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Design of smart grid energy management system and comparative analysis between heuristic and optimum management method

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Abstract

During grid-connected and islanded modes of operation, an Energy Management System (EMS) is necessary to govern the flow of power and match generation to load inside a microgrid. In grid-connected mode, a microgrid draws/supplies power from/to the main grid based on generation and load requirements, as well as market policies that maximize efficiency/cost, among other things. It can also disconnect from the main grid in the case of a severe power quality incident (such as a fault in the main grid) and continue to power important loads. To reduce the cost of energy drawn from the grid, generated inside the grid, and consumed by the loads, an optimization method is required.

Keywords:*RerunSmart grid, ESS; optimization; power.*

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I. INTRODUCTION

Electricity is a physical entity whose use has resulted in enormous advancements, mostly by allowing us to effortlessly move energy from one location to another. It has unquestionably become one of our society' backbones throughout the previous century. The electromagnetic force, one of the four fundamental forces, manifests itself as electricity (with gravitation, weak interaction and strong interaction). Certain particles, such as electrons with a negative charge and protons with a positive charge, are given an electric charge by this force [1-2]. Electrons can flow more or less freely in particular elements termed conductors because they are at the outer layer of atoms. A difference in electric potential between two places, referred to as voltage (U) and measured in Volts, triggers the flow of electrons known as electrical current, whose strength (I) is measured in Ampere. Charges flow in only one direction in a basic electric circuit, which is known as direct current (DC). Most commercial applications, on the other hand, use Alternating Current (AC), in which the current regularly reverses direction and the voltage follows a sine wave. The ability to change the voltage of alternating current using a transformer is its main advantage, which made its use more practicable throughout the construction of large-scale power networks. Indeed, the power or amount of energy transferred by an electric current (in Watts (W)) is equal to the current intensity multiplied by the voltage: $V\ I = P$ Because the intensity is the primary cause of heat losses in long power lines, being able to adjust the voltage allows you to lower the intensity while maintaining the same power output and reducing losses. It's a frequent misperception that charged particles carry electrical energy with them wherever they travel. In fact, electricity is a wave that transmits energy from one point to another in the same way that sound travels through air or a liquid in a piston transfers pressure. The large majority of developed nations now have a well-established electricity grid, which is often interlinked and has a design and organization that is fairly comparable [3-4]. We'll go through their makeup, how they approach the energy management challenge, and why fresh solutions are required. A power grid, like any other electric circuit, is made up of three parts: production, transmission/distribution, and consumption (see Fig. 1). Large power plants provide electricity to national power grids, which is then delivered via a backbone of high-voltage power lines to the loads where it is used.

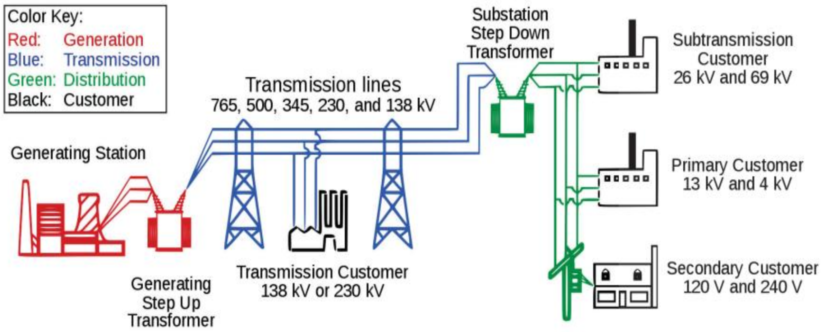


Fig. 1 structure of a large scale electric power system.

The centralization of power generation in large-scale power grids necessitates the transmission of electricity over considerable distances. However, power wires are not perfect conductors of electricity, and some of the energy carried is lost as heat (Joule heating). Because this loss is proportional to the current intensity travelling through the wire, increasing its voltage allows for more efficient transmission of the same quantity of energy [5-8]. The smart grid will increase the complexity of system monitoring and connectivity with other components by utilising information and communication technologies to acquire data from a smart grid component. It increases demand-side power management's interdependency. To reduce the physical and electrical distance between generation units and loads, the smart grid system will be divided into numerous sections, each of which will be referred to as an island. Each island is active, meaning it is self-sufficient and able to meet all of the region's demand, relying primarily on renewable energy sources. In the event that generation exceeds demand at the point of common connection, the island region could be connected to the utility grid. The point of common connection acts as a switch, allowing a network to be divided into island mode. This process improves the system's efficiency, dependability, and long-term viability. The smart grid interconnection guideline for understanding and defining the interconnection of an electric power system, a communication system, and an information system. A smart grid is a relatively recent concept. Figure 2 depicts an improved electrical grid in which information and communication technology is employed to improve the power system and maximise customer, distributor, and generation company profits. Furthermore, the smart grid may handle many types of electrical resources (for example, conventional plants (such as CHP and diesel generators) or renewable resources (such as PV arrays and wind turbines). Reliability, flexibility, efficiency, sustainability, peak curtailment, and demand response are all important characteristics of such infrastructure [9-10].

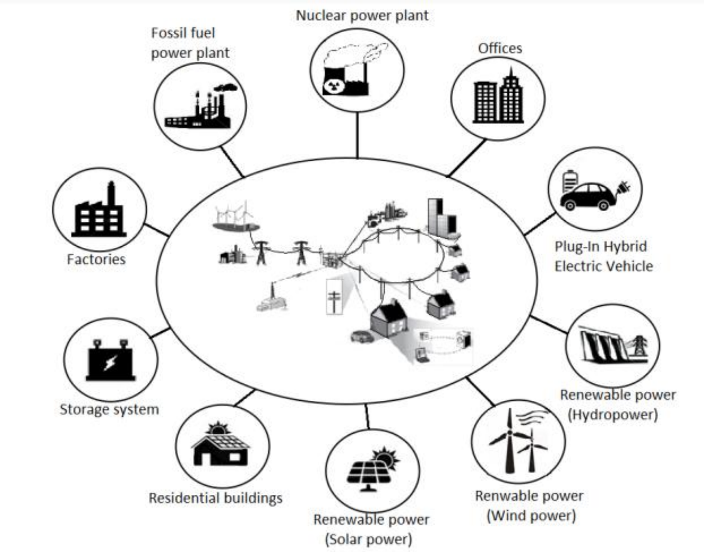


Fig. 2 Smart grid composition.

II. METHODOLOGY

In the coming years, the current electrical systems will undergo significant changes. The smart grid is the next generation, which is defined by an information and communication layer that allows communication between the grid's many components. It must consider all aspects of the power grid in order to make it more intelligent and flexible. This concept is given as a response to changes in the electrical market, with the goal of managing growing demand while assuring better service quality and safety. In the realm of energy power systems, a new problem is emerging: the growth of distributed generation from renewable energy sources (RESs). The intermittent nature of electricity generation from various sources is one of the major disadvantages. Optimization-based peak demand shift is used to minimize total cost of variable priced electricity:

$$C_{tot} = \sum_{k=0}^{N} C_{grid}(k).Egrid(k)$$

System operation constraints

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

Balanced power is given by

$$P_{pv}(k) + P_{grid}(k) + P_{batt}(k) = P_{load}(k)$$

Linear optimization method formulization

$$\min_{x} f^{T}x \begin{bmatrix} A.x \le b \\ A_{eq}.x = b_{eq} \end{bmatrix}$$

Where equivalent and inequality constraints represented as

$$\overbrace{\begin{bmatrix} I_{N\times N} & I_{N\times N} & O_{N\times N} \\ O_{N\times N} & \Upsilon_{N\times N} & \Phi_{N\times N} \end{bmatrix}}^{A_{eq}} x = \overbrace{\begin{bmatrix} P_{load}(1:N) - P_{pv}(1:N) \\ E_{batt}(1) \\ O_{N-1} \end{bmatrix}}^{b_{eq}}$$

$$\Upsilon_{3\times3} = \begin{bmatrix} 0 & 0 & 0 \\ \Delta T & 0 & 0 \\ 0 & \Delta T & 0 \end{bmatrix}$$

$$\Phi_{3\times3} = \begin{bmatrix} 1 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix}$$

For linear optimization states of x need to be defined

$P_{grid}(1:N)$: grid power from time step 1 to N.

$P_{batt}(1:N)$: battery power.

$E_{batt}(1:N)$: battery stored energy.

$$x = \left[Pgrid(1:N)Pbatt(1:N)Ebatt(1:N)\right]^{T}$$

Energy management systems (EMS) help to optimize the usages of distributed energy resources (DERs) in microgrids, particularly when variable pricing and generation are involved shown in Fig. 3.

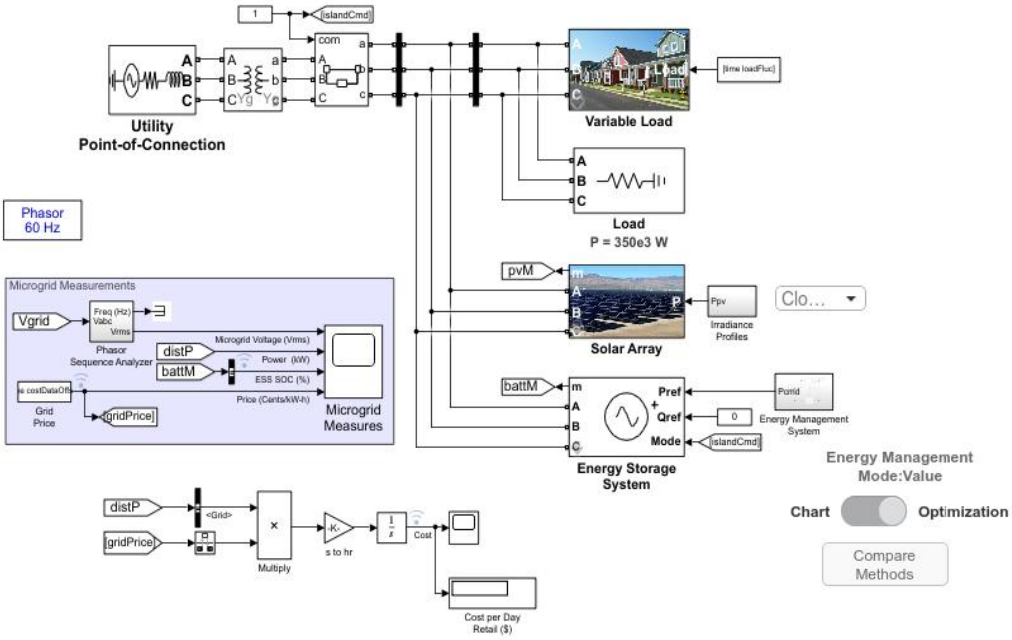
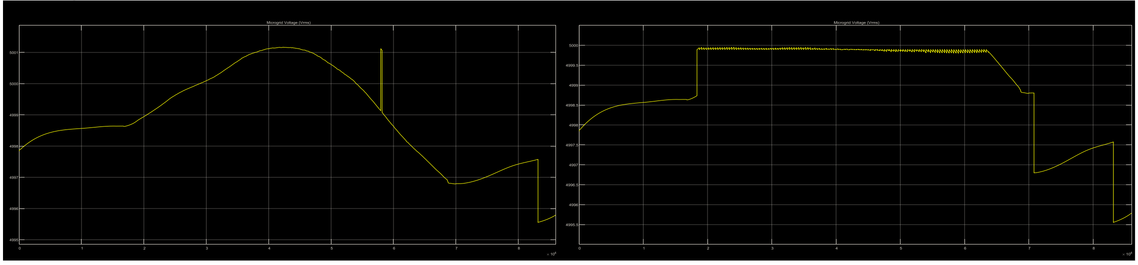


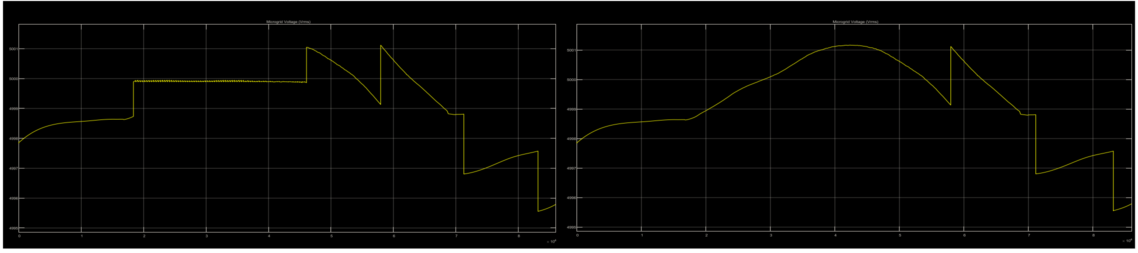
Fig. 3. Designed Simulink model.

III. RESULT AND DISCUSSION

Simulation were carried out to investigate the optimization performance of smart grid to supply required power with minimum wastage. Four set of simulation were carried with clear weather to provide maximum radiation to the PV panels to generate electricity. Then the state of charge (SOC) initial limit of the storage system was fixed from 20% to 80% with step size of 20% and system performance was computed to analyse the grid Vrms. Figure 4 and Figure 5 shows the grid voltage at 20%, 40%, 60%, and 80% SOC with clear and cloudy weather. It can be observed from the figures that the grid voltage rises with time after certain interval it fall back. At 20% of the SOC the behaviour is linear till it reaches a maximum. In case of 40% SOC the grid voltage increases and remain constant for certain interval of time. In case of 60% and 80% of the SOC a sawtooth wave is seen for the grid voltage. Figure 6 and 7 shows the graph for PV (yellow curve), energy storage system (blue curve), grid power (brown curve), and load (green curve) for different SOC percentage. Figure 8 and 9 shows the state of charge of energy storage system at different initial state and during the processing time interval.

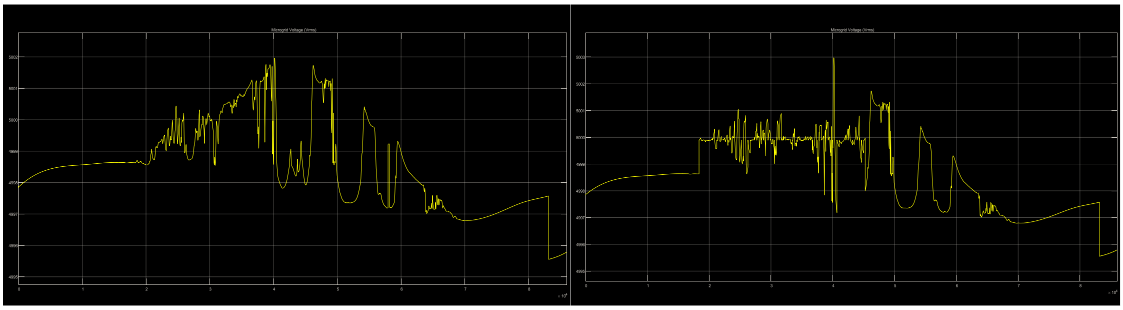


(a)20% SOC (b)40% SOC

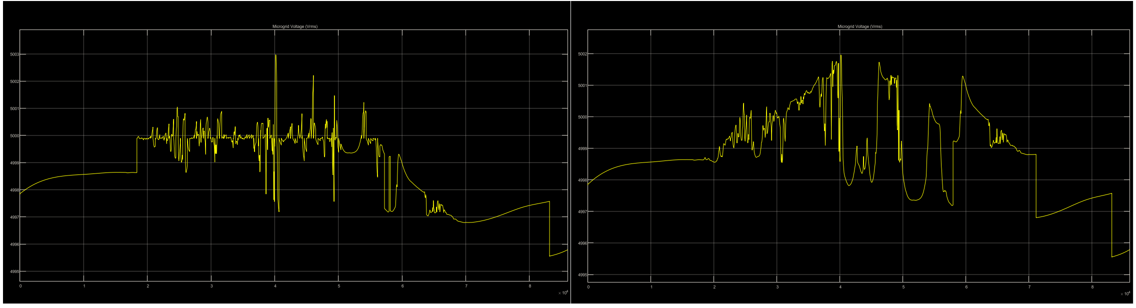


(a)60% SOC (d)80% SOC

Fig. 4. Grid voltage at different SOC with clear weather.

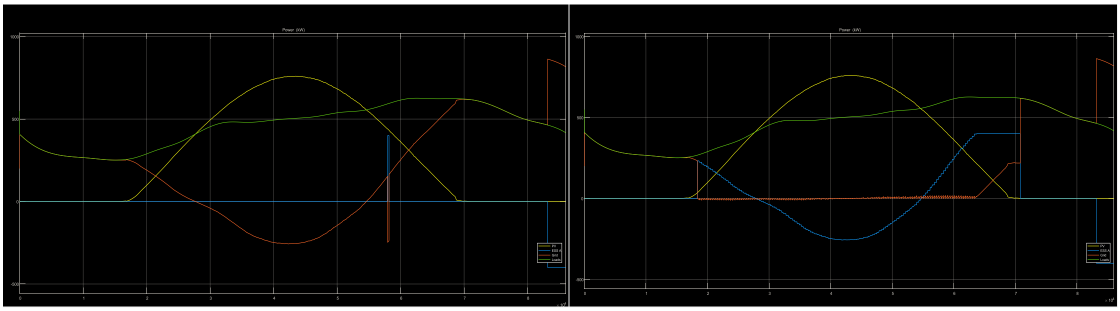


(a)20% SOC (b)40% SOC

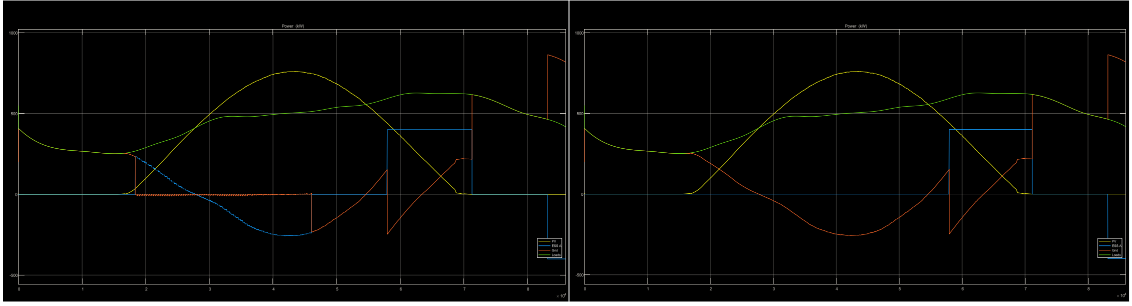


(c)60% SOC (d)80% SOC

Fig. 5. Grid voltage at different SOC with cloudy weather.

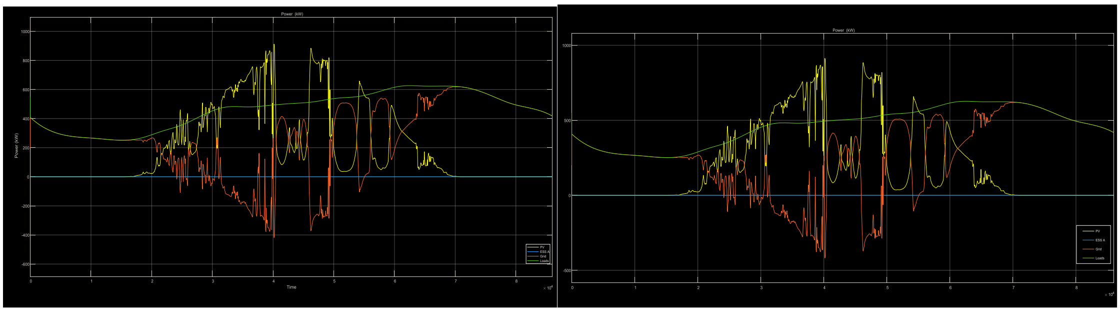


(a)20% SOC (b) 40% SOC

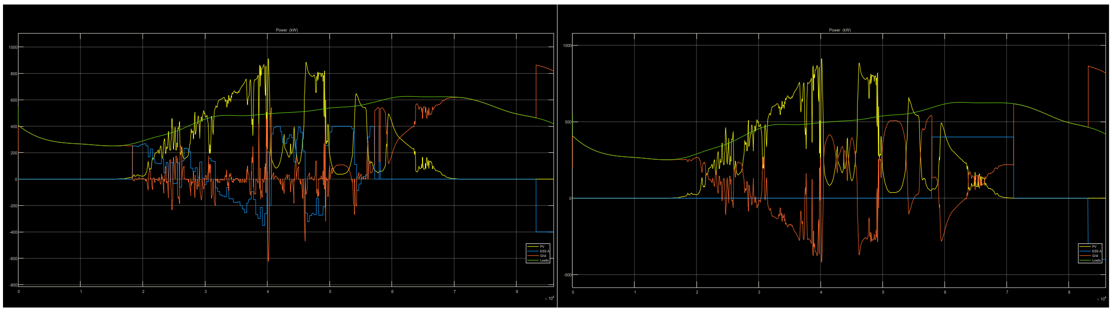


(c) 60% SOC (d) 80% SOC

Fig. 6. Grid parameters PV voltage, energy storage system, grid power, and load.

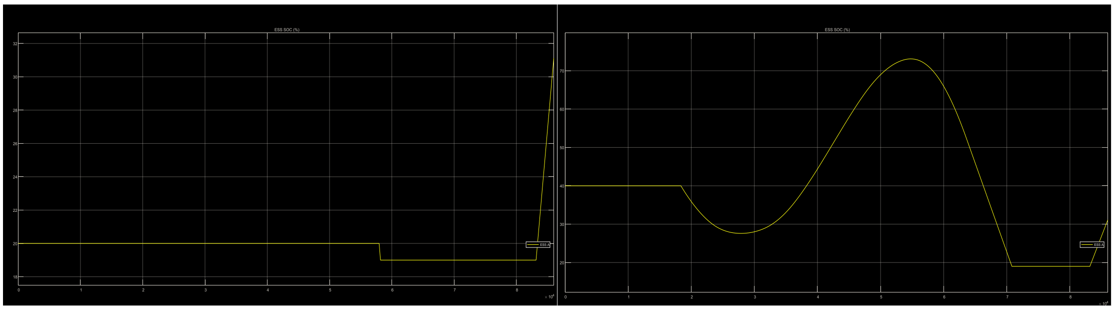


(a)20% SOC (b) 40% SOC

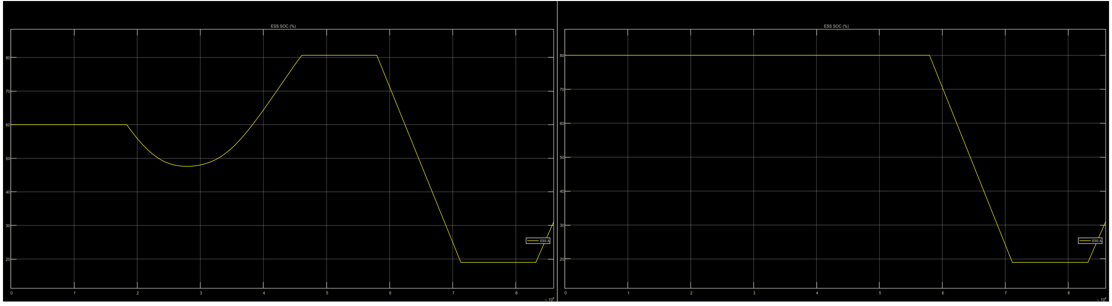


(c) 60% SOC (d) 80% SOC

Fig. 7. Grid parameters PV voltage, energy storage system, grid power, and load.

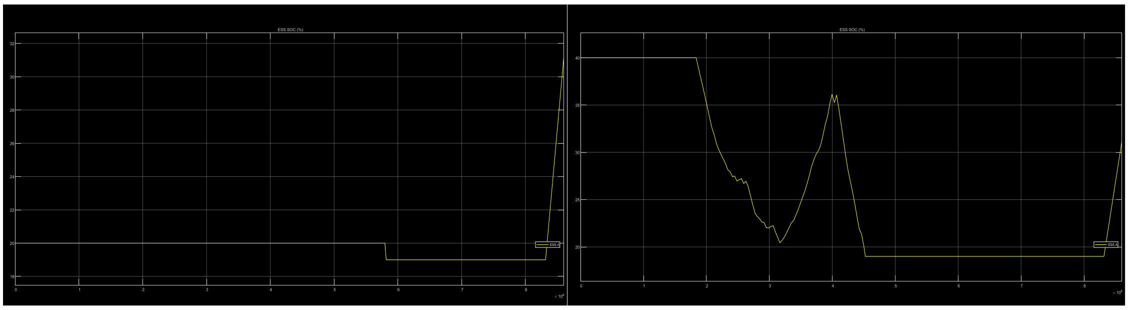


(a)20% SOC (b) 40% SOC

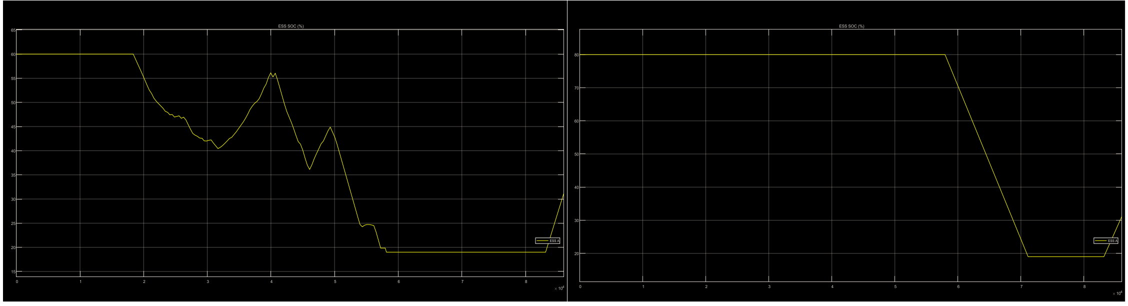


(c) 60% SOC (d) 80% SOC

Fig. 8 SOC of energy storage system with clear weather.



(a)20% SOC (b) 40% SOC



(c) 60% SOC (d)20% SOC

Fig. 9 SOC of energy storage system with cloudy weather.

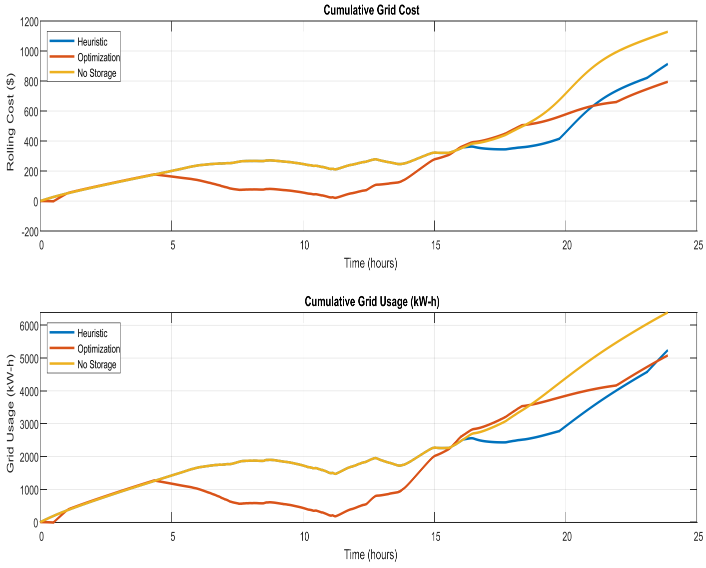


Fig. 10 Comparative analysis of using heuristic, optimized and with no storage system.

The heuristic and optimal grid usage per unit hour is shown in Fig. 10 to give the insight between the conventional grid system and optimized grid system. Also the grid with no storage system is shown in figure. Cumulative cost of the usage from the grid is plotted for heuristic, optimal, and with no storage system.

IV. CONCLUSION

This research paper projects the response of energy management of smart grid employing optimized algorithm to demonstrate its efficient use over the peak hours. Storage system state of charge over the usage with optimization is presented for effective irradiation for energy generation. As a measure of the quality of a solution option, we use running costs for power used during the whole duration. The better a solution option is, the lower the costs it generates. We present a framework for the optimization problem of determining the optimum solution alternative, with the energy storage system.

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