Energy Management Systems for Hospitals in Gaza-Strip

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Abstract—**This paper presents the general system of energy management in Al-Shifa' Hospital, as the largest medical complex in Gaza-strip, and the existing challenges to supply the critical facilities in that hospital which is seriously affected by the frequent power outages. Additionally, the presented work highlights the problem of power outage in Gaza-Strip as an example of the regions which are in dire need of humanitarian actions. It encounters serious electrification problems and frequent power failures. In order to propose an encouraging and realistic solution, the major challenges in performing an effective energy management program in such sensitive environments like hospitals are surveyed. As a contribution to the development projects of hospitals, this paper presents a PV/storage system as an alternative power supply to the conventional diesel generators. System design and associated costs of its utilization are illustrated. Despite of the necessity and vital role of the critical loads in hospitals which cannot be compromised with the costs, conventional cash-flow indicates that utilizing PV systems (instead of diesel generators) for typical critical loads in Gaza's hospitals is promising and more sustainable. Such a design can be transferred to other areas which suffer from frequent power failures and depend on conventional backup systems for long periods.**

Keywords—Humanitarian Action; Gaza-Strip; Hospitals; Energy Management; Grid Failure; PV-Storage

I. INTRODUCTION

The increasing demand for new innovative technologies to support humanitarian actions is obvious today. They could help bring people the feeling of security and hope. Undoubtedly, they can offer positive impact to their health and to the environment as well. According to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), the total supply of electricity to Gaza-Strip—before the latest conflict—meets approximately 46 % of the estimated demand and this seriously affects public services provision, including water, sanitation as well as 15 main hospitals inside Gaza-Strip [1].

Generally, hospitals are considered as large building complexes incorporating most types of technical systems encountered in other types of buildings with a high level of heat being generated internally [2].

For that reason, effective energy management actions should ensure that energy use and costs are as low as possible while maintaining high standards of comfort, service and productivity [3].

Efficient and economic technologies properly deployed and integrated should offer an accessible power source for hospitals in areas which suffer from numerous grid failures, poor infrastructure or even power resources' mismanagement. Additionally, the motivation to extend assistance to those in conflict regions has pushed researchers to the limits and led to considerable perseverance.

Some researchers debate about humanitarian actions to serve and govern the emergency situations in refugee camps such as [4] where off-grid solar power technologies were introduced to overcome such troubles.

Furthermore, other researchers introduced a Small-Scale Hybrid Integrated Renewable Energy System (HI-RES) as an emergency mobile backup power generation station [5]. This paper presents a typical load management system which is currently performed on the largest medical complex in Gaza-Strip: Al-Shifa' hospital. Surveyed works offer some solutions which are typically proposed to overcome the problem of power outage in Gaza-Strip [6], [7].

The focus of this work is on low-investment solutions through integrating critical facilities in hospitals by stand-alone PV-Storage systems which can serve efficiently in cases of emergency, conflicts, or daily power disruption.

The paper is organized as follows: Section II surveys the basic requirements to carry out an efficient energy management program in hospitals. Section III presents the actual state of the energy sector in Gaza-Strip. Section IV demonstrates the present energy management program in Al-Shifa' Hospital. Section V proposes a PV-storage system for typical critical loads in intensive care unit and evaluates the associated cash-flow analysis. Finally, Section VI presents the conclusion and an outlook.

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II. SPECIFIC REQUIREMENTS OF HOSPITALS

The main requirement of the hospitals from the power system availability point of view is the need for guaranteed supply with high power quality [8].

Precisely, when different researchers discuss the energy consumption, evaluating the latest technologies and summarizing their findings, few of them highlight the special qualities that distinguish hospitals from other buildings. This makes the management process vague and harder to be accomplished because it is important to understand the trends and patterns of each facility.

Here are the most common challenges related to the provision of medical services and energy management in hospitals [9], [10]:

1. Hospitals are continuously working facilities for 24 hours a day, seven days a week. Thus, some sub-systems or appliances might be turned-on all times.
2. Huge heat demand either in direct use such as heating air and hot water or indirect use such as in laundry or/and in sterilization unit.
3. The special requirements for positive pressure in surgical operating rooms or even air flirtation and infection control in medical devices to meet the standards make the process more complex to save energy.
4. Hospital buildings are designed to serve for 50-100 years. So, the chance to renovate a certain facility inside is little.
5. Some facilities require more energy to provide better quality, such as some imaging systems require much electrical energy to give a better resolution.
6. There are not currently any standard ratings for medical equipment where energy efficiency is not believed to be a priority for medical equipment designers [10].

III. ENERGY SECTOR IN GAZA-STRIP

Gaza-Strip is located in the South-West of Palestine. Its total area is estimated at 360 km^2. Gaza city is the major province in Gaza-Strip. It has one of the highest population densities and overall growth rates in the world with its small total area of 45 square kilometers [11], [12].

According to the OCHA [1], Gaza-strip is suffering from the insufficient and irregular power supply. At the best circumstances—when the Gaza Power Plant (GPP) is operated—, power supply and deficit in Gaza-Strip can be summarized by the diagram in Fig. 1.

The impact of power outage in Gaza-Strip makes it difficult for Gaza Electric Distribution Company (GEDCo) to schedule the supply and distribute it in a proper way.

Therefore, the authority in corporation with GEDCo used to schedule or recirculate the supply between the different zones according to the availability of power feeding lines.

Depending on the status of GPP, the daily average time of power-outage in all zones in Gaza-Strip may exceed twelve hours; including hospitals and clinics. More precisely, the most common schedules of supply are [13]:

A. *One-Third Schedule*

GEDCo cannot deliver more than one third averages hours per day to a certain zone when the deficit is around 70 %. Therefore, the electricity is turned ON for just six hours and in the next twelve hours it is turned OFF for that zone and rotated to other different zones, so the grid will be available just for six hours to a certain zone at the best expectations. Each zone will receive the electricity for eight hours per day as an average for a one full cycle which takes three days to be repeated.

B. *Half-Period Schedule*

When the deficit is around 50 % GEDCo can supply continuous electricity to a certain zone for no more than eight hours and then rotate it to another zone. By this mode it is observed that the electricity will be turned ON two times for the first day and just one time in the next day to a certain zone. Thus, the total hours of operation are half hours of these two days at the best expectations.

Further information about the energy sector in Gaza-Strip up to August 2014 is covered by [13–16].

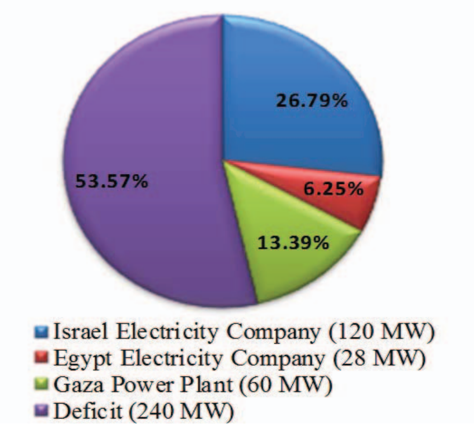

Figure 1. Power supply and deficit in Gaza-Strip [1]

IV. AL-SHIFA' HOSPITAL

A. *General Description*

Al-Shifa' Hospital is the largest healthcare complex in Gaza-Strip. It has more than 600 beds and serves more than 40 % of the population of Gaza-Strip [17], [18]. It consists of more than 20 buildings and provides diagnostic, surgical care, emergency medical care, intensive care, hospitality and labs. In addition to that it provides also general services such as laundry, food preparation with delivery and personal cafeteria.

B. *Power System*

The hospital complex is supplied by medium voltage level (22 kV) from GEDCo through two different feeding lines which are located in the northern and southern side of the hospital. Each feeding line supplies two parallel MV-LV (22 kV/400 V – 0.85 MVA) three phase transformers equipped into the two sub-stations as depicted in Fig. 2.

Every sub-station is responsible of a group of buildings representing half of the hospital's total electric demand. Additionally, each sub-station is equipped with a group of different capacities' diesel generators (Standby Station N/S) that serve as an emergency power supply system to cover the essential loads when the grid is unavailable.

Note that there is no available option to increase the capacity of any of the feeding lines in order to be sufficient to supply all hospital's demand every time; where the grid cannot maintain an acceptable voltage level at such high peak demand; otherwise, a huge modification need to be done on the grid which means great investment cost and longtime of operations with scarce income to both authority and distribution company.

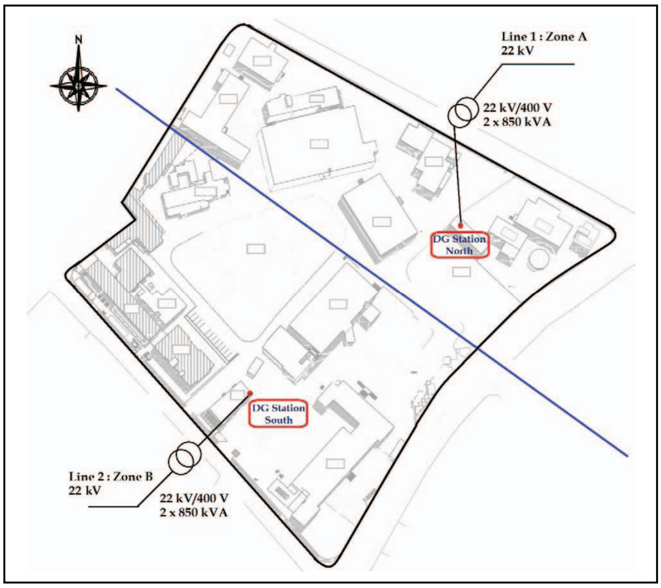

Figure 2. Al-Shifa' Hospital's power supplies [19]

The inevitable consequence of frequent and prolonged power outage, the administration of the hospital with the consultant of engineering office stores diesel in special tanks inside the hospital complex to operate the backup diesel generators when the grid is unavailable. These tanks are prepared to store enough fuel to operate generators for one week of regular power cut-off 12 hours/day in order to operate the essential loads normally. The authority in Gaza-Strip gives the first priority to hospitals and healthcare facilities to supply them by enough fuel to face the daily exacerbated challenge, but in the time of conflicts it becomes impossible for authority to buy fuel directly.

Therefore, civil society organizations used to help as much as they can. 10 years ago, the total rated power of each backup generator set at the two sub-stations was not more than 650 kVA, but the electricity crisis started sharply after 2006, when the local power plant was partially destroyed [16]. Accordingly, the general administration of engineering and maintenance there started to increase the capacity of generators to cover the increasing load and to be on the safe side from the frequent power failure. In addition, during a prolonged power outage, some normally non-essential services become essential, such as laundry, catering or steam supply; these facilities cannot be stopped more than 12 hours in a daily routine. Further clarification about how the engineering team there tries to beat the absence of grid electricity every day is presented in the following subsection.

C. *Current Energy Management System*

While load shedding of the hospitals in Gaza becomes a daily routine, all electric loads in the hospital complex are subdivided into three categories according to the level of importance as follows:

1) Very Important loads (VIL): They are automatically supplied by alternate power sources to supply any of them at any interruption even if short period; usually those types of loads are equipped with uninterruptable power supply (UPS) which can maintain good supply during a certain period of time (maximum 10 minutes).
2) Essential loads (EL): They are deemed as essential to life safety, critical patient care, and the effective operation of the healthcare facility, and these loads are supplied by the complete backup generators when the utility turns off to keep the patient comfort at an acceptable degree. Sure, the group of VIL is totally included in this group of loads.
3) Non-essential loads (NEL): They express the remaining loads after subtracting EL from all loads. They are not deemed essential to life safety, or the effective, and essential operation of the healthcare facility, such as offices' air conditioning, incinerator, general lighting, general lab equipment, service elevators, and patient care areas which are not required to be backed up with an alternate source of power.

In light of this information, the power system availability in Gaza's hospitals can be divided into three levels according to the available:

- The green level: when grid is available and the backup diesel generators are ready to operate without considerable concern about diesel transportation and logistics.
- The yellow level: when the grid is unavailable but the backup diesel generators can supply the essential load without fuel-logistic problems.

- The red level: when the grid is unavailable and there is a scarcity in fuel supply due to blocking in boarders or ports as occurred in conflicts.

The critical equipment such as in laboratories or clinics that are serious for a power outage even of a short period of time (10 minutes maximum) are supplied by special (UPS) systems. A set of UPS's are distributed on some critical buildings such as: Dialysis, Neonatal Care, Intensive Care Units, operatory rooms and some special diagnostic rooms.

Before presenting the decision making process of how the engineers used to supply the different types of loads in the hospital over different time horizons during a day according to the availability of grid or the status of diesel generators or even logistic status and fuel supply, the term "*emergency*" is defined to deem an expected scarcity in fuel supply during blockades or conflicts.

This means that the backup generators are available but the fuel supply is not; that's why they used to operate the least group of essential loads.

The existing load management program in Al-Shifa' hospital can be described as the flowchart in Fig. 3, where the first priority to supply all loads in hospital is given for the grid, then if there is no "*emergency*" and the grid is unavailable; the essential loads are supplied in the daytime by a larger generator set (GenSet 1) while they are supplied by smaller generator set (GenSet 2) in the nighttime [19].

This is done according to the experience of the operation engineers to save fuel and increase the life time of the two generator sets; where they prefer to maintain the loading factor to a certain generator round 85% and not less than 60 % of its rated capacity. In addition, it is well known that the majority of loads will be online at the daytime, which means that greater capacity is needed.

Bear in mind that the manufacturer of the diesel generator usually recommends the power generation limits of diesel generators correspond to the efficient fuel consumption [21].

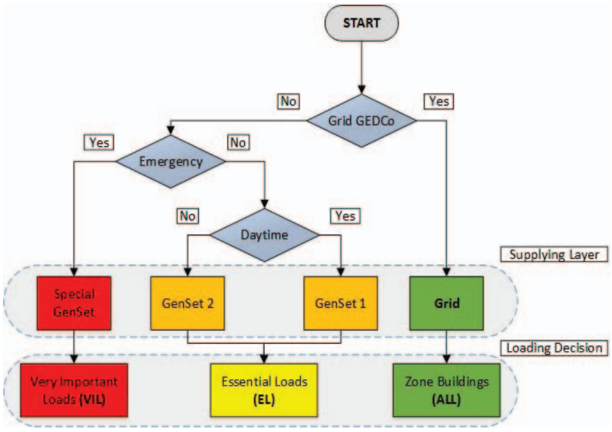

Figure 3. Loading decision at different circumstances.

Unfortunately, the existing infrastructure does not support an efficient energy management program as no monitoring-recording system has been installed yet; neither for the total consumption of the buildings inside hospital nor for a certain group of critical facilities.

Moreover, it lacks break-down details of electrical energy consumption for different loads. The availability of such a monitoring system can provide detailed load shapes of all different facilities, which are of great interest for the following reasons:

- Evaluating the percentage of consumption of each category of loads according to levels of criticality.
- Auditing the total numbers of power failure or blackouts within a certain period of time (yearly/monthly/weekly or even daily based).
- Following up the responding of backup system to the frequent power failures.
- Forecasting the load of different categories according to their historical behavior.
- Predicting the possible impact of the upcoming energy management actions on the load profile.

V. PV-STORAGE SYSTEM

Al-Shifa' hospital has a good solar potential. It is located at the global coordinates 31°31' N, 34°26' E. The beam normal irradiance in that region exceeds 2000 kWh/m^2 [21]. It is remarkable to mention that utilizing solar energy would be feasible since the daily average of solar radiation on horizontal surface was measured to 5.4 kWh/m^{2}day [22].

In fact, the proposed solution is inspired by [21] where a photovoltaic (PV) energy system is applied to supply a remote village in Palestine. On the other hand, the topology proposed in this work is different from its counterpart used in [21], where it depends basically on the new technology of bi-directional inverters instead of using inverter and charge controller. This configuration allows the charging of accumulators and the conversion of the voltage from either solar panels or accumulator into an alternative current (AC) using single device.

A. Load Profiles

The critical loads in a typical intensive care unit (ICU) of Al-Shifa' Hospital will be considered to demonstrate the proposed design. The common critical loads for maintaining good patient-care services and keep life safety in the ICU are: lights (general lightings and portable emergency lighting units); medical devices (ventilator, infusion pumps, syringe pump, suction device and DC shocking machine); imaging and observing devices (electrocardiograph, portable X-ray and bed monitors); clinic appliances (refrigerator, blood analyzer and lab devices). It is notable that these loads cannot be curtailed or even shifted. They represent the least level of service the facility must meet. They are specified in Table I.

TABLE I. TYPICAL CRITICAL LOADS IN INTENSIVE CARE UNIT (ICU)

ICU Loads	No. Of units	Operating Hours Per Day	Wattage Per Unit used	Wh / day
Main monitor	1	24	200	4800
Bed Monitor	10	24	60	14400
Ventilator	10	24	52	12480
Infusion pump	10	24	52	12480
Syringe Pump	10	24	52	12480
Lighting Units	20	24	72	34560
DC shock	2	4	50	400
Suction	4	4	60	960
Electrocardiograph	2	4	60	480
Portable X-ray	1	0.5	3800	1900
Blood Analyzer	1	6	2500	15000
ECO Doubler	1	4	50	200
Portable Light	5	6	250	7500

The total daily consumption E_l and maximum expected peak P_{max} correspond to the presented load (details in the appendix) are:

$$E_l = 117.64\ kWh$$

$$P_{max} = 11.86\ kW$$

Note that the design does not consider the time of use of each equipment due to high uncertainty and lack of specific information. In addition, the assumption of all equipment *ON* at same time may lead to *oversizing* of inverter and thus increase the cost but not much significantly. In the other hand this will secure any expected peak. Further details regarding calculations can be found in the Appendix.

B. Sizing of PV-Array

The appropriate blocks that describe the system and its functionality are illustrated in Fig. 4

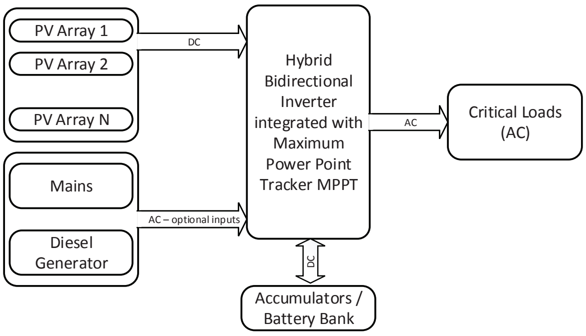

Figure 4. PV-Storage system to serve critical loads in hospitals

Considering daily energy, local solar irradiation and peak sun hours with the efficiencies of PV modules' and inverter, the peak power of the PV-array (P_{pv}) equals to:

$$P_{pv} = 30930\ W_p$$

To achieve this power, a polycrystalline PV module type SF220–30–P250L of a peak power of $P_{mpp} = 245\ W_p$ is selected [23]. The number of necessary PV modules (N_{pv}) is obtained as:

$$N_{pv} = 126\ PV\ modules$$

The configuration of these modules will be determined according to the technical specifications of the basic module SF220, namely: V_{mpp} voltage at maximum power point; V_{oc} open circuit voltage; I_{mpp} current at maximum power point; I_{sc} short circuit current.

In the design phase, these values should be carefully chosen to match the specifications of the chosen inverter as it will be mentioned in the next subsection. Further details regarding calculations can be found in Appendix.

C. Sizing of Inverter

The chosen inverter should be able to supply the maximum peak considering the conversion losses and the further expected extension of the system. For that reason, a hybrid bi-directional three-phase inverter integrated with maximum power point tracking unit can be chosen [24].

The corresponding power conversion rate is 20 kVA and it totally matches the voltage and current of the array. Moreover, the input of inverter has to be matched with the battery-bank voltage while its output should fulfill the voltage and frequency of the electric grid of the hospital.

D. Sizing of Battery-Bank

The capacity of accumulators for such system is significantly large and it will affect the overall price dramatically. Thus, special lead-acid cells with high cycling stability rate (> 1000 times) and capability of standing deep discharge should be selected. Such accumulators are available but at higher price than regular. Therefore, the associated price will be specified based on regular maintenance to keep the life time as long as possible.

Two main parameters are needed to determine the capacity of battery-bank: The ampere hour capacity C_{Ah} and watt hour capacity C_{Wh}.

Under these considerations and following the same structure of the bank used in [22], it is found that C_{Wh} should be at least 205 kWh as the total storage capacity to maintain the design requirements. Further details regarding calculations can be found in Appendix.

E. Economic Analysis

The associated costs of the components, material, equipment, and maintenance of the proposed PV system are listed in Table II.

It is known that the PV-modules' life-time exceeds twenty years. However, the expected life-time of the accumulators under hard circumstances is hardly ten years; the associated costs of them are adapted considering discount and inflation rates to ensure a unified life time of all components of the system which is twenty years. Take into account that all accumulators are durable and the total capacity of them exceeds the necessary limits. This will increase the life time, decrease the overwork and prevent expected exertion.

TABLE II. ASSOCIATED COSTS OF PV-POWER SYSTEM

No.	Item	Quantity	Unit Price ($)	Total cash flow ($)
1-	PV-module	126	250	31500
2-	Bi-directional inverter	1	18000	18000
3-	Accumulators	110	640	51504
4-	Installation materials	126	5	630
5-	Civil work	126	20	2520
6-	Preventive maintenance (PM)	20 year	1000 / year	10604
7-	Circuit breakers and switches	Lump sum	200	200

The presented system is expected to be sustainable for twenty years at least, and it can be extended by further developments. In order to accurately quantify the true cost of solar energy produced using a PV system, it is therefore necessary to calculate the Levelized Cost of Energy (LCOE) using equation (7) [25]:

$$\mathrm{LCOE}=\frac{\sum_{n=1}^{N}\frac{C_n}{(1+d)^n}}{\sum_{n=1}^{N}\frac{E_n}{(1+d)^n}} \qquad (7)$$

The numerator of the LCOE equation represents the total costs C_n over the project period (n years). In the denominator, E_n is the energy output of the system by year. Future costs and energy production benefits are discounted by d, the discount rate due to the time value of money. The calculation assumed realistic value of discount 8 % because of the present value of future payments. Thus, the total payments in (US dollars) according to Table II are found to be:

$$C_n = 114958\ \$$$

Obviously, the total energy produced in twenty years by the system can be obtained as follows:

$$E_{20} = 20 \times 365 \times E_l \qquad (8)$$
$$E_{20} = 858772\ kWh$$

Dividing the total payments by the total produced energy it is found that LCOE (end energy price) equals to *0.134 dollar per kilowatt hour* ($ / kWh).

Additionally, it is aimed to present a simple economic comparison with a diesel generator to show the superiority of the PV-system under hard circumstances such as daily power outage for more than eight hours.

Diesel generators are widely used in the areas which suffer from frequently power outage. In spite of durability and low investment cost, these generators require high running cost, frequent maintenance and they pollute the environment. According to the World-Bank indicator, the pump price for diesel fuel is 1.7 *dollar per liter* ($ / L) [26] and it is absolutely increased due to transportation and logistics.

The ratings of the diesel generator are determined by the load. Hence, a 20 kVA generator type (Catterpiller) with three phase output AC voltage (3×380 V), 50 Hz with a power factor of 0.85 is selected. Such generator has a maximum life-time of *20000* working hours; this means that it cannot be sustained for more than seven years under a daily power outage of eight hours. Moreover, it needs on average four liters of diesel fuel per hour to maintain the specified load. The associated costs of this generator over 20000 working hours are listed in Table III

TABLE III. ASSOCIATED COSTS OF DIESEL GENERATOR

No.	Item	Unit	Life time	Unit price ($)	Total cash flow
1-	Diesel Generator	1	20000 *h*	12000	12000
2-	Diesel fuel	Liter	3.6 L / *h*	1.85(a)	106992
3-	Engine oil	Liter	5 L / 150 *h*	2.6	1650
4-	Diesel filter	1	750 *h*	10	250
5-	Air filter	1	3000 *h*	40	250
6-	Periodic Maintenance	1	Quarterly	50	1150

[a] Diesel fuel price is assumed to be 1.85 $ / L, including transportation price and logistics.

The total payments over seven years applying the same discount rate of operative items are found by summation of the last column of Table III.

Total Payments of diesel system = 122292 $

LCOE = 122292 $ / 858772 kWh

= 0.142 $/kWh

VI. CONCLUSION AND OUTLOOK

This work presents the electricity situation in Gaza-Strip as an example of the areas which suffer from massive power outage and are in dire need of humanitarian actions. Afterwards, it demonstrated the general system of load management in Al-Shifa’ Hospital and the existing challenges to manage and distribute the supply between the different facilities. Certainly, the demonstrated management experience could be beneficial to other areas with similar situation. A PV-based power system has been proposed and the associated economic analysis has been demonstrated. The proposed system is sustainable and beats its counterpart diesel generator with its long life time and lower levelized cost of energy. The proposed solution is typical of critical facilities of hospitals in other areas which have plenty of solar radiation and encounter frequent power failures.

Future investigation and research will address the time of use of each equipment in the facility and other possibilities of saving and management. Mostly, these opportunities can be summarized under two points:

- Investigation of an optimized design of a hybrid standalone power system which aims at offering a secured power supply to the most critical loads even if there is a scarcity in fuel. Such a system should be suitable for different area around the world. Principally, it will depend on wind energy as another renewable resource beside solar energy and also the existing diesel generators to achieve the maximum profitability and sustainability.
- Investigation of the heat re-use opportunities and energy harvesting from the exhaust pipes of diesel generators [27]; here, a considerable amount of heat exceeds 65 % of the total energy of the fuel is exhausted from diesel generators and then dissipated into atmosphere as pollutants. It can be used for space and water loop heating, air conditioning (by absorption chillers) and medical services [18], or to use micro combined heat power µCHP to deliver the electric demand and heat in an efficient manner [28].

Finally, field test opportunities in Gaza's hospital will be explored as a step toward real development

ACKNOWLEDGMENT

The authors thank the German Academic Exchange Service—Deutscher Akademischer Austausch-Dienst (DAAD) for providing scholarship for Mohammed Hijjo to pursue his PhD degree at Saarland University. They are also thankful for The General Administration of Engineering and Maintenance at The Palestinian Ministry of Health for help to obtain realistic data from the Al-Shifa' Hospital.

APPENDIX

The total daily consumption E_l and maximum expected peak P_{max} correspond to the presented load (as in Table I) can be calculated as follows:

$$E_l = \sum_{i=1}^{N} (n \times P_i \times T_i) \tag{1}$$

Where:

N	is the number of all types of loads
n	is the number of all units of the same type of loads
P_i	is the total power rate of loads of the same type
T_i	is the operating time in hours of that type of loads

It is noted that the maximum expected peak occurs when all loads are in operation at the same time.

$$P_{max} = \sum_{i=1}^{N} (n \times P_i) \tag{2}$$

The peak power of the PV-array (P_{pv}) can be obtained as follows:

$$P_{pv} = \frac{E_l}{\eta_{MPPT}.\eta_R.PSH} S_F \tag{3}$$

Where:

E_l	is the daily energy consumption
PSH	is the peak sun hours
η_{MPPT}	is the efficiency of maximum power point unit
η_R	is the efficiency of inverter
S_F	is the safety factor for compensation of resistive losses and PV-cell temperature losses

The values have been used in substitution of equations (3) as follows:

PSH	5.4 [22]
η_{MPPT}	0.9
η_R	0.9
S_F	1.15

By applying the equations (1) to (3):

$$P_{pv} = 30930\ W_p$$

To achieve this power, a polycrystalline PV module type SF220–30–P250L of a peak power of $P_{mpp} = 245\ W_p$ is selected [21]. The number of necessary PV modules (N_{pv}) is obtained as:

$$N_{pv} = \frac{P_{pv}}{P_{MPP}} \tag{4}$$

N_{pv} = 126 PV modules

The configuration of these modules will be determined according to the technical specifications of the basic module SF220, namely: V_{mpp} voltage at maximum power point; V_{oc} open circuit voltage; I_{mpp} current at maximum power point; I_{sc} short circuit current. In the design phase, these values should be carefully chosen to match the specifications of the chosen inverter as it will be mentioned in the next subsection.

V_{mpp} = 30.4 V
V_{oc} = 37.2 V
I_{mpp} = 8.22 A
I_{sc} = 8.74 A

Therefore, the configuration of the total system will be formed from 14 parallel groups, each one has 9 panels. Correspondingly, the total open circuit voltage and short circuit current for the whole array are:

V_{oc} = 37.2 × 9 = 334.8 V
I_{sc} = 8.74 × 14 = 122.36 A

The corresponding values of the voltage and current at the maximum power point can be obtained from the I–V characteristics as follows:

$$V_{mpp} = 30.4 \times 9 = 273.6\ \text{V}$$
$$I_{sc} = 8.22 \times 14 = 115.08\ \text{A}$$

Two main parameters are needed to determine the capacity of battery-bank: The ampere hour capacity C_{Ah} and watt hour capacity C_{Wh}.

They can be calculated to cover the mentioned demand for a certain number of autonomous days according to the following formulas:

$$C_{Ah} = \frac{A_d E_l}{V_B . DOD . \eta_B . \eta_R} \quad (5)$$

$$C_{Wh} = C_{AH} V_B \quad (6)$$

Where:

A_d is the number of autonomous days
DOD is the permissible depth of discharge rate of a cell
η_B is the efficiency of the cell
V_B is the voltage of the cell

Assuming realistic values of $\eta_B = 0.85$, DOD = 0.75 and the voltage of the bank should be 220 V to match the specifications of the inverter. Two main parameters are needed to determine the capacity of battery-bank: The ampere hour capacity C_{Ah} and watt hour capacity C_{Wh}. Under these considerations and following the same structure of the bank used in [9]; it is found that C_{Wh} should be at least 205 kWh as the total storage capacity to maintain the design requirements. This can be achieved by installing 110 cells (2 V/1100 Ah type).

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