Energy management of renewable energy sources incorporating with energy storage device

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ABSTRACT

The best solution to exploit renewable energy sources (RES) together is by using the application of microgrid (MG). This indeterminate of resources such as solar panels, wind farm, diesel generator, and battery storage system paired with load profile result in random changes within the generation and the load phases, which create it is challenging to properly manage an MG. Due to this problem energy management technique for real-time scheduling of an MG takes into consideration the uncertainty of load demand, renewable energy, and electricity price are proposed. In this paper, linear programming with two methods (optimized problem and solver based) of dual-simplex are suggested to tackle the energy management issue of the renewable microgrid. The simulation is done in each method using four cases fast wind speed with clear solar irradiance, fast wind speed with cloudy solar irradiance, slow wind speed with clear solar radiation, and slow wind speed with clear solar irradiance. The result showed that the first and second cases in the first method are higher cost than the two corresponding cases in the second method. In addition, the third and fourth cases in the first method are lower cost than the two corresponding cases in the second method.

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NOMENCLATURE

δ	: Time between optimization calls.
W	: Final weight (tunable weight for final energy storage)
Ct	: Cost vector of current and forecast grid price [$/kWh]
$G_t - P_{grid}(k)$	: Power from grid
$B_t - P_{batt}(k)$	: Power from battery
E_t	: Stored energy
$s_t - P_{pv}(k)$	: Power from solar PV
$w_t - P_w(k)$	: Power from wind
$D_t - P_D(k)$	: Power from diesel
$d_t - P_{load}(k)$	: Power of load

A_{eq}	: real matrix Linear equality constraints
b	: real vector Linear inequality constraints
b_{eq}	: real vector $Linear\ equality\ constraints$
X	: the column vector of N variables
$P_{grid}(1:N)$	: Power from grid used from time step 1 to N
$P_{batt}(1:N)$	: Power from battery used from time step 1 to N
$E_{batt}(1:N)$	: Energy Stored in battery used from time step 1 to N
E_N	: Energy Stored in battery variables
E_{grid}	: Energy used from grid
batteryMinMax	: Structure of simplified battery properties
E_{init}	: Initial Battery Energy [J]
l_B	: batteryMinMax.Pmin
u_B	: batteryMinMax.Pmax
l_E	: batteryMinMax.Emin
u_E	: batteryMinMax.Emax

1. INTRODUCTION

The utilization of distributed energy resource (DER) units has grown recently due to progress in renewable energy technology and growing fears as to the increased price of electricity from non-renewable sources and global climate change [1], [2]. DER units are energy sources close to connected loads that are divided into two categories: distributed generation (DG) and distributed storage (DS) units [3]. DG units use a large variety of components such as photovoltaic (PV) systems, wind turbines (WTs), fuel cells, micro turbines (MTs) and diesel engines DS units are consisting of batteries, capacitors, flywheels, and adjustable loads. Both DG and DS units are included in a microgrid (MG) [4]. When the MG is tied to the grid, it has the ability to sell and buy electricity to the grid [5].

Renewable energy sources (RESs) have significant penetration in power systems, which has both benefits and drawbacks. Reduced power loss and emissions, increased power system reliability, and improved power quality are just a few of the advantages on the other side, if renewable energy sources are not correctly exploited, may generate grid concerns, such as ohmic losses and voltage sag in transmission network. Some of these drawbacks are discussed in the context of MG energy management [6]. So, this article invest ages the energy management of microgrid to achieve minimizing total cost of variable priced electricity.

Energy management is defined as a communication network that provides required functionally to ensure that generation, transmission, and distribution supply energy at the lowest possible cost when supported on a platform [7]. The main optimization issue for the MGs, when tied to the utility, is energy management (EM). Many researches have been interested in the describing of the EM issue and providing effective optimization approaches for tackling the EM problem in recent years [8]. Deterministic and probabilistic approaches are used to solve EM problem of the MG in the literature [9], [10]. The generated power of renewable energy sources, load power, market prices are considered to be identical to their predicted values in the deterministic EM of MG. While many of the input parameters in MG's probabilistic EM are uncertain. The power produced from WT and PV is difficult to estimate without inaccuracy due to the unpredictable speed of the wind and solar sunlight. Furthermore, the predicted load needed and the market price will not be accurate. This is due to unanticipated disruptions, forecaster errors or load, and pricing variances [10]. Several recent studies, [11], [12] have focused on energy management of microgrids with power exchange. several publications utilize an optimization strategy for the selection procedure of cases. Linear programming techniques were applied to reduce microgrid running cost, optimize battery charge states, and average electric power generation costs in a hybrid solar wind MG while environmental issues were taken into consideration [13], [14]. Mixed-integer linear optimization problem is presented in the literature [15]. Meta-heuristic optimization procedures often do not produce the globally optimal solution, but they always produce a reasonable solution. Furthermore, no single meta-heuristic optimization strategy provides the optimal solution for all optimization issues [16]. As a result of the factors considered, the optimization issue will be linear programming (LP).

The contributions of this paper are: i) This research presents a formulation of the issue of energy management having storage devices using a single objective function cost problem to reduce overall cost of variable priced electricity; ii) The suggested approach is implemented and used to obtain the optimum solution to the issue of probabilistic EM with uncertain input variables; iii) Comparative analysis of the proposed optimization algorithm is demonstrated via different two methods (problem and solver based); and iv) Improving the response of the probabilistic EM issue as compared to recently published optimization approaches using a grid-tied MG with energy storage modelling.

The paper is organized as: microgrid modelling are explained in section 2. The formulation of the issue is covered in section 3. The proposed optimization algorithm is presented in section 4. The modeling results are discussed in section 5. Finally, section 6 represents the conclusion of the research.

2. MICROGRID MODELLING

A Microgrid is composed of a variety of loads, energy storage devices, and generation systems. The microgrid of our study consists of PV array model, wind turbine, energy storage batteries, a diesel generator, fixed and variable loads. The MG is tied to the main grid via a common coupling point (PCC). Figure 1 shows the graphical layout of a microgrid.

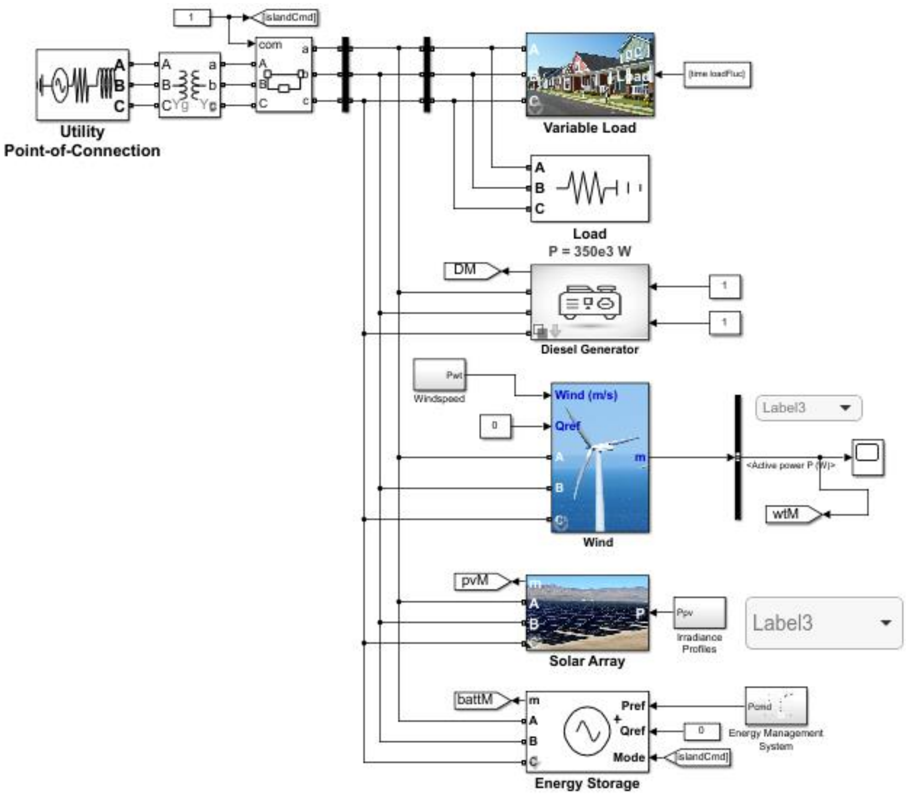

Figure 1. Layout of microgrid

2.1. Photovoltaic model

Photovoltaic power generation is a method of converting solar radiation to direct current utilizing semiconductors that demonstrate the photovoltaic principle [17]. The power generated from PV module relies on the number, type, and area of cells within it. PV panels are subject to manufacturer evaluation in terms of their peak power (Wp) under standard test conditions: i.e. 1000 W/m^2 of sunlight ('peak sun'), T = 25 and air mass of 1.5. Area of PV array is 2500 m^2 and global efficiency of the PV panel installation array is 0.3. The power produced from solar panels can be calculated using the area of solar panels in our modelling and the general sunlight data for each hour of the day given in [18]. Using the (1):

$$P = I_{rr} * A_{pv} * K_t \quad (1)$$

Where:

P [W] : power output, I_{rr} [W/m^2]: irradiance, A_{pv} [m^2]: solar panels surface.

K_t [%] : global efficiency of the PV panel installation.

2.2. Wind turbine

A wind plant converts the energy in the air (wind energy) to electricity. Cairo is not a particularly windy location, according to weather data condition [18], which is why a low start-up wind speed is one of the most crucial factors to consider when choosing a wind turbine. The following wind turbine was picked in the literature for these reasons [19]. The power of the wind can be defined as [20].

$$P = \frac{1}{2} * \rho * A * V^3 * C_p \tag{2}$$

Where:

A [m^2] : swept area at speed V [m/s], ρ [kg/m^3]: air density.

Cp : coefficient of power of rotor, the fraction of the wind's power that is produced by the blades.

2.3. Battery

The batteries in the microgrid are utilized for two purposes. One of its purposes is to serve as a backup or uninterruptible power supply for the loads in the event of low generation. The second is to lower the microgrid's operating costs by charging the batteries with extra PV or wind energy and discharging them to minimize the energy absorbed by the auxiliary units. Battery capacity of system is 2500 kWh.

2.4. Auxiliary generators

Because RERs have alternate output characteristics, when coupling them with a power grid typically restricts users' needs. DG is a critical component in the design of a microgrid structure since it offers several advantages in terms of emergency backup power, system dependability, time-consuming power, prime electricity, and continuing running power [21]. Generators of various sizes are available from the chosen generator supplier. The 60 kW diesel generator was chosen.

2.5. Load

The load is fundamentally the driving element behind every power system, large or small. The peak load of the area under consideration is critical since it aids in determining the microgrid's installed capacity. The load demand for a day of MG involves both fixed and variable loads, resulting in a total load as shown in Figure 2.

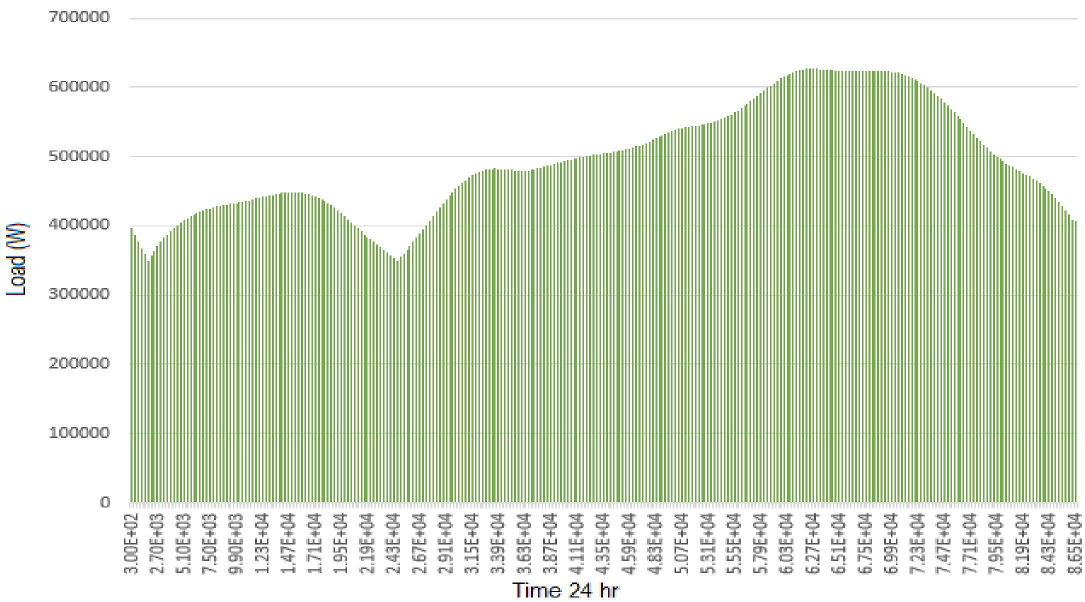

Figure 2. values of total load demand

3. PROBLEM FORMULATION

The aim of solving the EM issue is to reduce the MG's overall operational costs while fulfilling certain constraints [10]. The EMS can operate a microgrid by implementing various objective functions. The grid-connected mode cost function is formulated as follows.

3.1. Objective functions
3.1.1. Minimization of the operating cost

The price of various DG units as well as the price of power exchange between the MG and the grid are all included in the MG's overall price. As a result, the objective function (3) as shown in [22], [23].

$$C_{tot} = \sum_{k=0}^{N} C_{grid}(k)\, E_{grid}(k) \tag{3}$$

and can be expressed as (4).

$$minmize\ \sum_{t=1}^{N} \delta c_t G_t - W\, E_N \tag{4}$$

3.2. Constraints
3.2.1. System power balance

DG units, energy storage units, and the utility must be able to meet the total demand in the MG at any time. It is important to note that the MG's power loss can be ignored. So, the constraint of the system power balance constraint can be formulated as (5) [22], [23]:

$$P_{pv}(k) + P_{grid}(k) + P_{batt}(k) + P_w(k) + P_D(k) = P_{load}(k) \tag{5}$$

and can be expressed as (6).

$$s_t + G_t + B_t + w_t + D_t = d_t \tag{6}$$

3.2.2. Power input/output to battery

The limits of the stored energy amount and the charge/discharge rate of the energy storage units (such as battery) can be given:

$$E_{batt}(k) = E_{batt}(k-1) + P_{batt}(k)\Delta T \tag{7}$$

and can be expressed as:

$$E_{t+1=}E_t - \delta$$
$$l_B \le B_t \le u_B \tag{8}$$
$$l_E \le E_t \le u_E$$

4. PROPSED OPTIMIZATION ALGORITHM

Linear programming is the issue of finding an x-vector that minimizes a linear function $f^T x$ subject to linear constraints:

$$\min_x f^T X \text{ such that } \begin{cases} A\,x \le b \\ A_{eq}\,X \le b_{eq} \end{cases}$$

In this paper using dual-simplex algorithm with two methods optimization problems (problem based and solver based). The 'dual-simplex' linprog algorithm basically runs a simplex algorithm on the double issue [24]–[26]. Define states (x) necessary for LP optimization:

– $P_{grid}(1{:}N)$ – Power from grid used from time step 1 to N
– $P_{batt}(1{:}N)$ – Power from battery
– $E_{batt}(1{:}N)$ – Energy stored in battery

$$X = [P_{grid}(1{:}N) P_{batt}(1{:}N)\ E_{batt}(1{:}N)]^T \tag{9}$$

Linear program-based optimization
– Equivalent constraint

$$\begin{bmatrix} I_{N\times N} & I_{N\times N} & O_{N\times N} \\ O_{N\times N} & \gamma_{N\times N} & \emptyset_{N\times N} \end{bmatrix} X = \begin{bmatrix} P_{load}(1{:}N) - P_{pv}(1{:}N) - P_w(1{:}N) - P_D \\ E_{batt(1)} \\ O_{N-1} \end{bmatrix} \tag{10}$$

– Inequality constraints

$$\begin{bmatrix} O_{N\times N} & I_{N\times N} & O_{N\times N} \\ O_{N\times N} & -I_{N\times N} & O_{N\times N} \\ O_{N\times N} & O_{N\times N} & I_{N\times N} \\ O_{N\times N} & O_{N\times N} & -I_{N\times N} \end{bmatrix} \geq \begin{bmatrix} P_{max} \\ -P_{min} \\ E_{max} \\ -E_{min} \end{bmatrix} \tag{11}$$

Where:

$$\gamma_{3\times 3} = \begin{bmatrix} 0 & 0 & 0 \\ \Delta T & 0 & 0 \\ 0 & \Delta T & 0 \end{bmatrix}, \emptyset_{3\times 3} = \begin{bmatrix} 1 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix}$$

A flowchart for the dual simplex algorithm is illustrated in Figure 3 [26].

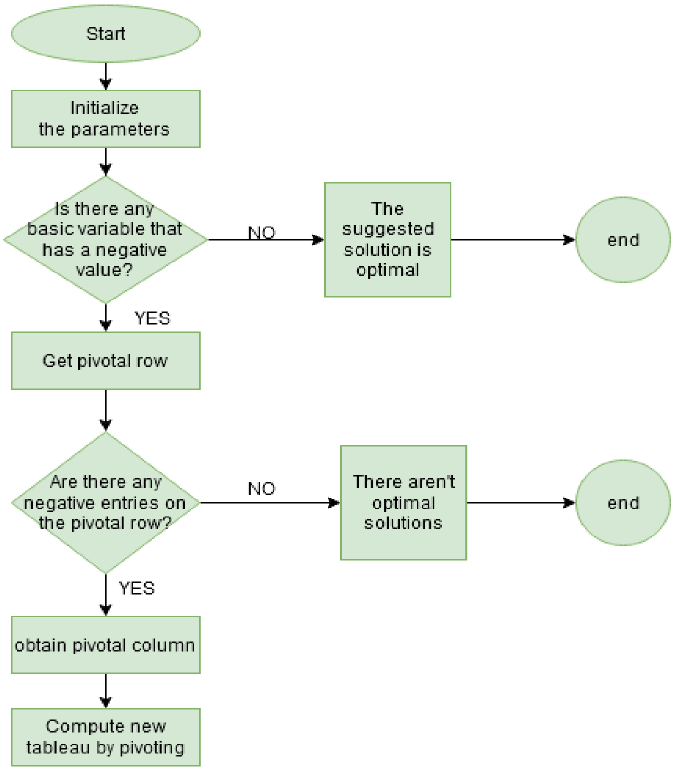

Figure 3. A flowchart for the dual simplex method

5. RESULTS AND DISCUSSION

To evaluate the effectuality of the linear programming algorithm in tackling the issue of probabilistic energy management with renewable micro-grid including storage devices, the suggested LP is verified using a typical medium grid-tied MG. All of the simulation tests were performed on 2.8 GHz i3 PC with 8 GB of RAM using MATLAB 2019. The MG modelling applied in this research as an experimental setup is shown in Figure 2, which comprises of several types of DG units. These units are PV, WT, diesel engine, and energy storage system. A day's load demand for MG is mainly composed of both fixed and variable loads. A step-down transformer (13.8 KV/5000 V) is often used to provide the employed MG from the medium voltage distribution grid. All information of the MG experimental setup and the predicted load demand, competitive energy price, wind and solar power model can be found in [22], [23]. Figures 4–11 shows the forecasted values of load demand, market price, output power of PV, and WT depend on weather data condition of Egypt [18]. In this paper using dual-simplex algorithm using two method optimization problems (problem based and solver based).

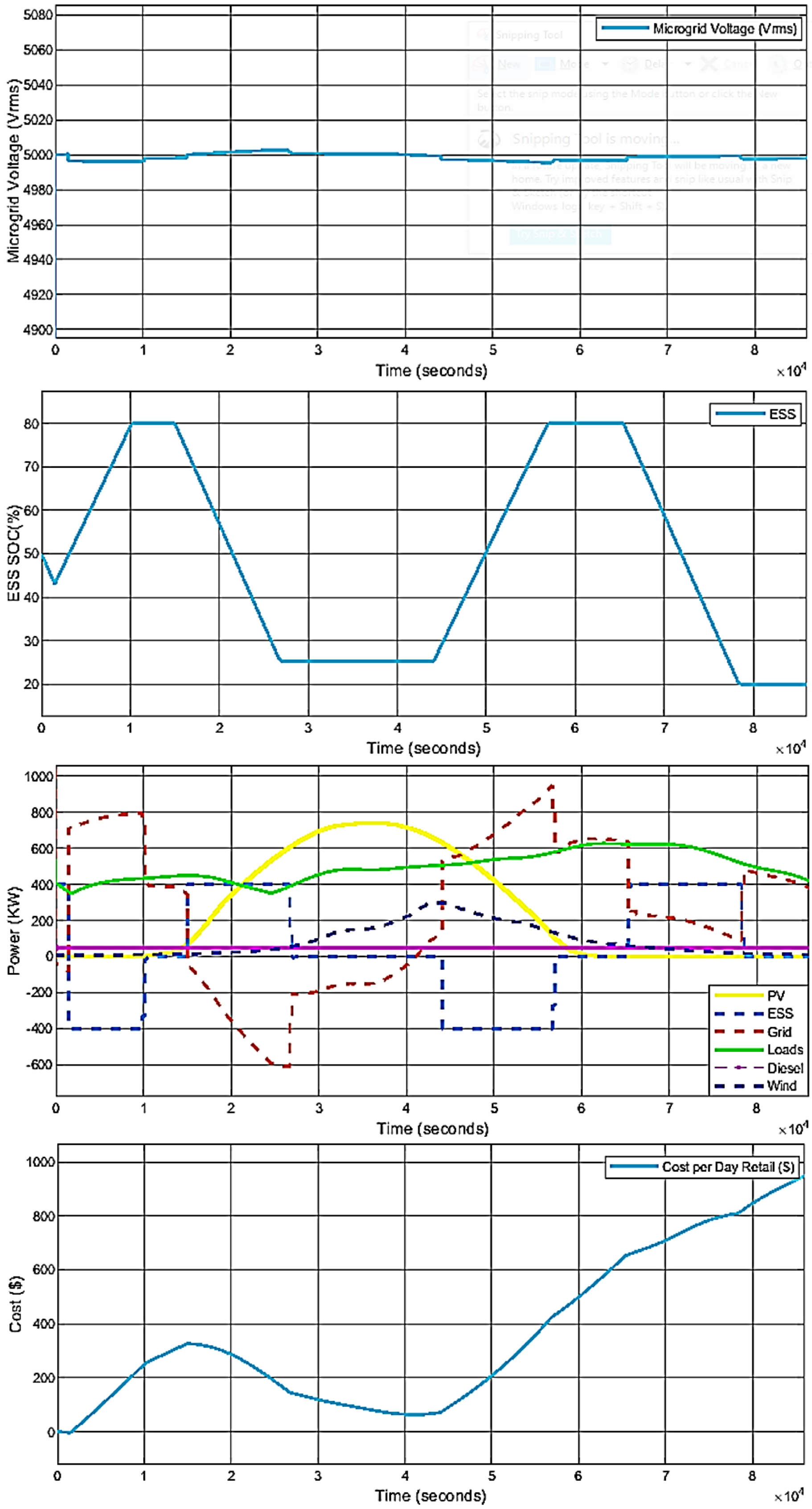

Figure 4. microgrid result of optimized problem based in case fast wind speed and clear solar irradiance

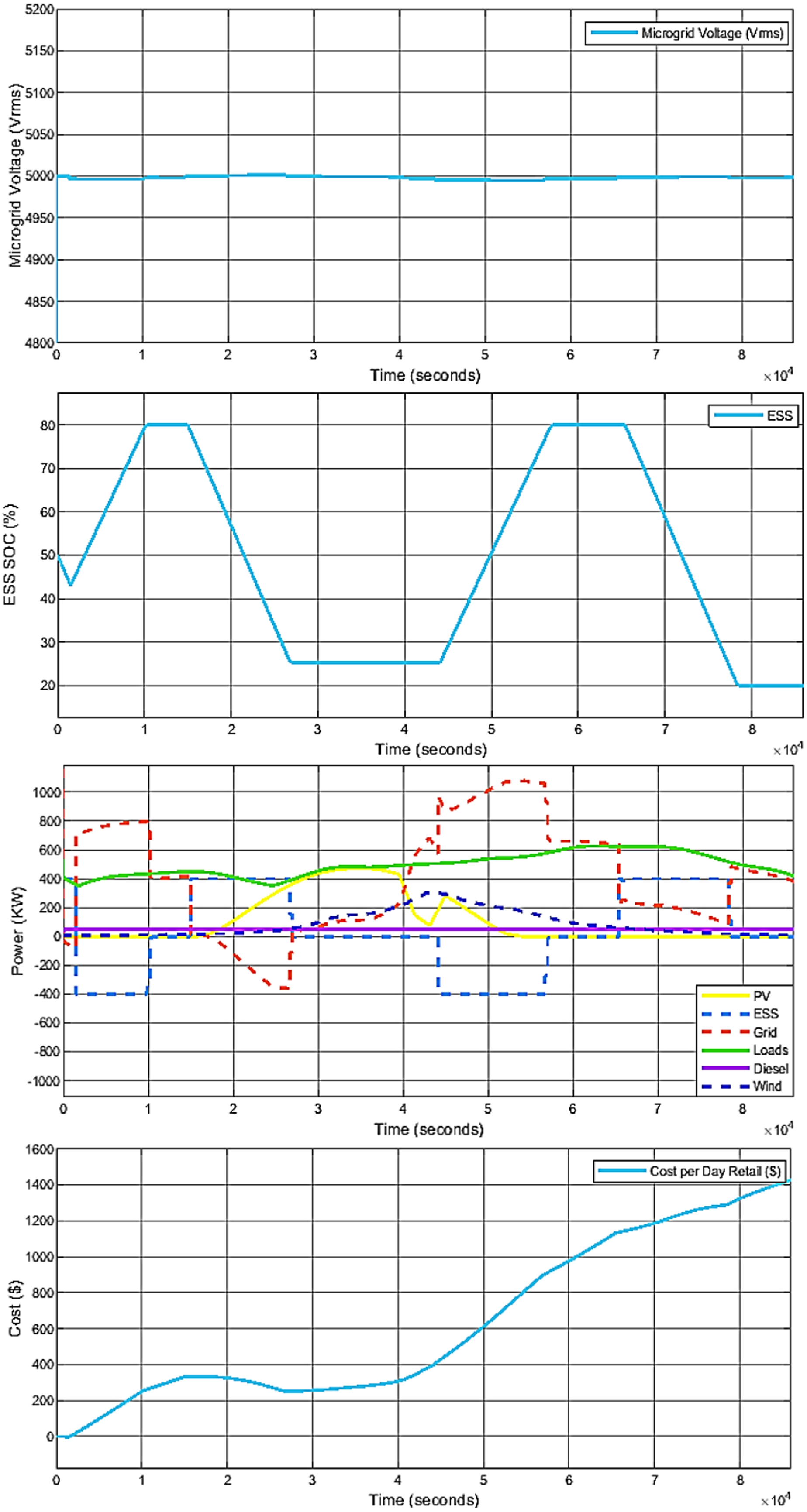

Figure 5. Microgrid result of optimized problem based in case fast wind speed and cloudy solar irradiance

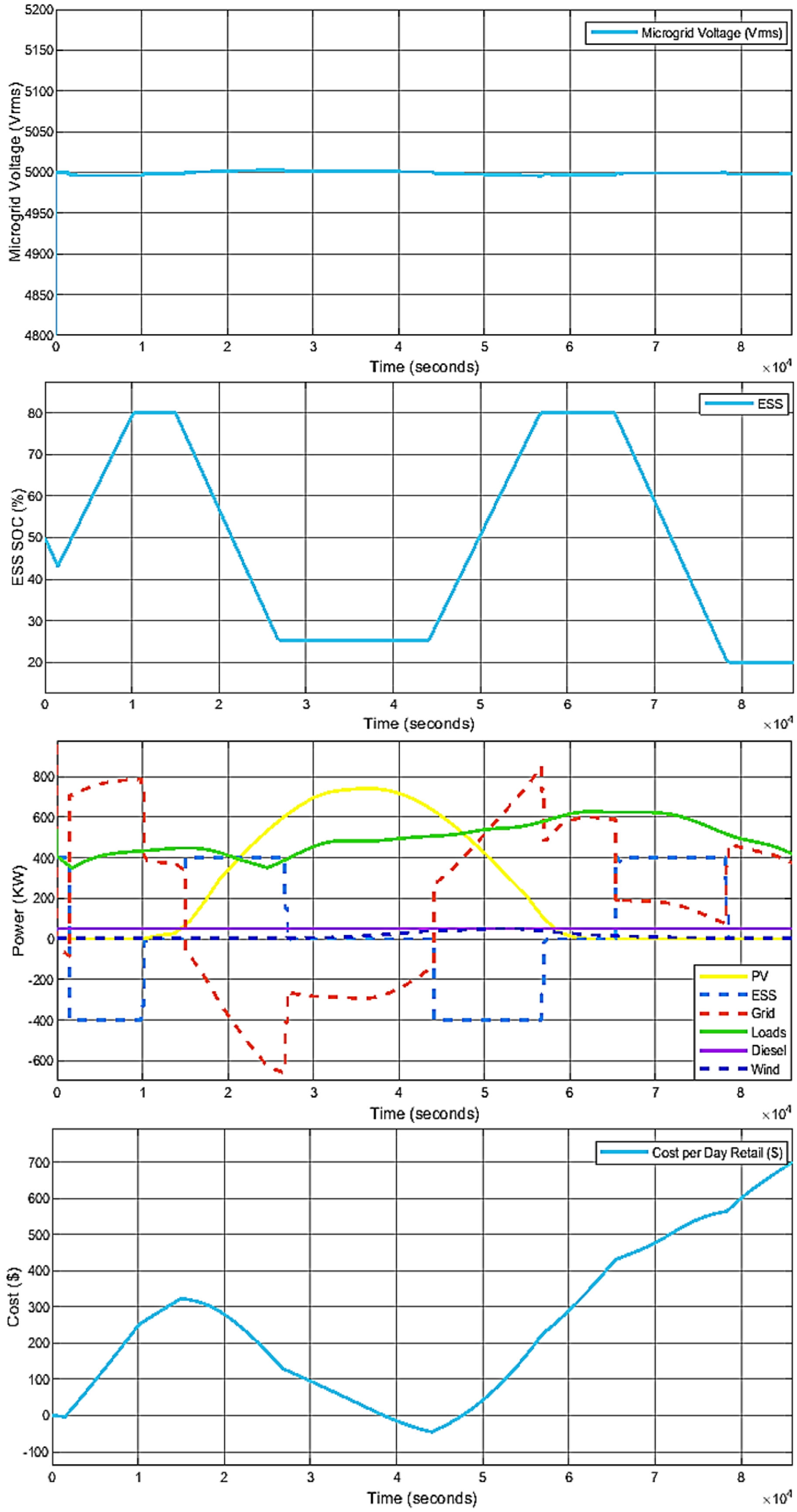

Figure 6. microgrid result of optimized problem based in case slow wind speed and clear solar irradiance

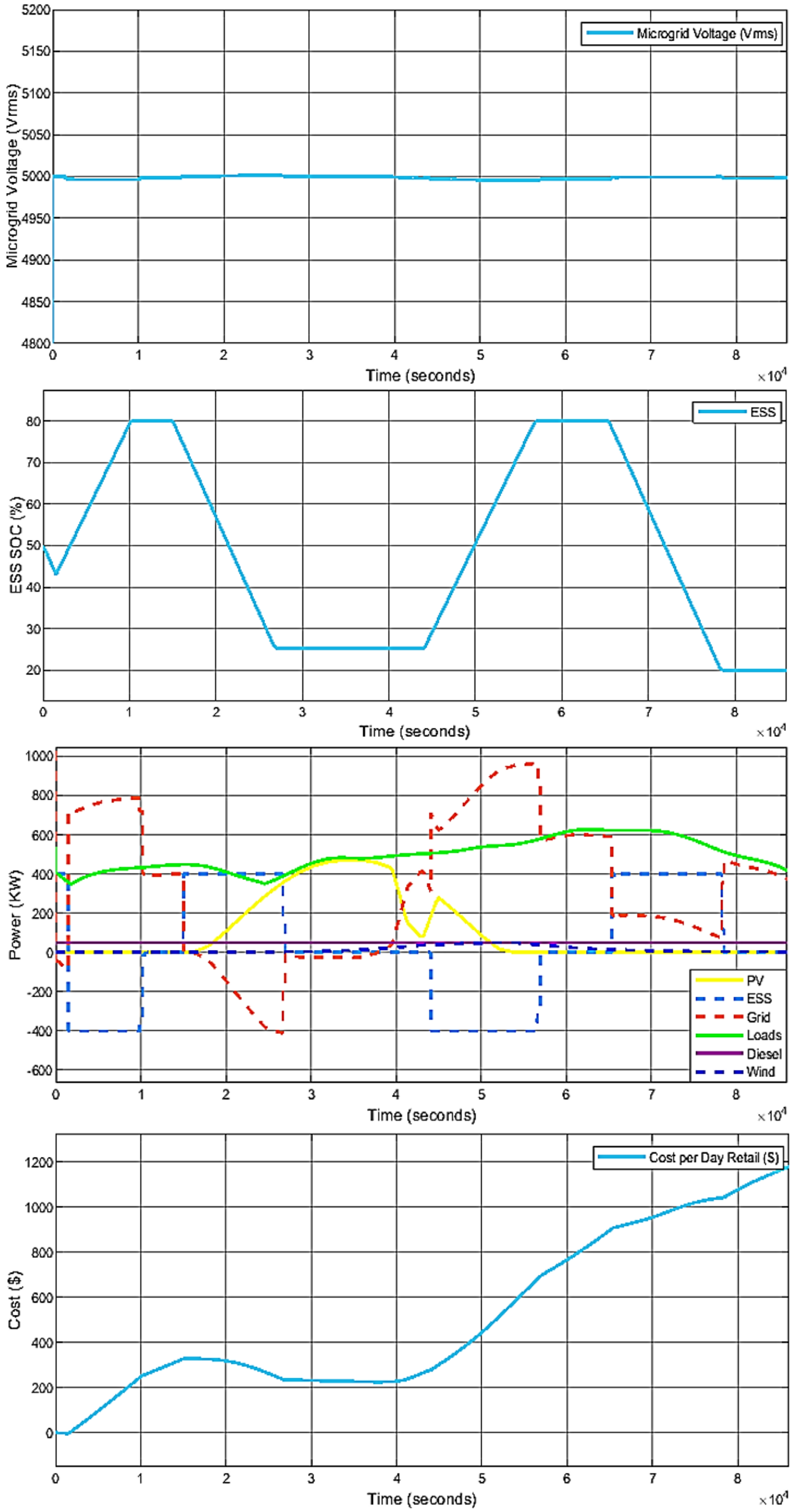

Figure 7. microgrid result of optimized problem based in case slow wind speed and cloudy solar irradiance

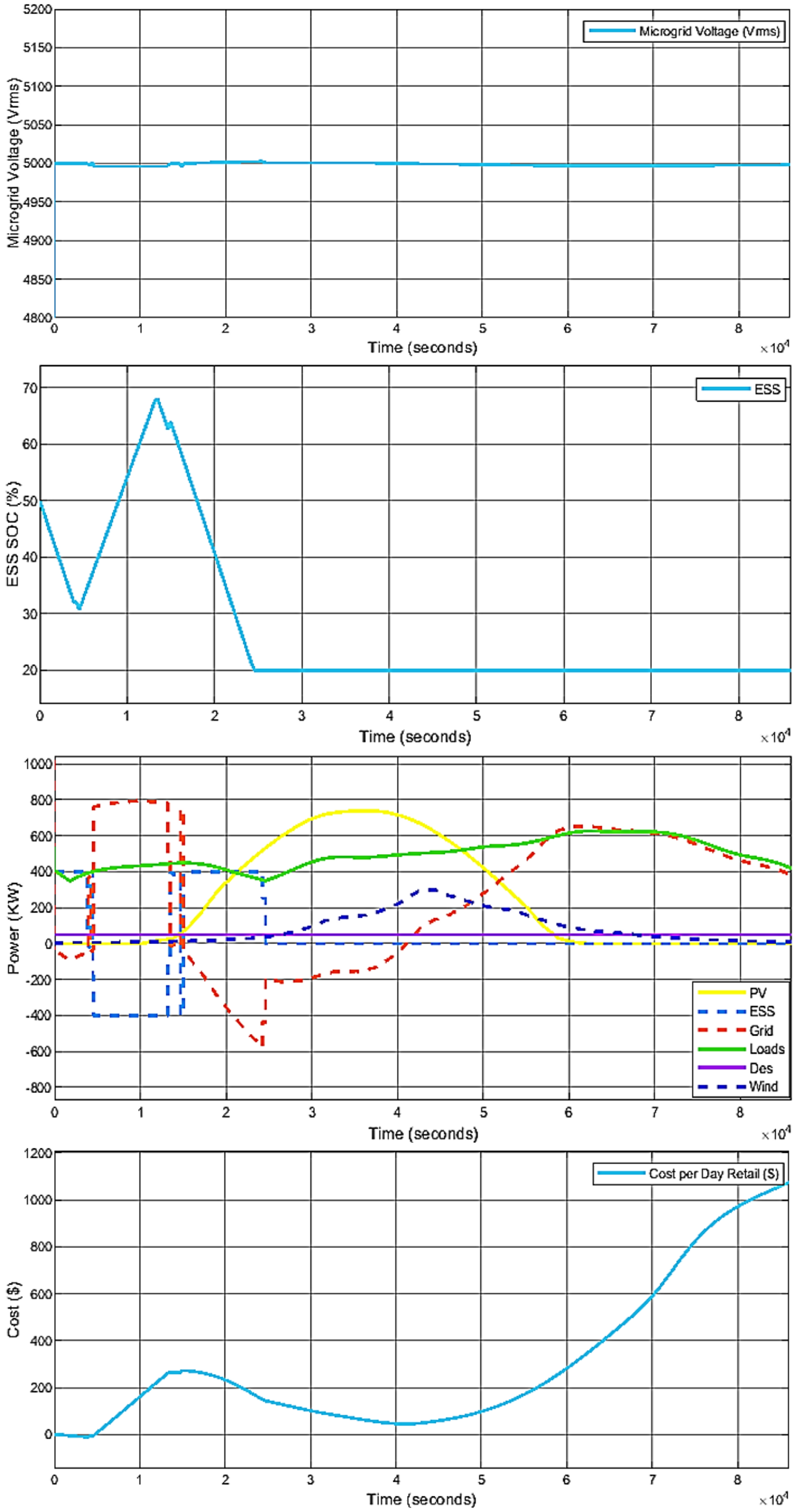

Figure 8. microgrid result of optimized solver based in case fast wind speed and clear solar irradiance

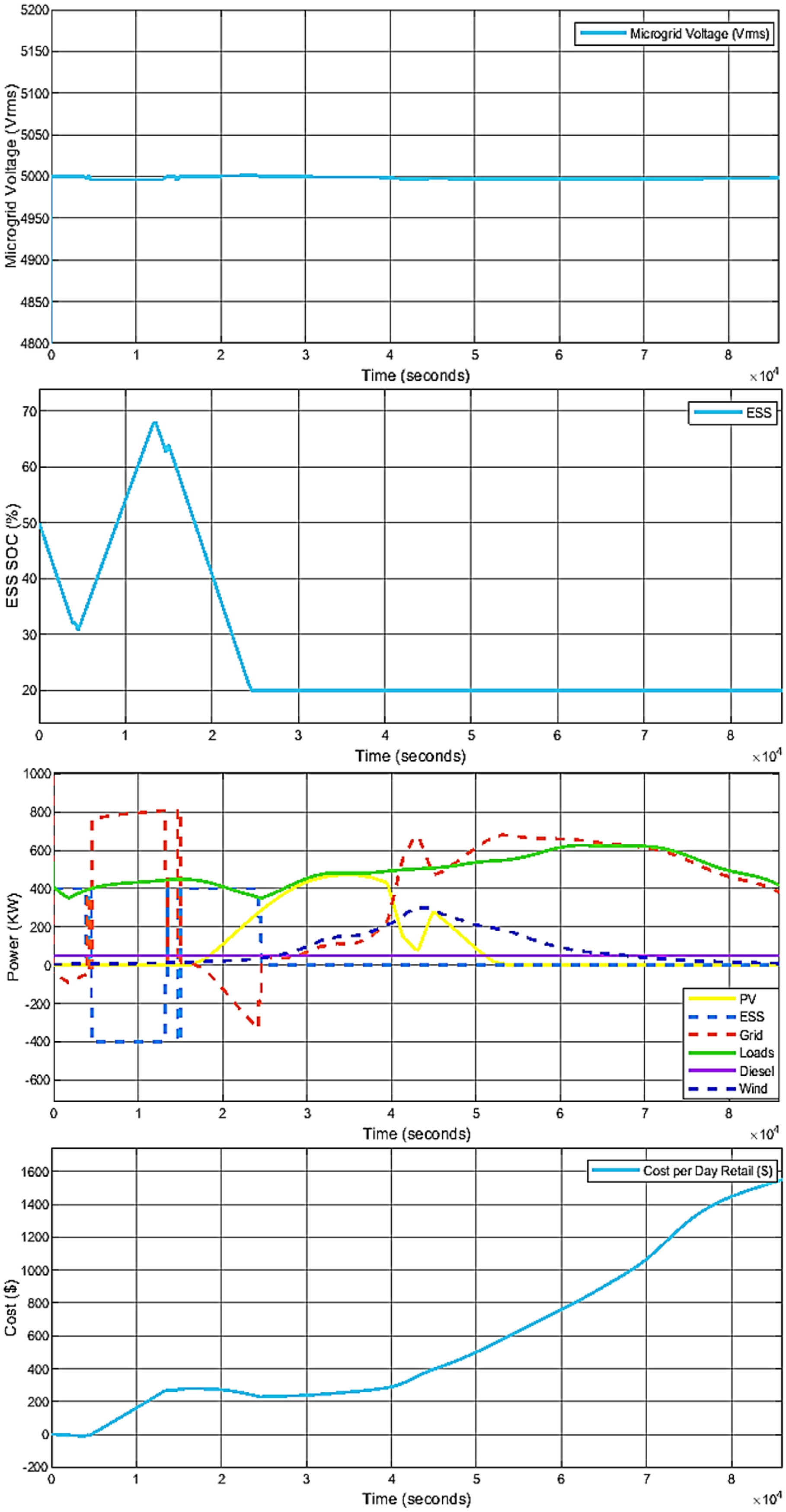

Figure 9. microgrid result of optimized solver based in case fast wind speed and cloudy solar irradiance

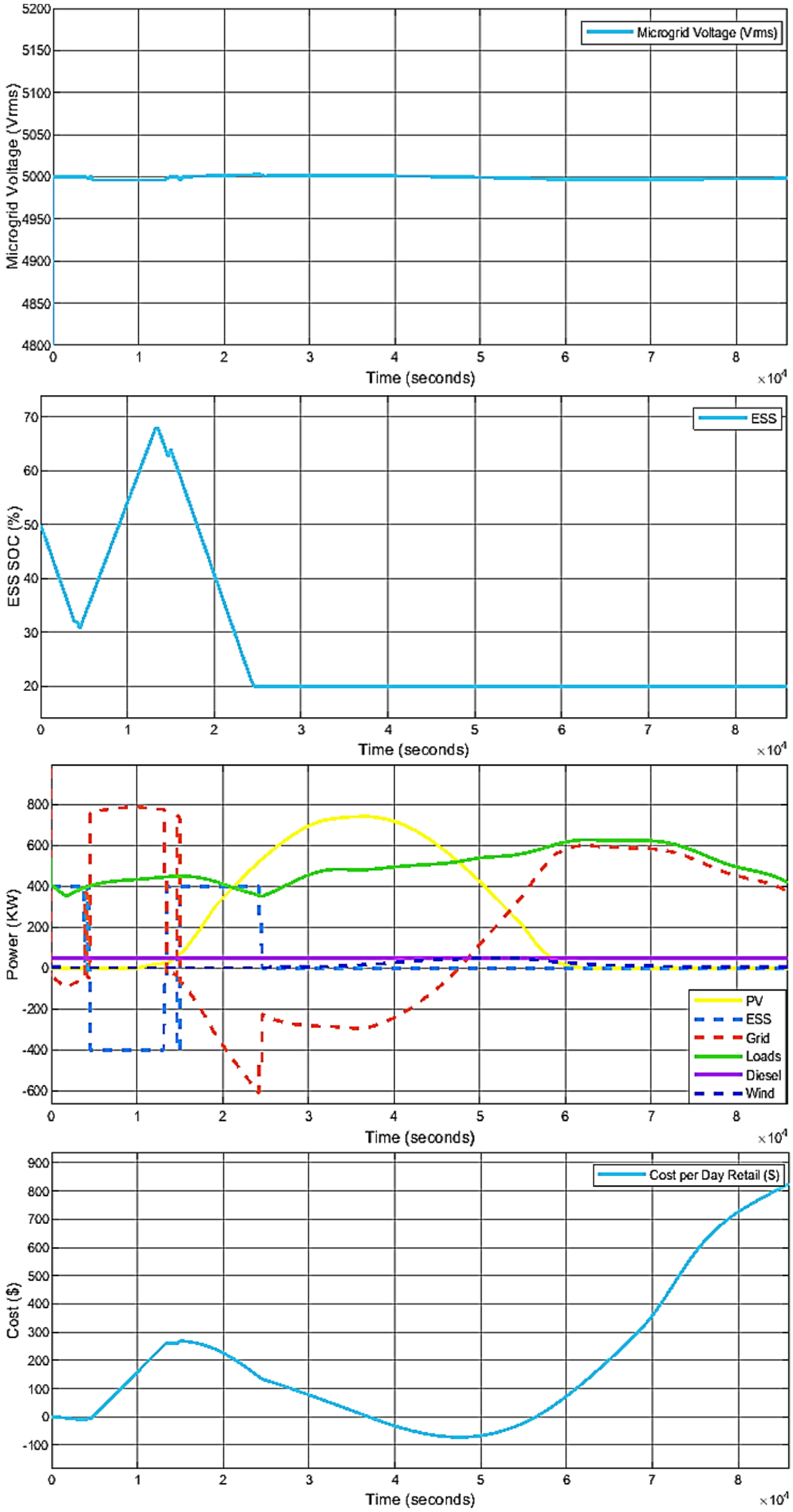

Figure 10. microgrid result of optimized solver based in case slow wind speed and clear solar irradiance

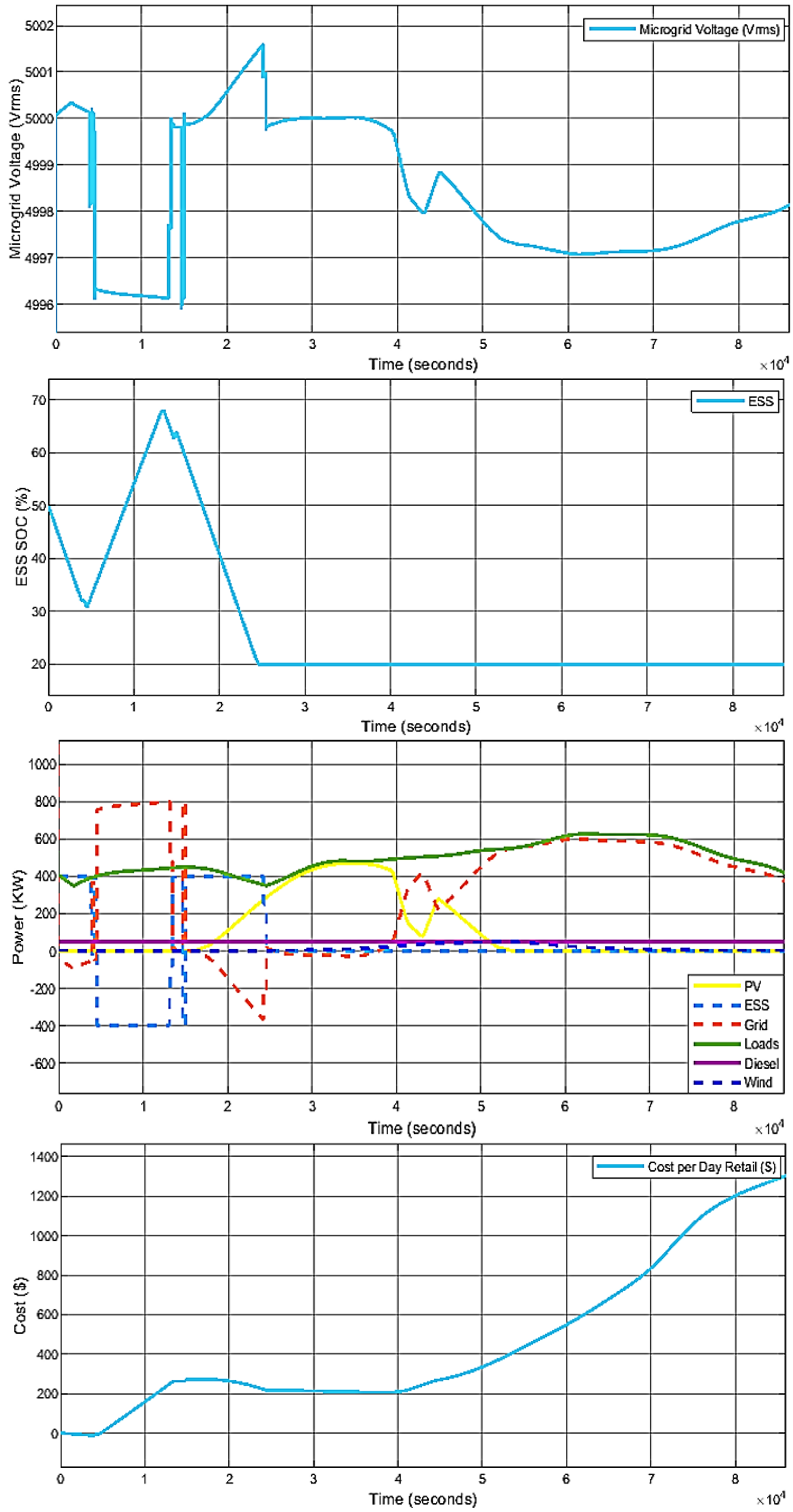

Figure 11. Microgrid result of optimized solver based in case slow wind speed and cloudy solar irradiance

The simulation has been done with PV array, wind turbine, diesel generator, battery energy storage and load consumption using dual-simplex algorithm using two method optimization problems (problem based and solver based). In each one there are four cases: fast wind speed with clear solar irradiance, fast wind speed with cloudy solar irradiance, slow wind speed with clear solar radiation, and slow wind speed with clear solar irradiance as shown in Figures 4–11 and recording data in Table 1 noted some changes in the cost curve throughout the day in all four cases. In the first method, the second case is the highest in cost, followed by the fourth case, then the first case, and finally the third case, which is the least in terms of cost. In the second method, the fourth case is the highest in cost, followed by the second case, then the third case, and finally the first case, which is the least. In comparison between the two approaches, the first and second cases in the first approach are more expensive than the two corresponding cases in the second approach. In addition, the third and fourth cases in the first method are less expensive than the two corresponding cases in the second method.

Table 1. Average retail cost of MG modeling using problem and solver based linear programming

Linear programming optimization method	Cases	Average retail cost per day ($)
Problem based	Fast Wind speed and Clear Solar irradiance	375.5
	Fast Wind speed and Cloudy Solar irradiance	599.6
	Slow Wind speed and Clear Solar irradiance	244.3
	Slow Wind speed and Cloudy Solar irradiance	549.9
Solver based	Fast Wind speed and Clear Solar irradiance	275.5
	Fast Wind speed and Cloudy Solar irradiance	442.3
	Slow Wind speed and Clear Solar irradiance	303
	Slow Wind speed and Cloudy Solar irradiance	565.5

6. CONCLUSION

Microgrids are generally composed of PV solar, wind turbine, diesel generator, battery energy storage, load demand, and microgrid energy management system. The proposed microgrid energy management techniques and solution strategies have been reviewed in depth and critically as in research study. The major aim of the energy management methodology is to minimize the total operational cost of the MG while achieving different constraints in grid-tied microgrids for a sustainable future. The method was based on linear programming using a dual-simplex algorithm using two methods, optimization problems (problem based and solver based). In comparison between the two methods the result showed that the first and second cases in the first method are more expensive than the two corresponding cases in the second method. In addition, the third and fourth cases in the first method are less expensive than the two corresponding cases in the second method. But in general, increasing cost as a result of using the second method is less than increasing cost due to the use of the first method. This project might be expanded upon in the long term in different directions such as using different optimization methods, investigating energy sharing between different MGs.

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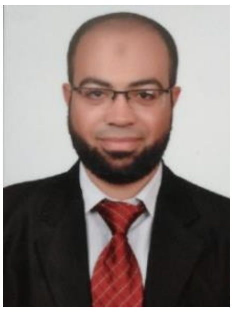

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