Demand Side Management using Grid-Tied Photovoltaic Energy System

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Abstract: ***This paper investigates the impact of investments in DSM technologies in Palestinian electricity market in order to solve the problem of supply shortages in electrical network, especially in peak demand periods. Renewable hybrid system, which can explore solar PV source at low cost, is a popular choice for this purpose nowadays, optimal energy management solutions can be obtained with great cost savings and active control performance. This paper analyzes the performance and feasibility of implementation DSM system in Palestinian distribution network, using on-grid PV system and energy management system.***

Keywords: Performance analysis, Renewable hybrid system, Demand side management, Optimal control, Hospital building.

I. INTRODUCTION

Renewable energy (RE) sources have become attractive choices of generating electricity in comparison to traditional fossil fuels due to different characteristics such as low cost, no pollutant emission, energy security as well as their modularity . Renewable energy sources can be used in islanded or as grid-connected mode where bidirectional power flow can be implemented to buy or sell power to the utility company. Because of the intermittent nature of their resources; renewable power systems are regularly coupled with storage systems such as batteries [1, 2]. Energy storage systems can be used to ensure that the variable load demand is continuously met irrespective of the intermittency of the renewable resources. Generally, grid-connected renewable systems do not necessitate battery storage systems. Therefore, advanced energy management systems are also not needed. Maximizing the use of the power from the renewable sources is the only operation strategy implemented when the power generated is less than the instantaneous load power demand. For grid-connected renewable with battery storage systems, the energy management becomes more difficult, as more complicated operation strategies must be taken into account, such as charging the battery from the grid or renewable source and discharging into the grid or to the load when necessary [3,4,5] . As a result, controllers are required for hybrid renewable-battery systems, such that the use of the renewable system can be considerably improved and the grid regulation can be enhanced in terms of safety, reliability and efficiency. For grid-connected hybrid renewable-battery systems, the changing electricity price imposed by the utility, the period of power transaction, and the balance between the instantaneous renewable power produced and the instantaneous load demand are main challenges encountered while implementing any suitable energy management strategy. Several demand side management (DSM) programs such as Peak shaving,direct load control, Capacity market programs or Time-of-use (TOU) can be implemented when renewable energy systems are connected to the grid [6,7,8,9,10]. In Palestine various renewable energy sources are available but the photovoltaic (PV) technology is considered a suitable technology, the average solar irradiation is about 5.4 kW/m2/day, therefore the investments in solar energy economically feasible [1, 5]. Generally, it is difficult to have free fault electrical power supply systems and these failures in some utilities like hospitals, banks, schools and telecoms utilities are not acceptable for any reason. So emergency backup systems were innovated there are many common types of power supply backup systems that depend on served facilities, load types, and rating. The most used one is diesel generator for many reasons such as availability in market, reliability, portability and maintainability. Other backup systems can use renewable energy sources especially photovoltaic systems which possible to use in critical facilities such as hospitals, telecom sites, and traffic lights. This paper analyze the performance done in the demand side management of grid-tied hybrid photovoltaic system in An-Najah Hospital, from technical and financial point of view.

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II. ENERGY ANALYSIS OF AN-NAJAH UNIVERSITY HOSPITAL – CASE STUDY BUILDING

The typical daily load curve at An-Najah Hospital obtained through energy analyzer is illustrated in Fig.1.

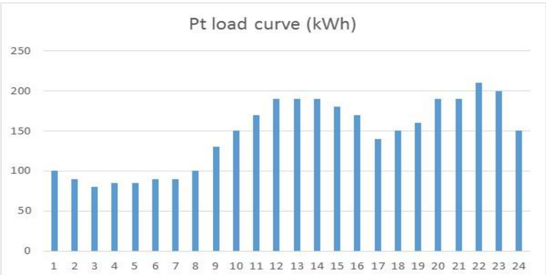

Fig. 1.Daily load curve of the building in July 2017

From monthly bills, was noticed that the hospital has a large consumption and suffering from shortage of supply from electrical company NEDCO, therefore the DSM will be important for hospital to minimize the effect of this problem , also the electricity bills can be reducing by using grid-connected PV system.

A. Photovoltaic System Design for An-Najah Hospital building

Referring to Fig.1 the area under the daily load curve represents the daily demand of the building (B) which was 2774 kWh. Using penetration level equation, the daily produced energy of PV system will be 561 kWh taking in account average solar radiation in Palestine which is equal to 5.4 kWh/day, the PV system capacity installed is 104kWp.

B. Simulation of PV System by Using Software Program

The simulation of the designed PV systems for the building was presented with the use of the computer software – PV Syst, the PV produced energy, performance ratio and the various power loss was calculated. The optimum PV size for the building was104kWp capacity , and the total expected produced energy which was 187374kWh/year, the performance factor was about 81.6% and the whole system losses (PV-array losses) was about 0.99 kWh/kWp/day and the System Loss (cabling, MPPT, inverter, ...) was about 0.1 kWh/kWp/day. These data are shown in Figs 2, 3 that illustrate the expected produced energy, collection losses and the system losses for the building system for each month individually.

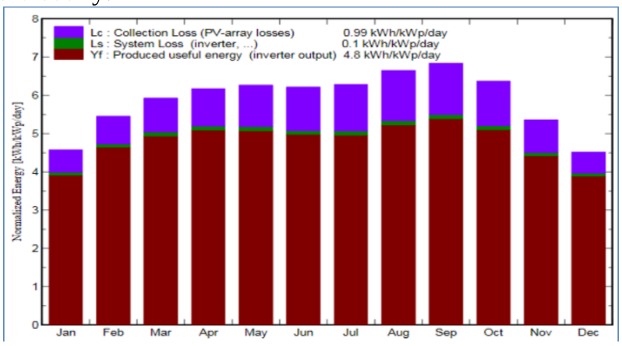

Fig. 2.Normalized productions for the building per installed kWp.

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	91.1	13.02	141.8	140.6	13232	12965	15.01	14.71
February	110.2	13.71	152.6	151.1	14171	13896	14.94	14.65
March	158.1	16.34	183.6	181.5	16710	16372	14.64	14.34
April	188.6	19.21	185.1	182.3	16651	16317	14.47	14.18
May	231.4	22.40	194.2	190.3	17175	16834	14.23	13.94
June	241.2	25.05	186.5	182.3	16293	15967	14.05	13.77
July	243.3	27.63	194.7	190.7	16779	16440	13.86	13.58
August	224.3	27.93	206.2	202.8	17672	17314	13.79	13.51
September	185.8	26.06	205.1	202.7	17636	17284	13.83	13.56
October	147.6	23.68	197.5	195.6	17249	16906	14.05	13.77
November	104.4	18.89	160.8	159.6	14450	14158	14.45	14.16
December	84.8	15.09	140.0	138.7	13142	12894	15.10	14.82
Year	2010.8	20.79	2147.9	2118.3	191160	187347	14.32	14.03

Legends: GlobHor Horizontal global irradiation; T Amb Ambient Temperature; GlobInc Global incident in coll. plane; GlobEff Effective Global, corr. for IAM and shadings; EArray Effective energy at the output of the array; E_Grid Energy injected into grid; EffArrR Effic. Eout array / rough area; EffSysR Effic. Eout system / rough area

Fig. 3.Building system main simulation results.

III. MODELING OF PV GRID -TIED FOR DEMAND SIDE MANAGEMENT

At An-Najah Hospital system we proposed to use DSM technique to manage and reduce peak demands period using the grid-tied PV system and battery bank system that integrated by smart monitoring and control system. This proposed system will reform the daily load curve especially the reduction in peak demand values and periods .The PV provides renewable energy and is the primary power output source of the system while a part of this output will be stored in storage batteries. Grid power is assumed to be always available, thus guaranteeing the stability of the electrical power supply .The energy flow in the system will mainly depend on the smart controller that decides where the flow have to be, based on many factors such as solar radiation, phase loads, batteries State of Charge SOC, and many other factors may be added in future as tariff policy that may use. Fig.4 illustrates the proposed DSM system configuration.

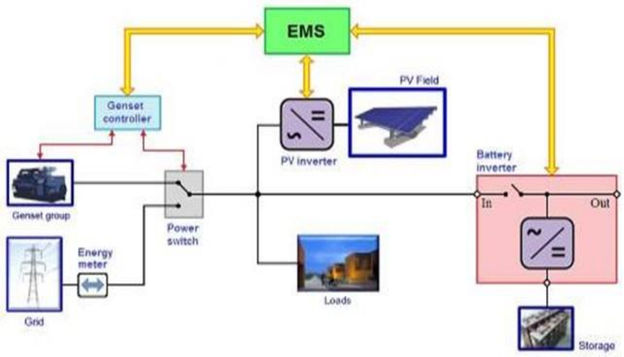

Fig. 4.Building Proposed Demand Side Management System Configuration.

The load shifting can be achieved by using batteries storage integrated PV system with storage also the control system. In the case of DSM system failure, the PV system should operate as normal grid-tied PV system and the produced energy should be injected to the utility regardless of the building demand status this will be achieved by the control system.

A. Effect of installing PV system

The on-Grid PV system with capacity of 104kWp was installed for the building to achieve 30% penetration value. To illustrate the effect of inserting PV on the system the real produced energy was measured using power analyzer and computer software program then it was compared with the old daily load curve, the PV real output for typical day 17th July 2017, shown in Fig.5.

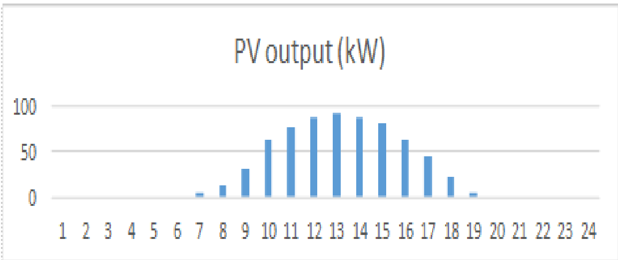

Fig. 5.Daily output PV system in 17th of July.

Fig.5 shows the output of the building PV system in a certain sunny day at which the panels started producing energy about 7:00AM until 7:00 PM, here this sunny day was on July with Sun Shine Hours about 8.2 and the produced energy of the building system was about 780 kWh. As mentioned before to reach the expected daily load curve of the building this will be achieved by subtracting the produced energy of Building from PV system from the consumed energy of the building, and the resulting new daily supply curve is shown in Fig.6.

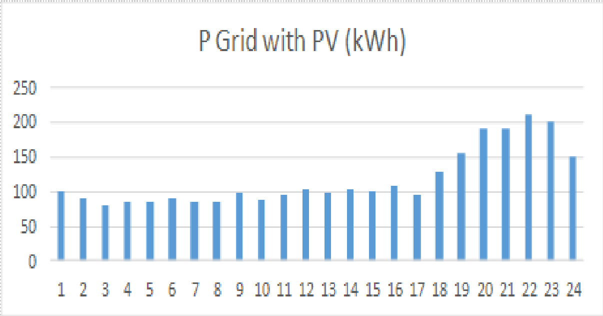

Fig. 6.Grid supply after PV installation

In Fig.6there is a big variation between the maximum and minimum demands which has a maximum demand about 210 kW in the evening, and minimum demand about 80kW.

B. Demand Side Management Using Battery Storage System

As the building case have a large deviation in demand values so an EMS is recommended to be added to the system to reduce this variation in demand and to use the excess energy in another period of the day especially in high demand periods from 7-11pm. To achieve this the EMS given energy from storage batteries devices, with capacity 110 kWh per day and the EMS allow to use this energy on determined max demand periods. Fig.7 illustrates the effect of on Grid PV system and the contribution of DSM on the above daily load curve of building.

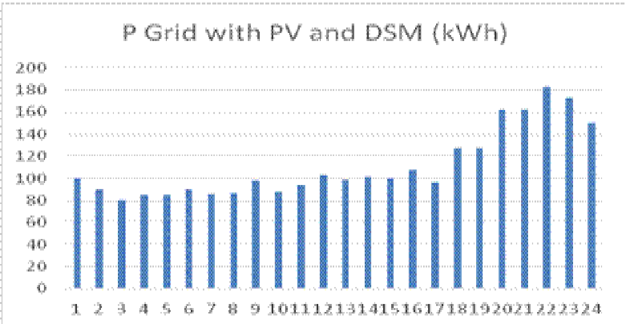

Fig. 7.Grid supply with effect of PV and DSM using EMS

The PV is working as peak demand management during the period (7-11) pm, and the period time can be changed daily or monthly through EMS.After inserting EMS to the building system in the evening, the minimum Grid supply demand was about 80 kW and the peak supply demand reduced to 182.5 kW.

C. Effect of DSM on daily load factor of supply

The load factor of grid supply can be calculated by using Eq (1).

Load Factor = Average demand/ Maximum demand ....(1)

Table.1 shows the load factor, maximum supply demand, and average Grid demand of building in three conditions, without PV, with PV system, and with PV system and DSM.

Table .1 Load factor of supply in three conditions.

Case	Average supply Demand	Peak supply Demand	Load Factor
Normal Case	71.3	210	0.34
With PV	50	210	0.24
With PV & DSM	46.3	182	0.25

The usage of DSM in hospital reducing the peak demand by 27.5 kW, this enhancement will be reflected on energy bill if the max demand billing strategy will be used by NDECO Distribution Company.

IV. PERFORMANCE ANALYSIS OF ILLUSTRATED PV SYSTEM WITH DSM

A. The Energy Output Vs Energy Expected

The output real energy vs the expected energy illustrated in Table 2 and Fig.8.

Table 2. PV Expected Monthly Outputs Energy –PV Syst Simulation

Month	System expected monthly output (MWh)	System real monthly output (MWh)
Jan	12.965	10.261
Feb	13.896	11.726
Mar	16.372	10.99
Apr	16.317	13.872
May	16.834	14.848
Jun	15.967	15.468
Jul	16.440	14.462
Aug	17.314	13.241
Sep	17.284	13.421
Oct	16.906	13.631
Nov	14.158	11.547
Dec	12.894	8.965
Total	187.347	152.432

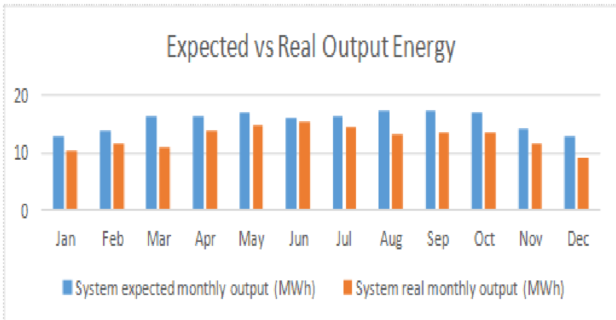

Fig. 8.The expected output energy from the PV Systems – PV Syst Software

B. Performance Ratio (PR)

Performance ratio (PR) is illustrated the overall effect of real output and losses on the expected output due to PV real conditions and efficiencies of parameters.

Normally PR varies depending on the location, and it can be calculated by using Eq (2).

$$PR = \frac{\text{Actual energy generated by PV system (kWh)}}{\text{Energy produced by system at STC (kWh)}} \ldots\ldots\ldots\ldots (2)$$

To get accurate evaluation, the data was evaluated yearly for the targeted sites, and PR was different according to variation of radiance, system losses...etc. The performance ratio for Hospital in different months summarizing in Table.3.

C. Solar Fraction of PV system

Solar fraction is the amount of energy produced by PV system divided by the total energy required in hospital, the SF summarizing in Table 3.

D. Capacity Utilization Factor

The capacity utilization factor (CUF) is defined as the ratio of actual annual energy generated by the PV system (Ea) to the amount of energy the PV system would generate if it is operated at full rated power for 24 h per day for a year.

$$CFU = Ea/PV\ rated ** 24 * 365 \times 100\% \ldots\ldots\ldots\ldots (3)$$

Where Ea is the annual AC energy output (kWh), PVrated is the rated pf PV system.The capacity factor for a grid connected PV system is also represented by CUF = (Peak sun hours/day)/24 h/day.The CUF for Hospital in different months summarizing in Table.3.

Table.3 Performance Analysis

Month	Performance Ratio (PR)	Solar Fraction (SF)	Capacity Factor (Cf)
January	84.80	0.11	0.34
February	93.81	0.13	0.43
March	68.69	0.12	0.36
April	85.63	0.15	0.47
May	90.54	0.16	0.49
June	98.52	0.18	0.52
July	88.72	0.16	0.47
August	80.25	0.13	0.43
September	91.27	0.15	0.48
October	99.66	0.16	0.47
November	93.88	0.12	0.39
December	70.06	0.09	0.27
Total	87.15	0.14	0.43

V. ECONOMIC ANALYSIS OF USING DSM SYSTEM

An economic analysis that will evaluate the feasibility of installation on- grid PV system and DSM in An-Najah national hospital will be based on Rate of Return method (ROR) and Simple Pay Back Period (SPBP).

A. Rate of Return Method

The Rate of Return (ROR) is an economic technique that used in project feasibility evaluation and it is a well-accepted way of determining if the project or investment is economically acceptable. ROR can be defined as the gain or loss on an investment over a specified period, ROR expressed as a percentage increase over the initial investment cost also, the ROR can be defined as or the rate of interest earned on the unrecovered balance of the investment.

The ROR value can be determined in a different way compared to the PW or AW value for a series of cash flows, here it will be estimated using the PW technique depending on the lifetime cash flow that shown in Fig.9 which illustrate project initial cost, O&M costs, batteries replacement cost, salvage value and annually produced energy saving (revenues). In revenues calculation Eq (4), the energy cost will be considered as 0.2$/kWh.

$$\text{Annual Revenues} = \text{Annual Produced Energy (kWh)} \times \text{Energy Cost} \ldots (4)$$

The annual revenue of produced energy will be as follow:
Annual Revenues = 187348 x 0.2 = 37470$

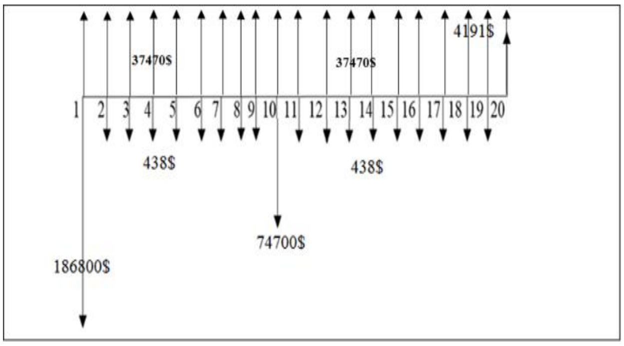

Fig. 9.Lifetime Cash Flow of the building

From cash flow that shown in Fig.9, the initial cost, batteries replacement cost, and O&M cost considered as outcomes. While the annual revenues and the salvage value was considered as incomes.

PW (Outcomes) = Initial Cost + (P/A, i, 20) of O&M + (P/F, i, 12) of Batteries Replacement.

PW (Outcomes) = 186800$ + 438$*(P/A, i, 20) + 72000$*(P/F, i, 12)

PW (Incomes) = (P/A, i, 20) of Energy Revenues + (P/F, i, 20) of Salvage value.

PW (Incomes) = 37470*(P/A, i, 20) + 4191*(P/F, i, 20).

To find the ROR the PW of incomes will equal to PW of outcomes and method of trial and error can be used.

Using Microsoft excel and the IRR function the ROR was found and it was equal to 23%, this mean that this project will return 23% of its initial cost every year which makes the project feasible.

B. Simple Payback Period

Simple Payback Period (SPBP) is another technique can be used to analysis the project feasibility and it can be defined as the length of time required to recover the capital cost or the (LCC) of an investment. If the SPBP was lower than the project lifetime this mean the project is feasible otherwise is not. The SPBP can be estimated using Eq (5).

S.P.B.P = Investment / saving cost per year -------------(5)

SPBP = 261045/37470 = 6.9 Years

In this evaluation all costs were taken in into account, such as O&M and batteries replacements
This SPBP which equals to 7 years means that all project cost will be recovered by the first 7 years of the lifetime and the other 13 years it will profit which mean also the project is feasible.

VI. CONCLUSION AND RECOMMENDATION

Based on this study the following conclusions can be made:

- Palestine has an excellent solar energy potential that can be used in electricity production.
- The usage on-grid PV can reduce the lack of supply on the electrical network in Palestine.
- Energy management has valuable impacts on electrical grid enhancement especially in peak demand reduction and load factor improvements which reflect the quality of supply.
- The economic analysis of using PV systems and energy management systems shows that it is feasible to use PV in electricity production and has a good LCOE which was between (0.15-0.19)$ and this cost was less than IEC price.
- The usage of time-based tariff structure will motivate the consumer to use energy management systems.
- The simple payback period of An-Najah Hospital project was about 6-7 years which means it is a good investment.
- Reduction of emission of CO_2, due to PV system at hospital, was about 180 ton per annum.

Based on this study and analysis the following recommendations can be made:

- It is recommended to increase the usage on PV in electricity, especially for peak demand management to solve the problem with shortage of supply especially in peak demand period.
- Modify the existing flat rate tariff structure and to apply the time use tariff structure for large consumers such as hospitals, factories, and universities.
- Encourage consumers to use energy management systems in their facilities.

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