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Energy Management Scheme for Buildings Subject to Planned Grid Outages

Mohammed Hijjo, Felix Felgner and Georg Frey

Chair of Automation and Energy Systems
Saarland University, Germany

Abstract—A huge attention is paid to integrating buildings with renewable energy resources (RES) as a key factor to act on increasing demand. Meanwhile, utilizing different power resources can be a viable alternative for communities suffering from frequent and planned power outages. Conventionally, diesel generators are utilized as emergency backups to lessen the impact of power outages, but they consume a massive amount of fuel in case of extended outage periods. In this context, the work proposes an alternative microgrid power supply system incorporates photovoltaic solar array and lead-acid battery bank in addition to the conventionally utilized diesel generator for buildings experiencing frequent power outages. Besides, an energy management scheme is proposed to carry out the proposed supply. The main components of the system are modeled in MATLAB and the simulation is performed over a relatively long period (two weeks) to capture the pertinent dynamics of the system. The work is conducted using the example of Al-Shifa' Hospital in Gaza-Strip to verify the effectiveness of the proposed approach. Moreover, different operation scenarios are tested from different perspectives with respect to the planned outages in Gaza-Strip. Simulation results indicate significant fuel savings in addition to a reduction in the total operation time of the diesel generator set (GenSet).

Index Terms—Microgrid, Power Outage, Diesel Generator, Battery Bank, Energy Management System

I INTRODUCTION

Local power supplies are becoming popular idea to overcome the problem of frequent power outages. These systems can be installed and operated to cover the essential demand of wide range of facilities. Mainly, such systems are equipped with diesel generators which need an enormous amount of fuel in case of extended outages. However, a proper battery storage system in addition to renewable energy resources RES can play a vital role to alleviate the risk of outage and decrease the fuel consumption significantly. In spite of that, robust operation of local power systems is complex since power outages are stochastic events, and local energy suppliers have different operation costs, constraints, and efficiency characteristics [1]. Concurrently, different smart grid topologies are utilized and developed for specific purposes. Effective outage management system (OMS) is an ambitious target for the smart grid realization [2]. Deeply, a microgrid is defined by the U.S. Department of Energy as “a group of interconnected loads and distributed energy resources (DERs) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island modes” [3]. Microgrids firstly appeared in [4] as innovative concept assuming a cluster of loads and micro-sources; all are operating as a single controllable system. By this definition, microgrids can be a good alternative to serve different societies, buildings, rural areas and small districts. They are a viable solution for buildings depending on resources other than the main grid (where the main grid expansion is either impossible or not economical). Especially in developing countries, a large number of buildings including healthcare facilities, schools and small businesses are not connected to a main electrical grid system [5].

Although considerable related work has been done to manage power flows and energy in buildings, every new application is setting up different requirements, so that previous approaches cannot be fully applied. For instance, [1] and [6] present online energy management systems to supply constant loads for different purposes based on real-time solving the economical dispatch of generators. However, they consider relatively long time steps to work out this problem (e.g. one hour). Besides, other online energy management schemes have been implemented as in [7], but they did not consider safety ranges for the operation of the battery bank which ensure longer lifetime [8].

The contribution of this work is to offer an online energy management scheme (EMS) for buildings experiencing a planned grid electricity outage. It aims to reduce the fuel consumption of the diesel GenSet and maximize the use of RES in order to supply the load efficiently as well as hold the state of charge (SoC) of the battery bank within safety operation ranges. The proposed scheme is carried out over an accurate load profile with relatively short time steps (two minutes). Also, a certain degree of uncertainty is imposed in order to offer a better understanding of the system dynamics.

This paper is organized as follows: Section II presents the main problem which is going to be solved; Section III presents the system model including resources and loads; Section IV presents the proposed energy management scheme; Section V demonstrates a case study including the experienced outage and load profile of a hospital complex in Gaza-City in order to conduct this work with the corresponding simulation results concerning various criteria. Finally, Section VI discusses the results and concludes the outcomes of this paper.

II PROBLEM STATEMENT

The focus of this work is to solve the problem of frequent and planned grid outage where the load is imposed to be disconnected from the main grid at certain periods of time. The distribution company usually informs the customers previously about the period of interruption, so they can manage to schedule their consumption or even use a proper standby power supply system to cover their demand.

Simply, this work proposes a microgrid-based power supply and the corresponding management criteria in which the load demand can be supplied more efficiently.

Specifically, such a problem includes, on the one hand, the modeling of the available power from the grid and other resources such as renewables, battery storage and diesel GenSet. In the other hand, it includes managing these resources to decrease the fuel consumption and increase the reliability of the system.

III SYSTEM MODELING

The system under consideration can be described by three interacting subsystems which form the all power flows; namely: load demand, grid and secondary power supply. The system consists of a microgrid composed of PV array, lead-acid storage bank and diesel GenSet representing the microgrid in addition to the critical load which all are connected to the main grid as depicted in Figure 1.

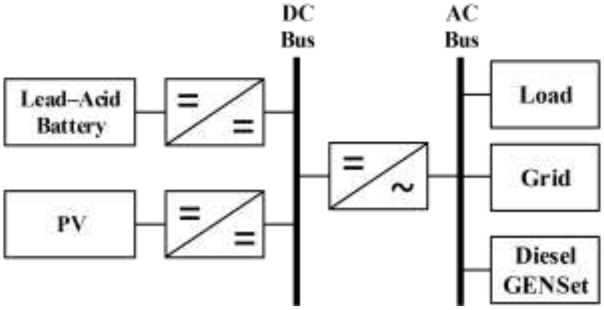


Figure 1 General model of the system

A Load Demand:

The load demand or profile represents the instantaneous power consumption of the load and can be modeled by discrete values $P_L(\tau)$ over a fixed time horizon (e.g., a day), where $\tau \in [t_0, t_0 + T]$. Obviously, the most important part of proposing an efficient EMS to buildings is to identify their individual consumption patterns and maintain power supply even in blackouts, rather than to save energy. To this end, a method is required to mockup a load profile for a relatively long period from available basic data. For the purpose of testing control strategies, the load forecasting model should avoid complicated configuration processes [9]. Essentially, such a method is advantageous when a comprehensive monitoring action is not possible either.

Considering a load profile $P_L(\tau)$ is available over a specific period which represents the basic data window. In additon, the consumption pattern is constant or changed slightly, in which the load of the next window can be described as a term of the main window but including a scaling factor and time delay, then the load profile for the next day can be mathematically formulated as follows:

$$P'_L(\tau) = \alpha^i P_L(\tau + \beta^i) \quad (1)$$

Where:

α^i is the weighting factor indicating the uncertainties of the power demand of the next window (day) referred to the basic data window, i.e. if its value is equal to 1.15 this means that the whole load profile of the day i is 1.15 times the basic load profile.

β^i is the shifting factor representing the global shift over the next day referred to the basic day.

In this work, these factors of α and β are generated using uniformly distributed random variables within a proper range of uncertainty.

B Main Grid

The grid is supposed to supply the load continuously, but according to different reasons, their might be a total deficit in supply at certain periods. Here, we consider the grid as a binary-state power supply where the grid can be ON at certain periods and OFF at the rest. Note that grid power can supply the load sufficiently whenever it is in ON state. Such a timely grid behavior is illustrated simply in Figure 2.

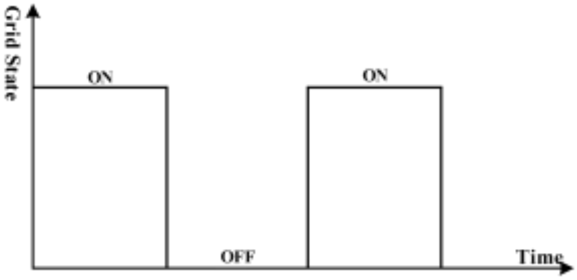


Figure 2 State of the Grid

C Microgrid Supply:

Microgrid is mainly acting as a secondary power supply which is represented by the different micro power resources. It can interact with the main grid to charge the battery bank in case of low charge due to its relatively low cost power. Simultaneously, it can supply the load in case of the absence of grid according to specific management criteria, which will be discussed in the next section. Mainly, the proposed micro grid supply consists of three sources: PV array, lead-acid battery bank and diesel GenSet. They can be modeled as follows:

PV array:

The output power of a PV module can be obtained by its rated output power at the standard test condition, light intensity, and the operating ambient temperature [10].

$$P_{PV} = P_{STC}\frac{G_C}{G_{STC}}[1 + k(T_c - T_{STC})] \tag{2}$$

P_{PV} is the output power from a single PV panel. The standard test condition (*STC*) means that solar irradiance G_{STC} is 1000 W/m^2, *PV* temperature T_{STC} is 25°C, and relative atmospheric optical quality is AM1.5 condition. G_C is the irradiance of the operating point, k is the power temperature coefficient, P_{STC} is the rated output power under *STC*, and T_c is the PV temperature at the operating point. Note that the output from the PV array are connected directly to a dc-dc power converter which has inside a maximum power point tracking unit (MPPT) to maximize power extraction under the different operational conditions.

Battery Bank:

The energy storage system (ESS) is the most essential part of most microgrids. It is, therefore, necessary to have a well-sized battery bank in order to ensure that the power supplied by RESs during high generation periods will be available when the load requires it [11]. The strategy of managing batteries can significantly impact the performance of the overall system. The following condition is imposed to limit the power in/out flows of the battery:

$$P_{chr\ max} \leq P_{Bat} \leq P_{dis\ max} \tag{3}$$

where P_{Bat} is the power thrown from or injected into the battery. It is positive at discharging and negative at charging. It should not exceed the limits of charging P_{chr_max} and discharging P_{dis_max} to ensure acceptable operation conditions [12]. Besides, another variable that should be kept within a certain range is the state of charge (SoC). It can be expressed as:

$$SOC(\tau) = \frac{E_{Bat}(\tau)}{C_{Bat}} \tag{4}$$

$$SOC_{min} \leq SOC \leq SOC_{max} \tag{5}$$

where E_{Bat}, C_{Bat}, SOC_{min} and SOC_{max} are the actual energy stored in the battery at time τ, the total energy capacity of the battery, and the minimum and maximum allowed state of charge of lead-acid batteries, respectively. The SoC value at time $(\tau + \Delta)$ is determined by the SoC value at time τ and the battery power during the time period. It can be expressed by the following equations:

$$E_{Bat}(\tau + \Delta) = E_{Bat}(\tau) - P_{Bat}(\tau) \times \Delta \tag{6}$$

$$SOC(\tau + \Delta) = SOC(\tau) - \frac{P_{Bat}(\tau)}{C_{Bat}} \times \Delta \tag{7}$$

The charging efficiency and discharging efficiency are both assumed to be $\eta_b = 95$ %. [13].

Diesel Generator

Basically, diesel generators act as a backup power source. In accordance to the concern of this work, the model of diesel GenSet is limited to fuel consumption F_c (L/kWh), which can be formulated as a quadratic function of the corresponding generated power [14]. Consequently, fuel cost can be found using Eq. (9), where D_c is the diesel fuel cost per liter ($/L)

$$F_c(P) = \sum(aP^2 + bP + c) \times \Delta \tag{8}$$

$$Fuel\ Cost = D_c F_c(P) \tag{9}$$

where a, b and c are the coefficients of fuel cost function and can be found by curve fitting according to the given chart by different manufacturer [15]. In addition, its generated power P_{Gen} should not violate the rated capacity P_{Gen_max} and also should not drop behind a certain lower limit P_{Gen_min} to keep its efficiency higher [16]:

$$P_{Gen\ min} \leq P_{Gen} \leq P_{Gen\ max} \tag{9}$$

Power Inverter:

A bi-directional power inverter is assumed to perform the needed power conversion between AC and DC buses. The following equation describes an abstract model of the used inverter:

$$P_{out} = \eta_c P_{in} \tag{10}$$

where η_c is the efficiency of the power conversion.

IV ENERGY MANAGEMENT SYSTEM

At each time step, the following power balance must be fulfilled:

$$P_{PV} + P_{Gen} + P_{Bat} = P_{Load} + P_{Loss} \tag{11}$$

where:

P_{PV}	is the total output power from photovoltaic;
P_{Loss}	is the total power losses on the system.

The developed control strategy consists of three cascaded stages:

1. The first stage gives the priority to the grid in order to supply the load in case of insufficient power generated from renewables.
2. The second stage becomes active in case of power outage where the microgrid takes the responsibility of supplying the load in case of insufficient renewable power.
3. The third and last stage is a master-slave control strategy adopted from [17, 18] which is typically developed for islanded operation mode where the battery bank and the diesel generator serve in succession depending on the available SoC and power from renewables.

Overall, the control strategy gives the priority of power supply to RES even if it is modest comparable with diesel GenSet. Basically, the diesel GenSet operates in case of grid outage and low SoC of the battery to supply the load demand and charge batteries (with excess power) up to a certain point SoC$_{\text{max}}$ according to the constraint in Eq. (5).

Note that two maximum threshold are chosen to stop the charging process: SoC_{stp1} is chosen to stop the charging process from RES and SoC_{stp2} is chosen to stop the charging process either from grid or from the diesel GenSet while it is running. Here, SoC_{stp2} is chosen lower than SoC_{stp1} to maximize the usage of RES rather than depend too much on the grid or the diesel GenSet.

```
DECLARE STATE VARIABLES $SOC_a$, $P_{GenSet}$, $P_{GRID}$, $P_{LOAD}$, $P_{RES}$,
$P_{Batt}$, $F_{incr}$
DECLARE GenSet COEFFICIENTS a, b, c
READ $SOC_i$, $SOC_{stp1}$, $SOC_{stp2}$, $SOC_{min}$, $P_{GEN}$, $F_c$, $P_{Batt\_max}$,
$GenSet_{Flag}$, Eff, K

$F_c = 0$
FOR t = 1 to T
DEMAND[t] = $P_{LOAD}$[t] - $P_{RES}$[t]
    IF Demand[t] < 0
        $P_{GenSet}$[t] = 0
        $P_{GRID}$[t] = 0
        IF $SOC_a$[t] < $SOC_{stp1}$
            $P_{Batt}$[t] = Eff * Demand[t]
        ELSE
            $P_{Batt}$[t] = 0
        END IF
        $SOC_a$[t+1] = $SOC_a$[t] - ($P_{Batt}$[t]/K)
    ELSE
        IF $P_{GRID}$ == 1
            $P_{GenSet}$[t] = 0
            IF $SOC_a$[t] >= $SOC_{stp2}$
                $P_{Batt}$[t] = 0
            ELSE
                $P_{Batt}$[t] = -$P_{Batt\_max}$
            END IF
            $P_{GRID}$[t] = Demand[t] - ($P_{Batt}$[t]/Eff)
            $SOC_a$[t+1] = $SOC_a$[t] - ($P_{Batt}$[t]/K)
        ELSE
            $P_{GRID}$[t] = 0
            IF ($SOC_a$[t] >= $SOC_{min}$) AND ($DG_{Flag}$ == 0)
                $P_{Batt}$[t] = Demand[t]/Eff
                $P_{DG}$[t] = 0
            ELSE
                $P_{DGenSet}$[t] = Demand[t]
                $P_{Batt}$[t] = Demand[t] - $P_{GEN}$
                IF $SOC_a$[t] < $SOC_{stp2}$
                    $GenSet_{Flag}$ = 1
                ELSE
                    $GenSet_{Flag}$ = 0
                END IF
            END IF
            $SOC_a$[t+1] = $SOC_a$[t] - ($P_{Batt}$[t]/K)
        END IF
    END IF
$F_{incr}$[t] = (a*$P_{GenSet}$[t]$^2$ + b*$P_{GenSet}$[t] + c)/K
$F_c = F_c + F_{incr}$[t]
END FOR
```

Figure 3 A pseudocode of the proposed 3-stages EMS algorithm.

In addition, the control strategy aims to operate the diesel GenSet in its most efficient range by keeping the loading factor as high as possible instead of fluctuation according to load, where the excess power is used to charge the battery as long as it does not violate the charging constraints. Bear in mind that too fast discharging of the batteries is to be avoided, cf. constraints in Eq. (3). Additionally, high frequent changes in the state of the diesel GenSet have to be prevented. Therefore, the design parameters such as battery charging limit P_{chr_max} and capacity of diesel GenSet should be carefully chosen according to the system behavior and characteristics.

The advantages of this strategy can be summarized as follows:

1. It reduces fuel consumption which is desirable from the environmental and economic point of view.
2. It allows the utilization of renewable energy by minimizing the operation time of the diesel generator.
3. It leads to increase the expected life span of the generator by reducing its daily operation time.
4. It keeps the SoC within an acceptable range, even if there is no generation from RES, which leads to increased battery lifetime.
5. It offers sufficient time for system maintenance by reducing the total operation time of diesel GenSet.

In the following section, the EMS is applied and simulation results are demonstrated in detail.

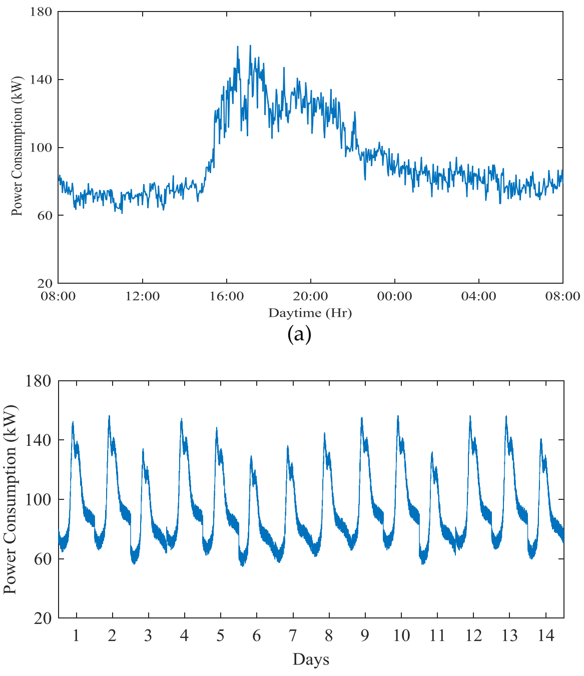
V CASE STUDY

Al-Shifa' Hospital in Gaza-City is chosen to conduct this work. It is considered as the largest healthcare facility in Gaza-Strip. It faces a semi-predictable daily power outage according to several electrification problems in the region [19]. An exhaustive description of the power system of that hospital was demonstrated and clearly discussed in a previous work [20]. An authentic load profile was adopted from [21] to conduct this work. It was a single-day load profile which was measured every two minutes. However, the simulation of the present work is carried out over an extended period (two weeks) to capture the system dynamics more comprehensively.

According to [21], it was identified that the daily electrical load profile has almost the same pattern during the whole year; this can be observed since the clinical services are continuous all over the year [21]. Obviously, this may be debatable because of seasonal variations. However, an acceptable explanation of this phenomenon is the Mediterranean-arid nature of the climate in that region with mild winters and dry, hot summers subject to drought [22]. Therefore, the cooling load in summer approximately substitutes the heating load in winter. Besides, another scientific interpretation based on validation was mentioned by [9] and [23] that weather variables do not influence load consumption, but the work calendar which has more influence.

Hence, a fraction of this load (one fifth) is considered to be initially recognized as basic data from which the load profile is generated for a relatively long period according to

Eq. (1). The uncertainty parameters α^i and β^i are generated using uniformly distributed random variables. Both load profiles, the basic and derived long-time one, are illustrated in Figure 4.

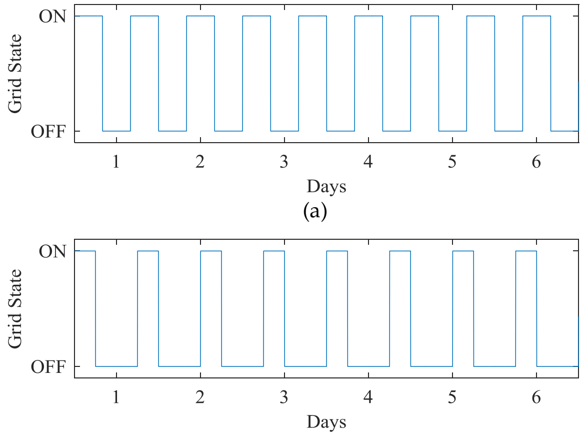


(a)

(b)

Figure 4 Load profile: (a) for the basic day, (b) over two weeks.

Two outage scenarios are frequently experienced in Gaza-Strip [20] and modeled according to the earlier illustration in Figure 2. The first scenario is called *half-period schedule*; it occurs when the grid deficit is around 50 % in which the grid is ON for eight hours and then changed to OFF for the next eight hours over an extended period (cf. Figure 5a). The second scenario, the *one-third schedule*, occurs when the deficit is around 70 % in which the grid is ON for six hours and then changed to OFF for the next twelve hours over a long period of time (Figure 5b).



(a)

(b)

Figure 5 Grid states: (a) half-period schedule, (b) one-third schedule.

The components of the proposed microgrid are adopted from [17] but without using the wind-turbines. They are listed in details in Table I.

TABLE I

Components of microgrid system

Module	Power ratings	Quantity	Capacity
PV solar panel	180 Wp	556	100 kWp
Diesel Generator	200 kW	1	200 kW
Deep Cycle Lead-Acid Battery	2V / 1000 Ah	480	960 kWh

Note that the rating of the diesel GenSet is given in kW not in kVA (kilo Volt-Ampere); whereas it is known that kW is the unit of real power and kVA is a unit of apparent power. However, the power factor, unless it is defined, is therefore an approximate value (typically 0.8), and the kVA value will always be higher than the kW value for [24]. The parameters used in simulation with the corresponding nomenclature and values are listed below in Table II.

TABLE II

Simulation parameters

Parameter	Nomenclature	Value
E_{bat}	Total battery bank capacity	960 kWh
SoC_{int}	Initial state of charge	60 %
SoC_{min}	Minimum allowable state of charge	45%
SoC_{stp1}	Stop charging threshold from RES	100%
SoC_{stp2}	Stop charging threshold from GenSet	85%
η_b	Efficiency of charging and discharging	95%
η_c	Inverter efficiency	95%
P_{Batt_max}	Maximum charging/discharging power	$\mp E_{bat}/(5h)$
P_{GenSet}	Maximum output power from GenSet	185 kW
D_c	Diesel fuel cost per liter	1.85 $/L
Δ	Time step	(1/30) h

The expected lifespan of the batteries is highly affected by the timely varation of the SoC, i.e., by the depth of discharge. According to [12] and [25], it has been reported that the effective cumulative lifetime of lead-acid batteries is associated with its operating SoC values. Therefore, the maximum charging current should be carefully chosen to guarantee a long battery lifetime and protect the battery from overheating or fast degradation. Different manufacturers have their different recommendations and preferences of the charging technology. Generally, maximum current must not exceed a certain C/(4 h) [26]; C is the battery capacity in Ampere hours (Ah).

The MATLAB simulation is performed using the the generated two-weeks load profile. To conduct this work, a baseline simulation is carried out firstly considering diesel GenSet only as a standby power supply. For illustration, Figure 6 presents the baseline power consumption from both grid and diesel GenSet over three days, applying the half-period outage scenario. The fuel consumption of the diesel GenSet over the whole period of simulation is found to be 4850 and

6444 liters in case of half-period and one-third schedules, respectively.

Obviously, during these schedules, GenSet is operated for the half period of time in the first case and almost two-thirds of the whole period.

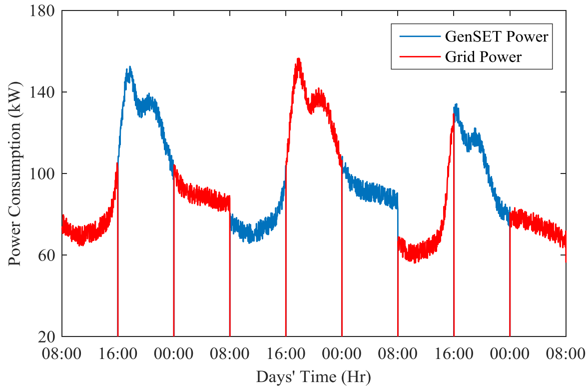


Figure 6 Baseline power consumption in half-period schedule case

The solar metrological data required for carrying out this work is gathered from the global metrological database software METEONORM [27]. Extensive simulation for the whole-year data indicates that solar power gained at the site can beat 1750 kWh/kW$_p$ annually. Figure 7 presents the generated power from PV array over the 14 days.

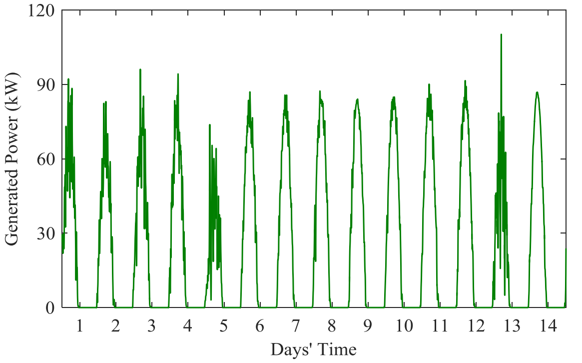


Figure 7 Generated power from PV array

For illustration purposes, three days simulation results of the corresponding system are presented in Figure 8, where the aggregated power flows of both grid and microgrid with the corresponding load profile and SoC dynamics are shown.

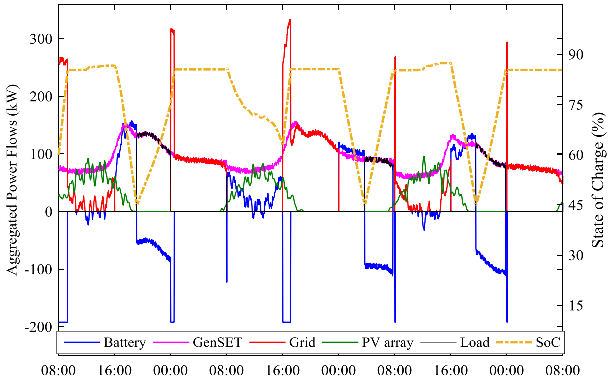


Figure 8 Aggregated power flows (Grid & Micogrid with EMS)

Both the battery and the load can profit from the power of the PV array at the hours of daylight. In addition, the power gained from the PV array is modest as compared with the charging load of the battery or even the load demand. Therefore, the SoC is decreased in the morning slower than in the evening because of the availability and the assistance of the solar power. Expectedly, the diesel GenSet is OFF when the grid is ON or the SoC is greater than its minimum allowed threshold. Besides, the proposed EMS tries to operate the diesel GenSet at its maximum efficiency with the highest loading factor instead of varying supply according to demand as in the baseline case (cf. Figure 6).

The final results according to the simulation parameters are listed in Table III.

TABLE III

Final Simulation Results (14 Days)

Output	**Half-Period schedule**		**One-third schedule**	
	Grid & Diesel (Base-line)	**Grid & Microgrid (With proposed EMS)**	**Grid & Diesel (Base-line)**	**Grid & Microgrid (With proposed EMS)**
Total Energy Supplied by GenSet (kWh)	15645	5826	20798	7117
Total Energy Supplied by Battery Bank (kWh)	(n/a)	6667	(n/a)	9829
Total Energy Supplied by Grid (kWh)	15673	13778	10520	11950
Total Energy Supplied from PV array (kWh)	(n/a)	7714	(n/a)	7714
Fuel Consumption (L)	4850	3724	6444	4034
Operating Time of the GenSet (Hr)	168	59	222	71
Final SoC (%)	(n/a)	85.44	(n/a)	63.04
Operational Cost ($) (*)	11794	9369	13815	9614

(*) End price of grid purchase per kWh is considered 0.18$

The total operating hours and the corresponding fuel consumption of GenSet is significantly decreased after applying the microgrid with the proposed EMS. In addition, the cost savings are calculated and found to be **2425 $** and **4201 $** in case of half-period and one-third schedules, respectively.

VI DISCUSSION AND CONCLUSION

This work presents an energy management scheme for a microgrid operating in two modes: grid-connected and islanded mode. It consists of photovoltaic (PV) solar arrays and a deep-cycle lead-acid battery bank in addition to the conventionally utilized power source diesel generator (GenSet). Simulations are performed on a load profile of a hospital in Gaza-City. Eventually, the GenSet is switched on when the grid is off and the state of charge (SoC) of batteries is below a defined threshold SoC_{min}. Likewise, the generator is kept at least until batteries reach a certain threshold below the fully charged level SoC_{stp2}. The presented EMS provides significant fuel savings and can enlarge the lifespan of diesel GenSet. Lastly, simulation results indicate the advantage of performing such model-based analyses before utilizing new components on site.

Future work will consider long-time optimization of the system parameters in order to further increase the overall efficiency and maximize the life-time of the system components.

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REFERENCES

[1] A. Hooshmand, B. Asghari and R. Sharma, "*A power management system for planned & unplanned grid electricity outages*," Innovative Smart Grid Technologies Latin America (ISGT LATAM), 2015 IEEE PES, Montevideo, 2015, pp. 382-386.

[2] G. Kumar and N. M. Pindoriya, "*Outage management system for power distribution network*," Smart Electric Grid (ISEG), 2014 International Conference on, Guntur, 2014, pp. 1-8.

[3] Microgrid Exchange Group. "*DOE Microgrid Workshop Report*" Aug. 2011

[4] R. Lasseter,"*MicroGrids*" Power Engineering Society Winter Meeting, IEEE 2002

[5] J. Lukuyu, "*Wind-diesel microgrid system for remote villages in Kenya*," North American Power Symposium (NAPS), Champaign, IL, 2012

[6] A. C. Luna, N. L. Diaz, M. Graells, J. C. Vasquez and J. M. Guerrero, "*Online energy management system for distributed generators in a grid-connected microgrid*," 2015 IEEE Energy Conversion Congress and Exposition (ECCE), Montreal, QC, 2015, pp. 4616-4623.

[7] P. Malysz, S. Sirouspour and A. Emadi, "*An Optimal Energy Storage Control Strategy for Grid-connected Microgrids*," in *IEEE Transactions on Smart Grid*, vol. 5, no. 4, pp. 1785-1796, July 2014.

[8] IEEE Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power Systems, in IEEE Std 1561-2007 , vol., no., pp.C1-25, May 2008

[9] I. Fernández, C. E. Borges and Y. K. Penya, "*Efficient building load forecasting*," Emerging Technologies & Factory Automation (ETFA), 2011 IEEE 16th Conference on, Toulouse, 2011, pp. 1-8.

[10] E. Gavanidou, A. Bakirtzis, "*Design of a stand alone system with renewable energy sources using trade off methods*," in Energy Conversion, IEEE Transactions on , vol.7, no.1, pp.42-48, Mar 1992

[11] F. Marra, G. Yang, C. Træholt, J. Østergaard and E. Larsen, "A Decentralized Storage Strategy for Residential Feeders With Photovoltaics," in IEEE Transactions on Smart Grid, vol. 5, no. 2, pp. 974-981, March 2014.

[12] D. Jenkins, J. Fletcher, D. Kane, "*Lifetime prediction and sizing of lead-acid batteries for microgeneration storage applications*," in Renewable Power Generation, IET , vol.2, no.3, pp.191-200, September 2008

[13] PowerSonic, Technical Manual (PDF), p. 19, retrieved March 2015

[14] G. Moshi, M. Pedico, C. Bovo, A. Berizzi, "*Optimal generation scheduling of small diesel generators in a microgrid*," in Energy Conference (ENERGYCON), 2014 IEEE International , vol., no., pp.867-873, 13-16 May 2014

[15] Approximate Diesel Fuel Consumption Chart: retrieved in March. 2016: www.dieselserviceandsupply.com

[16] C. Wang, M. Liu, L. Guo, "*Cooperative operation and optimal design for islanded microgrid*," in Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES , vol., no., pp.1-8, 16-20 Jan. 2012

[17] B. Zhao; X. Zhang; J. Chen; C. Wang; L. Guo, "*Operation Optimization of Standalone Microgrids Considering Lifetime Characteristics of Battery Energy Storage System*," in Sustainable Energy, IEEE Transactions on , vol.4, no.4, pp.934-943, Oct. 2013

[18] J. Peas Lopes, C. Moreira, A. Madureira, "*Defining control strategies for analysing microgrids islanded operation*," in Power Tech, 2005 IEEE Russia , vol., no., pp.1-7, 27-30 June 2005

[19] United Nation Office for the Coordination of Humanitarian Affairs OCHA, "*The humanitarian impact of Gaza's electricity and fuel crisis*," March 2014; last accessed May 2016: http://www.ochaopt.org/documents/ocha_opt_electricity_factsheet_march_2014_english.pdf

[20] M. Hijjo, P. Bauer, F. Felgner, G. Frey, " *Energy Management systems for hospitals in Gaza-strip*," Proceedings of the IEEE Global Humanitarian Technology Conference (GHTC2015), pp. 18-25, Seattle/WA, USA, Oct. 2015

[21] M. Mushtaha, G. Krost, "*Performance study of self-sufficient and renewables based electricity supply of a hospital in the Near East Region*," in Power and Energy Society General Meeting, 2012 IEEE , vol., no., pp.1-8, 22-26 July 2012

[22] The climate of Gaza (Palestinian Territories), Online: retrieved in March 2016: www.whatstheweatherlike.org

[23] Y. K. Penya, C. E. Borges and I. Fernández, "*Short-term load forecasting in non-residential Buildings*," AFRICON, 2011, Livingstone, 2011, pp. 1-6.

[24] G. Moshi, M. Pedico, C. Bovo, A. Berizzi, "*Optimal generation scheduling of small diesel generators in a microgrid*," in Energy Conference (ENERGYCON), 2014 IEEE International , vol., no., pp.867-873, 13-16 May 2014

[25] R. Kaiser, "*Optimized battery-management system to improve storage lifetime in renewable energy systems*," Journal of Power Sources, Volume 168, Issue 1, Pages 58-65, May 2007

[26] E. Koutroulis and K. Kalaitzakis, "*Novel battery charging regulation system for photovoltaic applications*," in IEE Proceedings - Electric Power Applications, vol. 151, no. 2, pp. 191-197, Mar 2004.

[27] Meteonorm: Global metrological database. Online: retrieved March 2016: http://www.meteonorm.com/en/