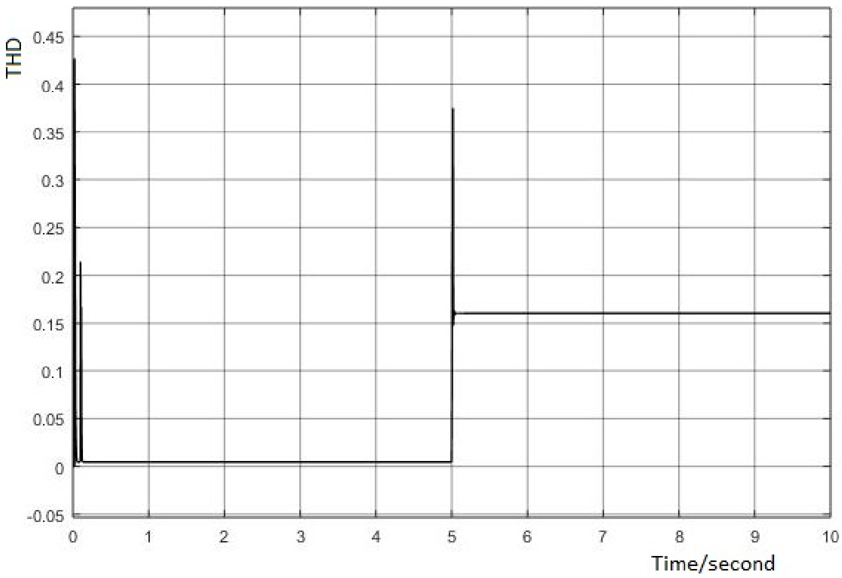

Figure 12. THD of the Grid.

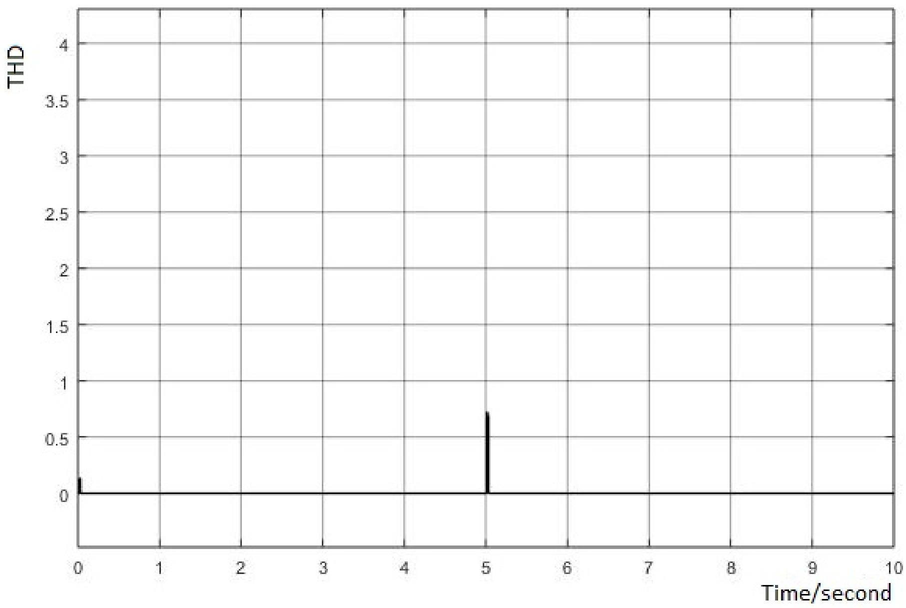

Figure 13. THD of the target load.

Usually, the THD is variable and depends on other loads connected to the grid, Figure 12 shows at 5 seconds some undesirable loads enter the grid, disconnecting the grid and operating in islanding mode will be good solution to improve the THD as shown in Figure 13.

4. ECONOMIC DISPATCH

After running the system, the total amount of energy bought and sold, using microgrid operation for every month is shown in Figure 14.

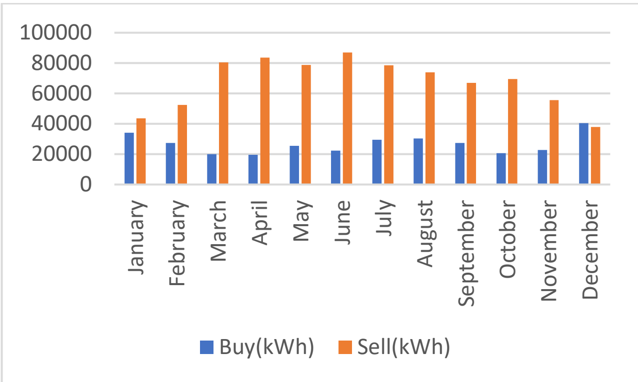

Figure 14. Energy bought and sold in 2018.

Microgrid system supply the target load 365 days 24 hours, and the excess energy is sold to the grid, which increases the revenue, the expenses depend on the amount of energy bought from IEC, the buying tariff from IEC in 2018 is 0.371 NIS, and the selling tariff is 0.5448 NIS, Figure 15 shows the expenses vs revenue monthly, they are calculated using the following formulas.

*Expenses = amount of energy bought * buying tariff*

*Revenue = (amount of energy sold to the grid + demand) * selling tariff*

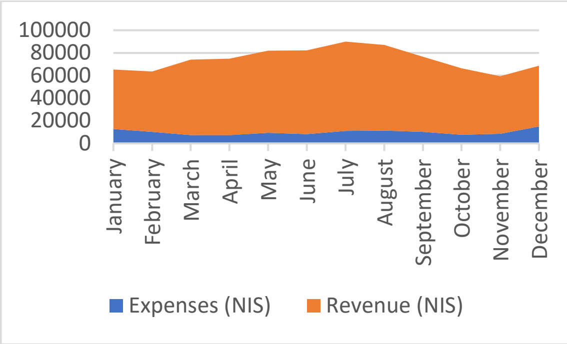

Figure 15. Expenses vs revenue.

The monthly profit with microgrid implementation equals revenue minus expenses minus battery usage factor which is 6562NIS/month based on practical experience, profit without microgrid implementation equals demand multiplied by the difference between selling and buying tariff, if the grid is on. Figure 16 shows the profit comparison between microgrid operation and supplying the load without using microgrid.

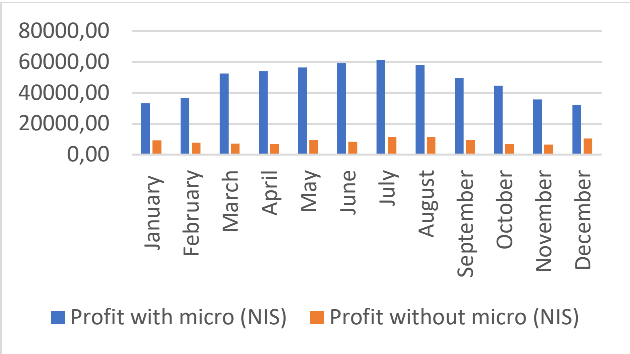

Figure 16. Profit comparison.

The cost of the station contains the fixed cost and running cost and modification cost, it is shown in Table 1.

Table 1. Total cost.

Item	Cost US $
Old station	700,000
Inverters	45,000
Controller and accessories	20,000
Running cost for 5 years	35,000
Sum	**800,000**

With a degradation factor the profit will be minimized for every year, Table 2 shows the profit for 5 years with degradation factor of 1%.

Table 2. Five years' economic dispatch.

Year	Profit (US $)
1	164,045
2	162,405
3	160,781
4	159,173
5	157,581
Total	**803,985**

Based on the above data, the payback period is within 5 years with overall station cost of $800,000 USD and degradation factor of 1%.

5. CONCLUSIONS

Design and implementation of a real microgrid based on real data and as per the recommended microgrid topology and dispatch methodology is proposed in this paper. The proposed microgrid achieved good power quality and sustainability by eliminating load shedding for the selected load as well as economic benefits with a payback period of fewer than five years and increasing the reliability of the system. This study aimed to analyze the techno-economic and environmental feasibility of a solar PV microgrid system that is able to supply the load during both grid availability and outage periods and showed that implementing this sort of project can provide clean, economical, and continuous electricity production in countries with daily blackouts. A section of household in Jericho was selected as a case study.

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