Pakistan Journal of Engineering and Technology, PakJET
Multidisciplinary & Peer Reviewed
Volume: 4, Number: 2, Pages: 21- 27, Year: 2021

Optimal Day-Ahead Scheduling for Campus Microgrid by using MILP Approach

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***Abstract*- In this paper, energy management system (EMS) is proposed for institution which helps in reducing the operational cost with the help of using different distributed generators (DGs) and electric vehicles. For this purpose, a scenario is created in which university is connected with national grid having self-powered PV plant, electric vehicles and a diesel generator. Impact of various distributed generators and optimally scheduled energy storage system (ESS) are analyzed for the university campus which helps in reducing operational cost of energy by using campus load data. The proposed model consist of different distributed generators and their effects are observed in various scenarios. Mix Integer linear programming (MILP) is used to get optimized result and then it is compared with Ant Colony Optimization and Linear programming (LP) techniques. Economic and environmental benefits are also discussed. Operational cost was measured and compared and found the role of ESS by using MILP in minimizing operational cost from $798.560 to $756.3850.**

***Index Terms*-- Microgrid, energy storage system, energy management system, renewable energy resources, smart grid, mix integer linear programming (MILP).**

I. INTRODUCTION

Electric vehicle are the necessary part of modern technology, they can fulfill the requirement of energy in the microgrid with no air pollution emission irrespective to the previous oil consumed vehicle. Electric vehicle are more advantageous in terms of efficiency and have positive effect on environment, but there are also many issues arise by connecting electric vehicle with microgrid. These issues may be technically like reverse power flow or economically like installing more energy smart meters. Electric vehicle can provide bi-directional flow of energy i.e. grid to electric vehicle or electric vehicle to grid that can help in reducing the shortage of energy during off-peak hours. Electric vehicle and distributed generators can help the microgrid to meet demand load. The focus of modern technology is to provide low carbon energy generators which can meet energy demand and helps in decreasing pollution. Energy resources faced problems such as the expense of increasing production, greenhouse gas (GHG) pollution, network overcurrent due to overloading etc.

The smart grid offers different possibilities for sustainability and deployment of renewable energy to prosumer microgrids through the implementation of energy management systems (EMS) [1]. These techniques in energy management include safe coordination between the prosumer and utility for smart control operations [2]. Since the distribution grid comprises of a microgrid array of an individual distribution microgrids of DGs, power storage, and DR systems on location, which may play a crucial role in minimizing the expense of the electricity and overburdening of the network. The advantages for microgrids with heavy loads are more prominent [3].

University campuses are one of the high load demand microgrid that come into the combined load consumer level because of the varying structure of their loads. Such buildings will sell their excess power to a grid that functions as a prosumer, due to the availability of on-site generation resources [4]. Several researchers have worked to evaluate the role of different distributed generators in microgrid. Some have especially involve electric vehicle to get cost benefit and some have worked to meet load demand. Author in [5] purposed energy management system to minimize operational cost by connecting different distributed generators. Secondly, Author in [6] aim to reduce loss and meet power demand by using different distributed generators in campus microgrid. Author in [7] discusses the impact of electric vehicle in microgrid. Author in [8] proposed a priority based charging station in parking, which consider different challenges faced during different scenarios. Author in [9] proposed optimizing technique for reducing grid load and also minimize 16% of monthly cost.

This paper focus on implementation and deployment of EMS for microgrid having different storage units and DGs. This proposed EMS can reduced energy cost by optimally scheduling the charging and discharging of batteries and two-way flow of energy between local grid and microgrids. The load data of university (National University of Sciences and Technology, Islamabad) has been analyzed. This microgrid is connected with local distribution company and a two condition is developed. In one condition institution is connected with electric vehicle and DGs while in other condition institution is connected only with DGs. Economic and environmental impacts of PV generation and energy storage in proposed EMS are also discussed [10]. In the end ant colony optimization and linear programming techniques are also implemented and then the obtained operational cost is compared by MILP technique.

The main contributions of this paper are as follows.

- A smart EMS is introduced to maximize on-site management of ESS, DGs, electric vehicles and grid resources using Mix Integer Linear Programming algorithm in MATLAB considering the price-based DR to maximize self-consumption of energy supplied by DGs and reduce grid demand operating costs in peak times which tend to reduce overall operating cost.
- Battery storage power, stage of charge and degradation cost are measured at different intervals and electric vehicle are incorporated along with DGs to improve the mathematical model of campus µG.

II. PROPOSED MODEL

The computational structure depicted in Figure 1 of the proposed system consists of an EMS, power system and prosumer microgrid. The prosumer microgrid consist of separate forms of loads, battery units for electricity and two dispersed energy supplies. The prosumer can use net metering facility with the energy supplier and is willing to transfer its excess electricity to the local distribution grid [11]. The suggested EMS uses the data collected by prosumer i.e. weather forecast data, market information, and the initial condition of storage devices. This seeks an appropriate optimal solution to satisfy the load demand by means of existing resources without infringing their operational and planned constraints[9]. To disperse usable capital this optimum approach is sent to the controller. There is also a clause in the revised EMS to store numerous key factors which could be used for several future advantages [6]. Real-Time Database (Sql), Business Server, and Prosumer plugin store data on energy trading, electricity price information, and load data for prosumers [12].

A. Problem formulation

Mathematical model and formulation for proposed system is designed to minimize the operational cost of user while considering different resources and battery units. Different constraints are discussed below.

B. Objective function

This system intends to minimize the overall operating cost (J) of microgrid which includes cost of exchanging electricity, cost of producing diesel and cost of deteriorating power storage. The description of the various cost types is given in equation (1). The lifespan of the battery relies on several variables, such as its capital expense, amount of cycles used and its overall power as seen in equation.

$$cost = J = \sum_{t=1}^{24} \left(C_t^e + C_t^{dg} + C_t^{es} + C_t^{ev} \right) \tag{1}$$

Where,

$$C_t^e = \left(p_t^g \right) \lambda_t \tag{2}$$

$$C_t^{dg} = \alpha T_G + \beta p_t^{dg} \tag{3}$$

$$C_t^{es} = \left(\frac{capital_{cost}}{No.of\ cycles \times total\ capacity \times 2} \right) \left(\eta_{ch} p_t^{ch} + \frac{p_t^{dch}}{\eta_{dch}} \right) \tag{4}$$

$$p_t^{bat} = \eta_{ch} p_t^{ch} - \frac{p_t^{dch}}{\eta_{dch}} \tag{5}$$

Where $C_t^{ev}, C_t^e, C_t^{es}$ and C_t^{dg} are cost function of electric vehicle, energy exchange, energy storage degradation and diesel generator at any interval t respectively. α, β and T_G are fuel curve intercept, fuel curve slope and rated capacity of a diesel generator respectively. Value of α is 0.0165 l/h/kW and value of β is taken as 0.267 l/h/kW while value of T_G is taken as 600kW. The university scheduled time of use (TOU) for connection from local distribution grid. During any hour t, the power flow of grid and its unit cost are denoted by p_t^g and λ_t respectively [5].

The battery capacity charging rate, discharge speed, charging energy and discharging energy are respectively expressed by $\eta_{ch}, \eta_{dch}, p_t^{ch}$ and p_t^{dch}. the battery's total strength (p_t^{bat}) is expressed in equation (5) [13].

C. Load balance constraint

The load balance constraint represents the supply-demand balance constraint consisting of power of grid, PV, battery and diesel generator which must be equal to load [14]. To achieve this balance, equation (6) must be satisfied.

$$p_t^g + p_t^{pv} + p_t^{bat} + p_t^{dg} = p_t^l \tag{6}$$

Where p_t^{pv} and p_t^l are output power of the solar PV in kW and load demand of the prosumer respectively. p_t^g is the value of power that is exchanged by grid in unit time.

D. ESS Constraints

Energy storage system (ESS) is an integral part of the energy distribution network, since it facilitates supply charges in the event of grid disruptions[15].

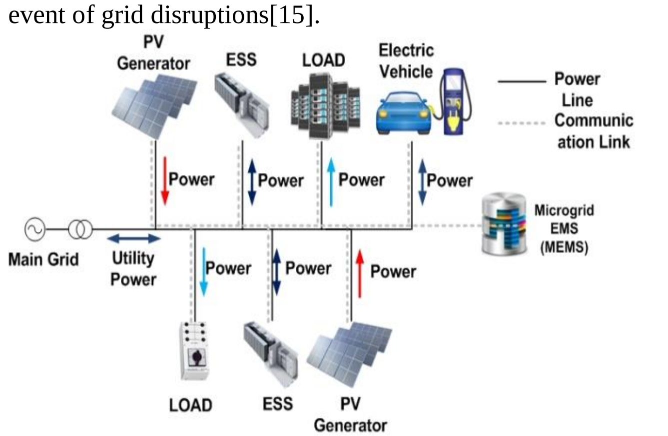

FIGURE1. Proposed Conceptual EMS

Therefore, because an Energy storage system (ESS) cannot be paid or discharged immediately, the restrictions of its strength are integrated into limitations in equations (7)-(11). The charging battery condition $BSOC$ in ESS at any period t '$BSOC_t$' is based on its corresponding condition $BSOC_{t-1}$

integrated in equation (12). $BSOC_{max}$ And$BSOC_{min}$, respectively, describe upper and lower limits of $BSOC$ in equation (13) to prevent overloading and full discharging of ESS. It is presumed that the battery charging status at the end of the day value of BSOC at time t ($BSOC_t$) is equivalent to its original charging initial level of BSOC (%) $(BSOC_0)$ that appeared at the start of the day as specified in expression (14).

$$\frac{BSOC_{t-1} - BSOC_{max}}{100} C^{ES} \le p_t^{bat} \tag{7}$$

$$p_t^{bat} \le \frac{BSOC_{t-1} - BSOC_{min}}{100} C^{ES} \tag{8}$$

$$0 \le \eta_{ch} p_t^{ch} \le u_t^{ch} p_{ch,max}^{bat} \tag{9}$$

$$0 \le \frac{p_t^{dch}}{\eta_{dch}} \le u_t^{dch} p_{dch,max}^{bat} \tag{10}$$

$$u_t^{ch} + u_t^{dch} \le 1 \quad \forall t \tag{11}$$

$$BSOC_t = BSOC_{t-1} - \frac{100 \times \eta_{ch} p_t^{ch}}{C^{ES}} - \frac{100 \times p_t^{dch}}{C^{ES} \eta_{dch}} \tag{12}$$

$$BSOC_{min} \le BSOC_t \le BSOC_{max} \tag{13}$$

$$BSOC_T = BSOC_0 \tag{14}$$

In order to plan its involvement in EMS, the storage output capacity, p_t^{bat} is already applied to the expression restriction (6). While negative and positive values shows discharging and charging of the ESS respectively [16]. Charging is represented by u_t^{ch} and discharging mode of the ESS is represented by u_t^{dch} in any interval 't'. The change is storage power can be controlled as given below.

$$\left| p_t^{bat} - p_{t+1}^{bat} \right| \le \Delta p^{bat} \tag{15}$$

$$e_{mes,t} = (1 - \Phi_{mes}) e_{mes,t-1} + \tau \left(\mathcal{P}_{mes,t}^{chg} \eta_{mes}^{chg} - \frac{\mathcal{P}_{mes,t}^{dch}}{\eta_{mes}^{dch}} \right) + E_{mes,t}^{conn} - E_{mes,t}^{disc} \tag{16}$$

$E_{mes,t}^{conn}$ *and* $E_{mes,t}^{disc}$ represent the energy level that is imported or exported respectively by electric vehicles (16). Energy storage level of electric vehicle are controlled by maximum and minimum levels represented by at interrval $\overline{E}_{mes,t}$ (17).

$$\underline{SOC}_{mes} = \overline{E}_{mes,t} \le e_{mes,t} \le \overline{SOC}_{mes} \overline{E}_{mes,t} \tag{17}$$

$$\overline{E}_{mes,t} = \overline{E}_{mes,t-1} + \overline{E}_{mes,t}^{conn} - \overline{E}_{mes,t}^{disc} \tag{18}$$

$$\underline{E}_{mes,t} = \overline{E}_{mes,t-1} + \overline{E}_{mes,t}^{conn} - \overline{E}_{mes,t}^{disc} \tag{19}$$

Electric vehicle that are connected or disconnected at t interval are given by $\overline{E}_{mes,t}^{conn}$ *and* $\overline{E}_{mes,t}^{disc}$ respectively.

$$0 \le \mathcal{P}_{mes,t}^{chg} \le u_{mes,t}^{chg} \overline{\mathcal{P}}_{mes,t} \tag{20}$$

$$0 \le \mathcal{P}_{mes,t}^{dch} \le u_{mes,t}^{dch} \overline{\mathcal{P}}_{mes,t} \tag{21}$$

$\mathcal{P}_{mes,t}^{chg}$ *and* $\mathcal{P}_{mes,t}^{dch}$ represent the maximum level of electrical vehicle charged or discharged respectively. Where $\overline{\mathcal{P}}_{mes,t}$ is given by:

$$\overline{\mathcal{P}}_{mes,t} = \overline{\mathcal{P}}_{mes,t-1} + \overline{\mathcal{P}}_{mes,t}^{conn} - \overline{\mathcal{P}}_{mes,t}^{disc} \tag{22}$$

Charging and discharging cycles plays their role in degradation of storage devices and they are modelled as follows.

$$v_{ses,t}^{chg} \le u_{ses,t}^{chg} \le u_{ses,t-1}^{chg} \tag{23}$$

$$C \le u_{ses,t}^{dch} \le u_{ses,t-1}^{dch} \tag{24}$$

$$C_{mes,t} = C_{mes}^{dg} \frac{1}{2} \left(v_{mes,t}^{chg} + v_{mes,t}^{dch} \right) + C_{mes}^{c} \overline{E}_{mes,t} + \frac{\mathcal{P}_{mes,t}^{dch}}{\eta_{mes}^{dch}} C_{mes,t}^{s} - \frac{\mathcal{P}_{mes,t}^{chg}}{\eta_{mes}^{chg}} C_{mes,t}^{d} c \tag{25}$$

$v_{ses,t}^{chg}$ *and* $v_{ses,t}^{chg}$ represent the starting point of charging and discharging point of stationary energy storage (ses) respectively. $u_{ses,t}^{chg}$ *and* $u_{ses,t}^{dch}$ are variables representing operation mode of stationary energy storage (ses). C_{mes}^{dg} represent degradation cost paid by microgrid operator. C_{mes}^{c} represent capacity charges paid by microgrid operator. $C_{mes,t}^{s}$ *and* $C_{mes,t}^{d}$ represent import and export price rate offered for prosumer.

E. Limitations of diesel generator and grid

Since utilities mount their modules according to demand requirement, they often make a deal with the customer for the highest output [11]. Any demand that reaches the contractual obligation would result in a cost or lack of communication. Similarly, a diesel generator is also unable to satisfy the load which exceeds its rated power as shown in equation (26) - (27).

$$p_{min}^{g} \le p_t^{g} \le p_{max}^{g} \tag{26}$$

$$p_{min}^{dg} \le p_t^{dg} \le p_{max}^{dg} \tag{27}$$

F. Exchanging of grid enegy

The net energy (E_{net}^{g}) import or export with the grid during a day is given by:

$$E_{net}^{g} = \sum_{t=1}^{t=24} p_t^{g} \times h \tag{28}$$

The import and export of power from grid is represented by positive and negative values as shown in output figure 6(a) and figure (7a).

G. Solution methodology

Objective function of proposed model and all constraints are linear with integer variables. To get optimal solution, mixed-integer linear programming (Mix Integer Linear Programming) is used to resolve these optimization issues. Mix Integer Linear Programming is a latest optimization methodology that solves numerous forms of linear optimization issues related to planning, distribution, development schedules, etc. [17]. In comparison, Mix Integer Linear Programming produces optimized outcomes globally compared with other meta heuristic approaches that produce suboptimal performance [18]. Mix Integer Linear Programming is also commonly used for constructing EMSs optimization. The fundamental Mix Integer Linear Programming structure is as follows:

$$\min_{x} J^t x \tag{29}$$

Subject to

$$\begin{cases} A.x \leq b \\ A_{eq}.x = b_{eq} \\ lower\_b \leq x \leq upper\_b \end{cases} \tag{30}$$

In equation (30) A and A_{eq} are matrices while x, $ub, b_{eq}, lower_b, upper\_b$ are vectors.

$$where\ x(intcon) are\ integers$$

Flowchart shown in figure (2) shows the strategy implemented in proposed model. Firstly, it will check the current scenario specific time, date, demand, unit price and initial storage of storage devices. Then it will check either PV is meeting demand or not. If yes then it will check charging constraints and if no then it will check discharging constraints. After that Mix Integer Linear Programming algorithm is applied which will provide optimum schedule. Then it will check either generated energy is enough to meet demand to or some energy has to be imported from grid or it will also check excess energy generated and if there will be excess energy then it will export it to the grid.

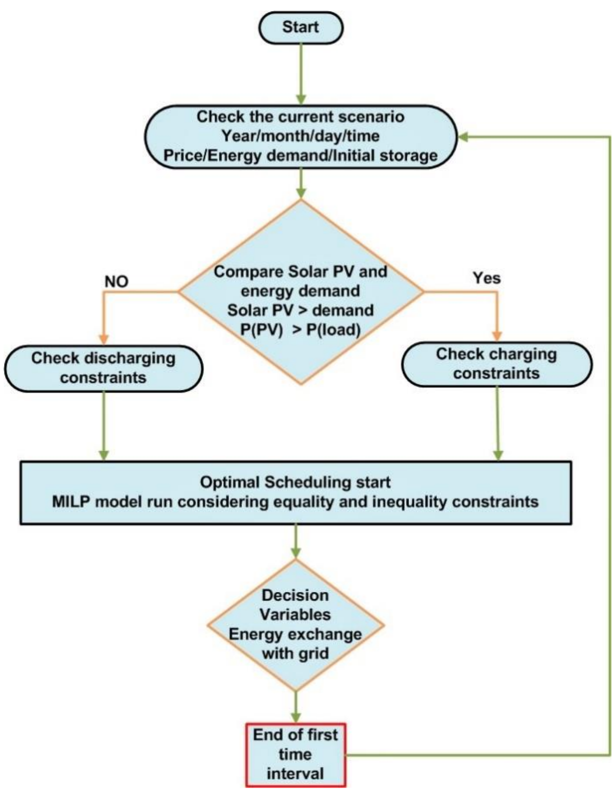

FIGURE 2. Flowchart of proposed strategy for campus

III. SIMULATION, RESULTS AND DISCUSSION

The proposed model is implemented in campus (NUST, Islamabad) and modified it into smart campus by applying Mix Integer Linear Programming algorithm which helps in optimizing load schedule while using different energy resources and storage units. Load data of campus is obtained in order to forecast load trend.

In Table (1), $p^{PV}_{rated}, p^{g}_{t,min}, p^{g}_{t,max}, p^{bat}_{t,min}$ and $p^{bat}_{t,max}$ represent rated power of PV, power imported to grid at interval t power exported by grid at interval t, power supplied from battery and power stored in battery respectively. $BSOC^b_{max}, BSOC^b_{min}$ *and* $BSOC_0$ represent maximum level of battery state of the charge, minimum level of battery state of the charge and initial state of charge respectively. p^{dg}_t represent power generated by distributed generators. C^{ES} shows rated capacity of storage.

TABLE I
SYSTEM PARAMETERS

Parameters	Value	Parameters	Value
p^{PV}_{rated}	2000 kW	C^{ES}	800 kWh
$p^{g}_{t,max}$	2000 kW	$p^{g}_{t,min}$	-1000 kW
$p^{bat}_{t,max}$	800 kW	$p^{bat}_{t,min}$	-800kW
$BSOC^b_{max}$	90%	$BSOC^b_{min}$	10%
$BSOC_0$	50%	p^{dg}_t	600 kW
p_{EV}	1000 kW		

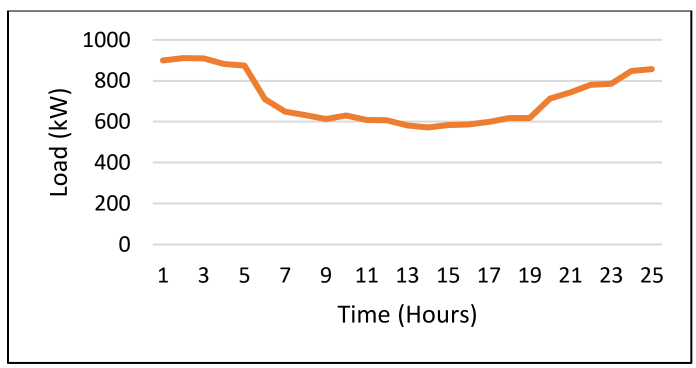

FIGURE 3. Daily Energy demand NUST Campus

Figure (3) is drawn using load data that shows energy demanded by National University of Science and Technology campus during 24 hours in a day which varies from 571.875 kW to 91-.938 kW.

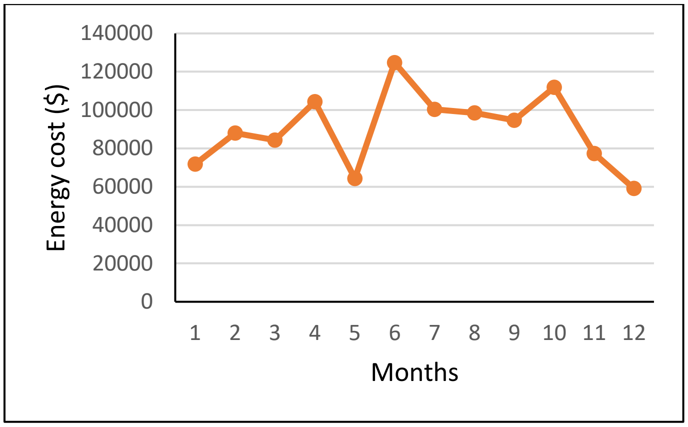

FIGURE 4. Monthly consumption cost NUST Campus

Figure (4) is also drawn using load data and it is showing monthly energy cost that has to be paid by National University of Science and Technology campus.

TABLE II
PRICE OF ELECTRICITY

Price of Electricity	
Hours	**Unit Price ($)**
0:00 to 19:00	0.091
19:00 to 23:00	0.134
23:00 to 24:00	0.091

In Table (2) price of electricity is shown that is $0.091 during 0:00 to 19:00 hours. $0.134 during 19:00 to 23:00 hours and again $0.091 during 23:00 to 24:00 hour. In figure (5), the first graph given below shows the cost of energy during full day while it is varying during 5:00pm to 7:00pm.
The second graph below is showing output of Solar PV which is working as DG and is providing during daytime, while third graph below shows campus load which is varying after every hour. Load varies according to the student's utilization schedule. From 12:00 am to 7:00 am students utilize hostels electricity and most of the research labs are in working condition, so at that time load demand is high. Then 8:00 am to 5:00 pm classes are conducted, so there is various load and from 5:00 pm to 6:00 pm there is least utilization of electricity and from 7:00 pm to 12:00 pm again load increases due to usage of electricity in hostels.

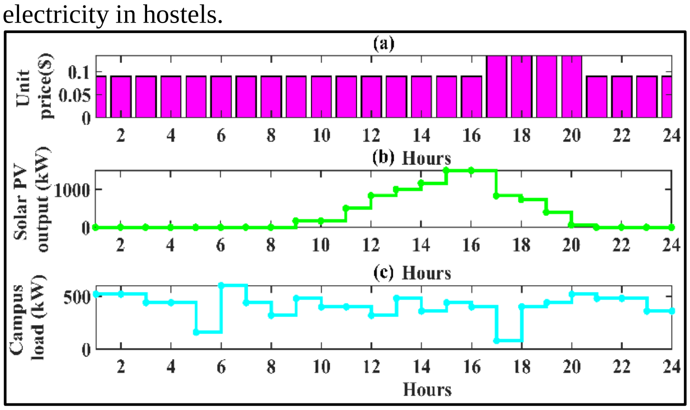

FIGURE 5. (a) Unit price, (b) Solar PV output, (c) Campus load

As the campus is also connected with grid, so during the absence of PV and battery storage, the campus utilize grid power, we studied two conditions. One condition in which institution is connected only with DGs and other condition in which institution is connected with both DGs and electric vehicle, where electric vehicle is conducting as load and as well as source.

So in figure (6), case A is shown in which only DGs are connected. The first graph figure (6a) below shows grid output power. When its value is positive it means prosumer is utilizing grid power and when it is negative it means prosumer is selling power to grid through net metering. For net-metering, campus followed all basics rules and regulations which are necessary for availing this services like campus must be registered with National Electric Power Regulatory Authority (NEPRA), smart meter should be installed in campus which shows two way flow of electricity [21]. Buying rates of electricity from residential, commercial and industrial will be $0.11 per unit, $0.1 per unit and $0.06 per unit respectively. 2000kW of PV system is installed and due to its 75 to 80 percent efficiency it will provide almost 1500kW to 1600kW that will be utilized by campus load and remaining will be sold to NEPRA through net-metering. Cost of installed PV system is $0.2 per watt and for installed energy storage device is $0.133 per watt.

While second graph figure (6b) shows storage power. During positive values the power is stored and utilized by prosumer while during negative power values, stored power is sold to grid. Third graph figure (6c) is showing state of charge of batteries. Rising values shows charging of battery while decreasing trend shows discharging of batteries and the last graph Figure (6d) is showing output power of DGs.

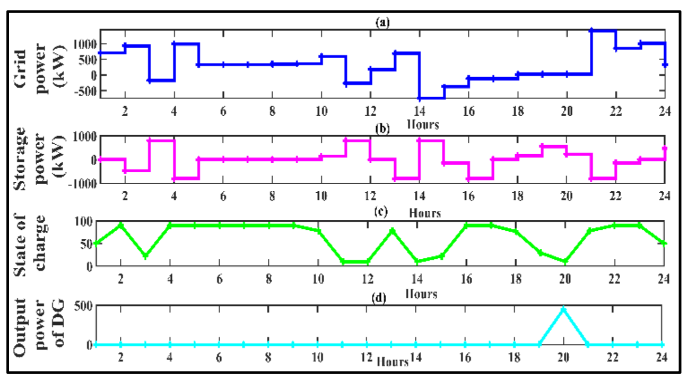

FIGURE 6. Case A: Model with only DGs. (a) Grid Power, (b) storage power, (c) state of charge, (d) Output power of DG

In figure (7) case B is shown in which institution is connected with DGs and electric vehicle. The first graph figure (7a) below shows grid output power. While second graph figure (7b) shows storage power. During positive values the power is stored and utilized by prosumer while during negative power values, stored power is sold to grid. Third graph figure (7c) is showing state of charge of batteries. Rising values shows charging of battery while decreasing trend shows discharging of batteries and the last graph Figure (7d) is showing output power of DGs.

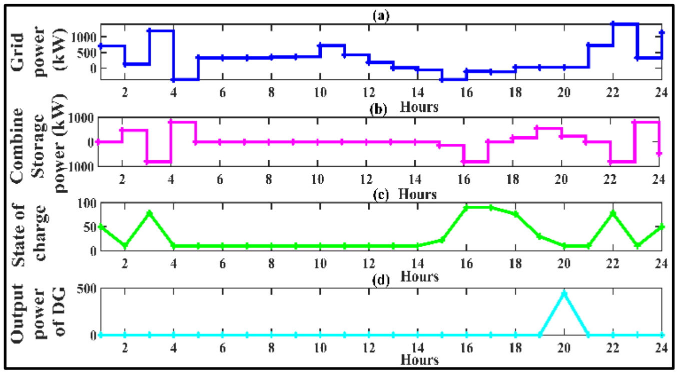

FIGURE 7. Case B: Model with Electric vehicle and DGs. (a) Grid Power, (b) storage power, (c) state of charge, (d) Output power of DG

In Table (3) comparison of three methodologies is shown. \$757.1240 operation cost is obtained by implementing linear programming which is a simple technique to solve complex optimization problems, \$760.4750 operation cost is obtained by implementing Ant Colony Optimization technique which is a population based meta-heuristic algorithm and can be used to find approximate solutions of optimization problems [19]. While \$756.3850 operational cost is obtained by implementing mix integer linear programing and by comparing these values, we conclude that implementation of MILP gives best optimum operation cost which is less than other methodologies and this method is used in proposed model to get optimum value.

TABLE III
COMPARISON OF METHODOLOGIES

Methodology	**Operation Cost (\$)**
Ant Colony Optimization	760.4750
Linear Programming	757.1240
MILP	756.3850

Figure (8) shows operation cost comparison between Ant Colony Optimization, linear programing (LP) and mix integer linear programming (MILP). Downward trend by using different methodologies can be seen in graph. Lowest operation cost is obtained by implementing MILP algorithm.

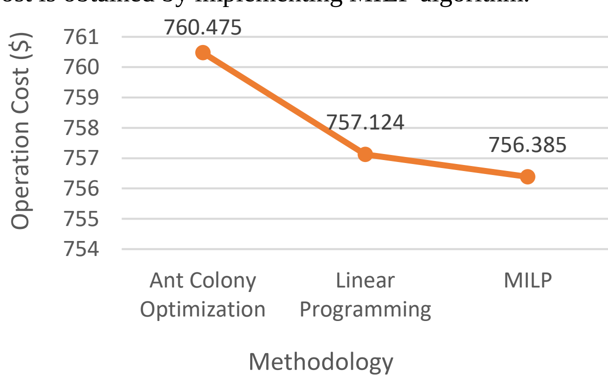

FIGURE 8. Comparison of Methodologies

IV. CONCULISION

In this paper, current issues of load scheduling is discussed. Major issues are occurred when we connect different types of DGs and electric vehicles for our convenience due to which we are getting high operational cost. In order to eliminate this issue we use energy management system in which Mix Integer Linear Programming algorithm is applied which help in optimal scheduling of load to achieve low operational cost. Proposed model is implemented in campus consisting of PV, diesel generator, electric vehicle and battery that are connected with grid along with energy management system and load data of campus is used to forecast the trend of campus load. And then Mix Integer Linear Programming algorithm is simulated in MATLAB in order to get optimized load schedule for the campus and reduce the operation cost from \$798.560 to \$756.3850 as well as reduction in carbon emission of about 375.23kg/day during summer and 365.34 Kg/day during winter by installing 1000kW PV.

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