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Optimization of Microgrid Energy Cost with Electrical Vehicles and Demand Response

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Abstract-**Increasing energy costs and greenhouse gases are the major challenges with current power systems. Participation in distributed generators (DGs) and demand response (DR) strategies inside the distribution network resolves the issues. The primary objective of this paper is to suggest an energy management system (EMS) strategy for commercial microgrid to mitigate the issues. A microgrid is considered to implement the strategy. Conventionally, the microgrid uses a utility grid to fulfill load demands. However, in this paper, the integration of a micro turbine, photovoltaic (PV) system, battery energy storage system (BESS), and Electric vehicles (EVs) is proposed. Mix integer linear programming MILP technique is used in MATLAB to solve the non-linear optimization problem. The energy management system (EMS) and demand response policies are used to optimally schedule the available resources and reduce energy costs. The integration of EVs is also observed as source and load. The simulation results are discussed and different case studies are analyzed. Simulation results show that 46% cost saving is observed while using EVs in the system as a source. The real-time energy interruption problem is also discussed in this paper.**

***Index Terms*— Battery energy storage system, Demand response, Distributed energy resources, Electric vehicles, Energy management system.**

I. INTRODUCTION

The microgrid is an essential part of the power system, consisting of a local power supply, load, energy storage system ESS, and distributed energy generators DERs. The microgrid can operate in both islanded and grid-connected modes [1]. In grid-connected mode, microgrid can purchase and sell power to a utility to balance the power and supply. In islanded mode, the sum of the power supply should be equal to the consumption plus all the losses in the microgrid. Power management is necessary for both modes of a microgrid to work in a safe, reliable, and cost-effective environment [2].

The issues related to microgridsare network overloading, environmental hazards, and an increase in energy costs. All these problems make the system unbalanced and non-reliable. A microgrid equipped with distributed energy resources (DER), an energy storage system (ESS), and demand response can overcome these problems [3].Many types of prosumers can participate in the power system. Prosumers can store energy during off-peak hours from different energy resources and sell this energy during peak hours to support microgrid [4].

By utilizing various charging schemes, the batteries can retain the excess energy produced by Renewable resources [5].

Air pollution is a major concern of power systems as the load demand is increasing day by day. Air pollution concerns of the microgrid can be reduced by introducing Electric vehicles and renewable energy resources [6]. Electrical vehicles in the system may cause new peaks and unbalance in the system but efficiently managing the charging and discharging behavior of EVs reduces these issues. As well as helps the peak loads shaving or valley filling of load demand. EVs can act as spin reserves by using them in emergencies. Modern research is focusing on vehicle-to-gridV2G and grid-to-vehicleG2V technologies to reduce all the concerns of power imbalance [7].

The efficient microgrid is using effective demand-side management (DSM). DSM is the strategy used by customers to control their demand by modeling their load patterns. DSM programmers allow their customers to buy energy-sufficient devices and shift their load on other resources in peak hours to save energy and cost. The focus of DR is to assist the power system in peak hours by adjusting or shifting loads in off-peak hours or efficiently scheduling the demand. There are mainly two broad categories of DR Incentive base DR and Price base DR [8].

Modern research estimated that in the US the DR programs and energy efficiency measures together can reduce the generation from 214GW to 133GW by saving 30% cost of generation. DR allow more renewable recourses in the system to meet the generation and demand balance [9].Customer can shift their load and enjoy bill saving.

Different batteries are used for the smooth function of a microgrid. Now a day lithium-ion batteries are used widely due to their long battery life and optimal cost. The degradation of batteries depends upon many factors including the number of cycles, temperature, the resistance of the battery, and depth of discharge [10].

This research paper's objective is as follows:

- Consider a university as a microgrid and model all its components in MATLAB. An energy management scheme is proposed for the optimal scheduling of all the recourses using the MILP and time of use (TOU) demand schemes.
- To incorporate the EVs in the model to evaluate the electricity cost of the grid by using EVs as source and load.
- Real-time analysis of power interruption is also considered in this model to ensure the continuous supply of power.

The remaining parts of the paper consist of section II, which presents the Literature review. Section III describes the proposed system model and its description. Section IV discusses the results of the simulation, and section V. presents the conclusion of the research paper.

II. LITERATURE REVIEW

The modern researcher is working on the optimization of a microgrid. The major and recent concern of Pakistan is the energy shortage due to monitoring and managerial issues. Generally, scheduled cut-off [energy is a practice of 4 to 6 hours per day [11]. In [12] the author proposes a model of the microgrid in Pakistan. The real-time data of Islamabad were used in the model to design the energy management system. The power algorithm in MATLAB is used in the model. Six cities of Pakistan were analyzed on the base of multitasking analysis on HOMER. Further analysis was performed on the model to find the optimization of recourse [13].

Different factors affect the performance analysis of microgrid in optimization. Many researchers are working on such factors. In [14] the author introduces the probability density function approach to find the uncertainty in renewable energy resources scheduling. The single objective function was used to locate the optimal point to optimize the microgrid recourse scheduling and find the optimal size of distributed generators' DGs. While in [15] the authors used a deterministic approach instead of probability density functions. A hybrid energy system was modeled and this approach was analyzed on it. The author used two scheme priority base scheme and load shifting scheme to find the optimal size of DG.

In [16] the different demand response programs were used to find to reduce the cost of the power system and to find the size of DGs. The environmental effects on microgrid were studied in [17] for the optimization of microgrid. Environmental uncertainties were not discussed in this paper. The 24-hour time steps were chosen in this paper.

HOMER tools were used to find the combination of RERs the bottleneck of the above paper was covered in this paper. The environmental impacts were also considered in this study by considering the combination of RERs [18].

In [19] the authors proposed a novel integrated model to optimize the size of the battery. the author proposes different parameters to focus on profit margin. A lead acid battery was used to determine the effect of the State of charge SOC. The result shows that lithium-ion batteries give a 6% more profit margin as compared to lead-acid batteries. in [20] the author proposed a microgrid model of an Australian university. The model consists of an EV charging station, PV generation 1600m^2, EMS, controller, and BESS of 500kWh. This research article aimed to facilitate the researches to work on this area to optimize the microgrid and update EMS. In [21] the author analyzes Dongshin University as a self-sufficient grid that contains a fuel cell, BESS, a PV system, and a CHP system. The main aim of this paper was to efficiently monitor and manage the power flow and energy cost in a grid.

EVs to the grid may result in additional peaks in load but carefully controlling the discharge and charging schedule of EVs is not only not hazardous but can contribute to peak shaving and load valley filling. Additionally, it might be beneficial to have backup power to accommodate rapid variations in demand and maintain the voltage and frequency of the grid [22]. Because of their durability and economic benefits, demand response as well as car-to-grid connections have received the majority of research attention. Here, however, the emission is also taken into account, and the proposed approach can solve both problems [23].

III. SYSTEM ARCHITECTURE DESCRIPTION

In 2016 the Pakistan Government started the net metering system but this system needs proper regulation and monitoring. The proposed model of a system is an academic campus of Pakistan University. The campus covers 163 arc area of land. The proposed system architecture is given in Fig. 1.

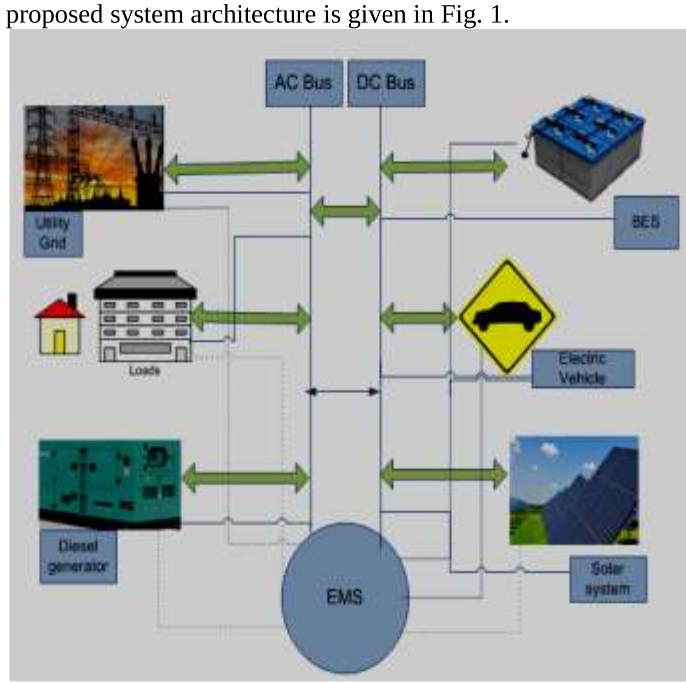


FIGURE 1: Proposed System Architecture

The proposed model consists of an energy management system EMS, microgrid, and main grid. The microgrid further consists of a load, storage system and diesel generator, photovoltaic system, and electric vehicles. In the supposed model selling and purchasing power price is the same to motivate the customers for selling excess energy in the utility grid. The last 10 years of historical load data is considered and forecasting has been done on load data. The load pattern is given in Fig. 2.

The price of energy in time of use tariff is given in the following Table I [25]:

TABLE I
ENERGY PRICE IN TOU TARIFF

Time (h)	Price ($/KWh)
1:00 to 18:00	0.098
18:00 to 22:00	0.13
22:00 to 24:00	0.098

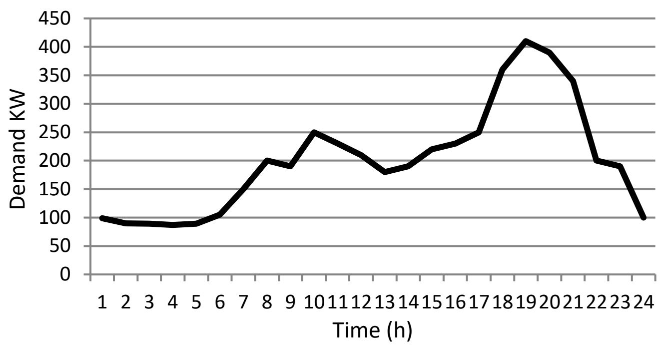


FIGURE 2: Daily average Load pattern [24]

A. *PROBLEM FORMULATION*

The proposed mathematical model is presented with a linear optimization method. The optimization aims to reduce the energy cost of microgrid. The proposed model architecture consists of an energy storage system, solar system, diesel generator, electric vehicles, and the utility grid. The rooftop photovoltaic system is considered with the energy storage system.

B. *THE OBJECTIVE FUNCTION AND SOLUTION METHODOLOGY*

To minimize the energy cost a nonlinear optimization problem is formulated by optimally scheduling all the available resources. The objective function equation is given as:

$$Obj = \min[JEV,t + J\,PV,t + Jgrid,t + JESS,t \quad (1)$$

$$JEV,t = (PEV,t)REV,t \quad (2)$$
$$JPV,t = (PPV,t)RPV,t \quad (3)$$
$$JGrid,t = (PGrid,t)RGrid,t, \quad (4)$$
$$JESS,t = (PESS,t)RESS,t, \quad (5)$$

In the above equation (1-5), $J_{grit,t}$, $J_{ESS,t}$, $J_{pv,t}$, $J_{EV,\,T}$ represent grid, energy storage system, photovoltaic system, and electric vehicles cost at time t. It is the unit price at any time.
The input data is given in the following table.
To balance the supply and demand gap the following equation is used:

$$P^g(t) + P^s(t) + P^{PV}(t) + Pev\,(\mathrm{t}) \; = P^L(t) \quad (6)$$

Where the sum of the output power of grid Pg(t), storage Ps (t), photovoltaic P PV (t), and P EV(t) should be equal to the load.
The battery storage system has upper and lower constraints for their good performance. The output power of the battery is controlled by the following equation:

$$\frac{SOC(t-1) - SOC_{max}}{100} Cap^s \le P^s(t) \quad (7)$$
$$P^s(t) \le \frac{SOC(t-1) - SOC_{min}}{100} Cap^s \quad (8)$$

Cap^s is the capacity of the storage system that is given by the manufacturer of the battery. SOC is the state of charge of the battery and Ps is the storage output power. Where SOC is given in the following equation:

$$SOE(t) = SOE(t-1) - \frac{100.\,P_t^s}{Cap^s} \quad (9)$$

The state of charge of the battery at the start and end of each optimal operation should be the same as given below:

$$SOC_{24} = \; SOC_0 \quad (10)$$

The utility grid power exchange and the storage upper and lower constraints are given in the following equations:

$$P_{min}^s \le P^s(t) \le P_{max}^s \quad (11)$$

$$SOE_{min} \le SOE(t) \le SOE_{max} \quad (12)$$

$$P_{min}^s \le P^s(t) \le P_{max}^s \quad (13)$$

Prosumers sell their excess power to the grid in emergencies. In the supposed model prosumers are allowed to exchange 1 MW of power to the grid. As the photovoltaic system stores its extra energy in lithium-ion batteries due to its effective performance. The net energy trading and total import and export energy are given by the following equations:

$$Net_e = \sum_{t=1}^{t=24} P^g(t) \; \times t \quad (14)$$

$$Net_{e,exp} = \sum_{t=1}^{t=24} P^g(t) \; \times t \quad \forall\, P^g(t) \pm P^s(t) > 0 \quad (15)$$

$$Net_{e,imp} = \sum_{t=1}^{t=24} P^g(t) \times t \quad \forall\, P_t^{grid} \pm P^s(t) < 0 \quad (16)$$

As in the proposed model, the length of a transmission line is supposed to be short so line losses are negligible and only active power is considered.
The following equations are used for both load and solar modeling.

$$f_l(P^L) = \frac{1}{\sqrt{2\pi}\sigma_L} exp\left(-\frac{(P^L - \mu_L)^2}{2\sigma_L^2}\right) \quad (17)$$

$$f_l(I) = \frac{1}{\sqrt{2\pi}\sigma_I} exp\left(-\frac{(I - \mu_I)^2}{2\sigma_I^2}\right) \quad (18)$$

Where μ and σ are the mean and standard deviation respectively both these parameters are used to calculate the solar irradiance I. The time of use pricing scheme is used in the model the mathematical modeling of the time of used model is given in the following equations:

$$\Delta dr^{min} \leq \Delta dr(t) \leq \Delta dr^{max} \quad (19)$$
$$dr(t) = dr^0(t) + \Delta dr(t) \quad (20)$$
$$,\lambda^{off,p} = \lambda^0 + \Delta\lambda^{off,p} \quad (21)$$
$$\lambda^p = \lambda^0 + \Delta\lambda^p \quad (22)$$

Where$dr(t)$, $\lambda^{off,p}$, and $\lambda^p$are energy demand, off-peak price, and peak price of electricity respectively.

TABLE II
PROPOSED SYSTEM PARAMETERS

Parameters	Value	Parameters	Value
$P_{pv\ rated}$	2000 kW	S Cap	2000 kWh
$P_{grid\ max}$	4000 kW	$P_{grid\ min}$	4000 kW
$P_{bat\ max}$	500 kW	$P_{bat\ min}$	-500 kW
SOC_{max}	90%	SOC_{min}	10%
The capacity of EV battery	100 kWh	Average power consumption EVs	0.1567 kWh/km

The proposed system is solved by using an optimization technique and parameters are given in Table II. The objective function and its constraints are modeled and Mix integer linear programming is used to solve the problem. In MATLAB, the solver interior point convex technique is used to solve the problem.

IV. RESULTS AND DISCUSSION

Different cases are analyzed in the results are explained in this section. A load of the campus is taken from the literature review and the time of use TOU demand scheme is analyzed. The cases are discussed here.

A. BASE CASE

In this case, the power is supplied from the system. The cost of the system comes out 621.42$. This case is taken as the base case for all other situations. This system is only run with grid and load no EV, ESS, or PV are considered.

B. SCENARIO 1

In this case, the cost of the system is analyzed by considering solar power, battery storage, and the utility grid. There is no PV production from evening to 7:00 am there is no or very little solar power. After morning PV system starts to generate energy and it reaches its maximum point at noon. When a load is fed with the PV and energy storage system and grid it is noticed that the load profile changes. In this scenario, the total cost comes out to 344.42 $. The output graph of this case is given in figure 3a.

C. SCENARIO 2

In this case, power interruption is considered and the result is analyzed. In this case, power interruption is assumed from 11:00 am to 12:00 am and 17:00 to 18:00 daily. In the morning time from 11:00 to 12:00, the power is supplied to load through PV energy because PV production is maximum at that time. While during 17:00 to 18:00 power is supplied through batteries. Grid exchange power is not considered in this case. The cost in this case is 462.09 $ per day. The output graph of this case is given in figure 3b.

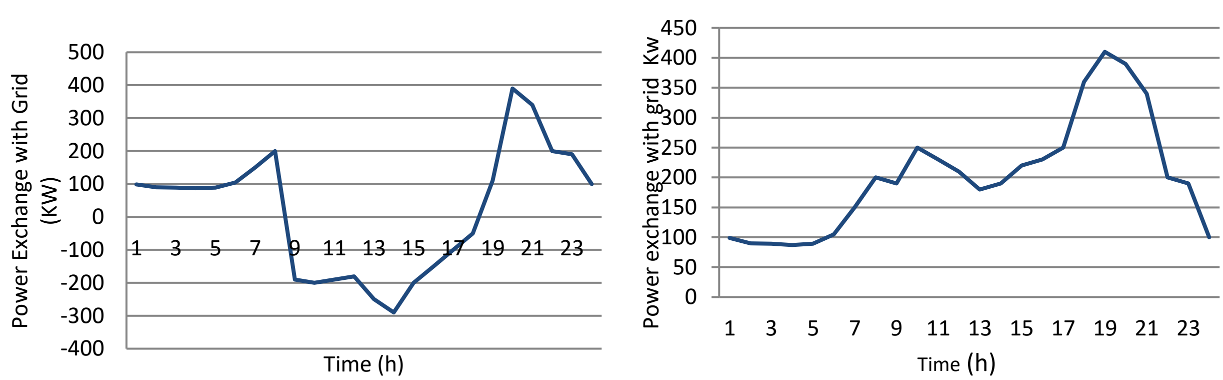
D. SCENARIO 3

In this case, the output is analyzed by incorporating EVs into the system. EVs are acting as a load in this case. EVs get charged to their maximum value and store energy and discharge this energy during peak time. The total cost in this case is 500.01$ per day. The result shows that the power exchange, in this case, is less because the EVs are trying to charge themselves at that time. The output graph of this case is given in Fig. 4a.

E. SCENARIO 4

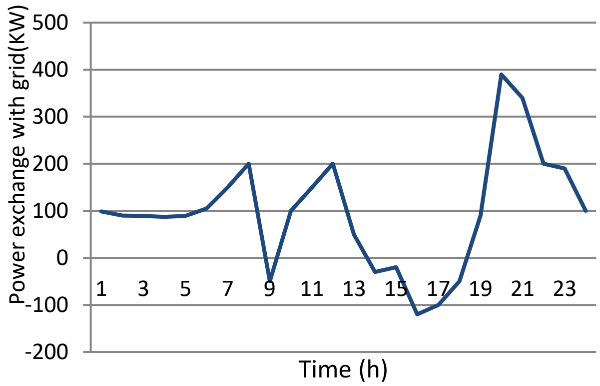
In this case, EVs are acting as sources. The capacity of EV batteries is assumed 100kWh. The cost of electricity during this case is 334.48$ per day. The output graph of this case is given in Fig. 4b.

The result comparison of each case is given in Table III:

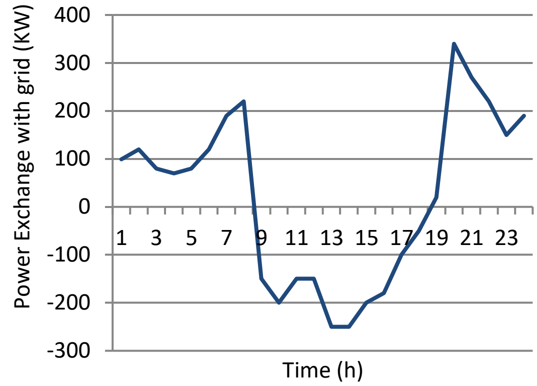


(a) (b)

FIGURE 3: (a) Power exchange with grid when PV, BESS, and the utility grid is considered (b) Power exchange with grid when PV, BESS, and power interruptions are considered



(a)



(b)

FIGURE 4: (a) Power exchange with grid when EVs are considered as load, (b) Power exchange with grid when EVs are considered as source

TABLE III
COST COMPARISION OF EACH CASE

Case	Parameters	Cost $/day	Cost saving %
Base case	Grid with load	621.92	0
1	Grid with PV and ESS	344.42	44
2	Grid with PV and ESS considering power interruption	462.09	25
3	EV as load	500.01	16
4	EV as source	334.88	46

V. CONCLUSION

In this research, the cost of microgrid is efficiently optimized by using different renewable resources like PV, BESS, and EVs. These components are efficiently scheduled by using the MILP technique in MATLAB. The linear optimization technique is used to formulate the problem. The microgrid was supplied with a utility grid only and thus the result comes as an increase in the cost of energy without using the distributed energy resources. Incorporating and efficiently scheduling the EV, PV and BESS result in a 48% cost reduction. Real-life problems are also investigated by using the power interruption scenario. The proposed technique insures the continuous supply of power to the grid. Moreover, EV integration was also analyzed in the system as both load and source. This work can be expanded by adding extra features of EVs and many other uncertainties associated with the distributed resources and other demand response schemes can also incorporate.

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The authors declare they have no conflicts of interest to report regarding the present study.

CONFLICT OF INTEREST

The Authors declare that they have no conflicts of interest to report regarding the present study

REFERENCES

[1] B. V. A. Boicea, "Energy Storage Technologies : The Past and the Present," vol. 102, no. 11, pp. 1777–1794, 2014. 524

[2] Hirsch, Y. Parag, and J. Guerrero, "Microgrid : A review of technologies , key drivers , and outstanding issues," *Renew. Sustain. Energy Rev.*, vol. 90, no. March, pp. 402–411, 2018, doi: 10.1016/j.rser.2018.03.040. 526

[3] T. Nasir *et al.*, "Recent Challenges and Methodologies in Smart Grid Demand Side Management : State-of-the-Art Literature Review," vol. 2021, 2021. 528

[4] R. A. Salam *et al.*, "An Overview on Energy and Development of Energy Integration in Major South Asian Countries : The Building Sector," *Energies*, vol. 13, no. 21, 2020, doi: 10.3390/en13215776. 530

[5] M. Qasim, "Population explosion – a real threat to Pakistan," Islamabad, Jul. 10, 2018.

[6] U. Rehman and M. Riaz, "Feasibility of the Smart Grid Implementation for Better Load Management in Pakistan," *2018 5th Int. Multi-Topic ICT Conf.*, pp. 1–5, 2018.

[7] S. Kanwal, B. Khan, and M. Q. Rauf, "Infrastructure of Sustainable Energy Development in Pakistan : A Review," vol. 8, no.

[8] NEPRA, "State of Industry Report 2020," 2020. [Online]. Available: https://nepra.org.pk/publications/State of Industry Reports/State of Industry Report 2020.pdf.

[9] F. Masroor, M. Ashfaq, M. Siddiqui, M. M. Hussain, M. H. Shahbaz, and P. E. S. Neduet, "The Power Sector Of Pakistan ; A Brief Review," pp. 2–6.

[10] Y. Li, Z. Yang, G. Li, D. Zhao, and S. Member, "Optimal Scheduling of an Isolated Microgrid with Battery Storage

Considering 540 Load and Renewable Generation Uncertainties," vol. 0046, no. c, 2018, doi: 10.1109/TIE.2018.2840498.

[11] S. Sinha and S. S. Chandel, "Review of software tools for hybrid renewable energy systems," *Renew. Sustain. Energy Rev.*, vol. 542 32, pp. 192–205, 2014

[12] R. B. Kristiawan, I. Widiastuti, and S. Suharno, "Technical and economical feasibility analysis of photovoltaic power 544 installation on a university campus in indonesia," vol. 08012, pp. 1–5, 2018

[13] M. R. B. Khan, J. Pasupuleti, J. Al-fattah, and M. Tahmasebi, "Optimal grid-connected PV system for a campus microgrid Optimal Grid-Connected PV System for a Campus Microgrid," no. December, pp. 899–906, 2018, doi: 10.11591/ijeecs.v12.i3.pp899-906. 548

[14] M. Huamani, L. Pinguelli, and A. Olímpio, "Barriers , challenges and opportunities for microgrid implementation : The case 549 of Federal University of Rio de Janeiro," vol. 188, no. 2018, pp. 203–216, 2021, doi: 10.1016/j.jclepro.2018.03.012.

[15] Waqar, M. S. Tanveer, J. Ahmad, M. Aamir, M. Yaqoob, and F. Anwar, "Multi-Objective Analysis of a CHP Plant Integrated Microgrid in Pakistan," 2017, doi: 10.3390/en10101625. 552

[16] M. G. M. Abdolrasol*et al.*, "An Optimal Scheduling Controller for Virtual Power Plant and Microgrid Integration using Binary Backtracking Search Algorithm," vol. 9994, no. c, pp. 1–10, 2018, doi: 10.1109/TIA.2018.2797121.

[17] M. Husein and I. Chung, "Optimal design and fi nancial feasibility of a university campus microgrid considering renewable energy incentives," *Appl. Energy*, vol. 225, no. February, pp. 273–289, 2018, doi: 10.1016/j.apenergy.2018.05.036. 556

[18] Y. Simmhan and V. Prasanna, "Demo Abstract : Toward Data-driven Demand-Response Optimization in a Campus 557 Microgrid," no. Figure 1, 2011.

[19] S. Hao and S. Coe, "Scheduling of Site Battery Energy Storage for Demand Response Capacity," 2015, doi: 10.1109/GREENTECH.2015.13.

[20] M. Shahidehpour and M. Khodayar, "Cutting Campus Energy Costs with Hierarchical Control," *IEEE Electrif. Mag.*, vol. 1 september, pp. 40–56, 2013, doi: 10.1109/MELE.2013.2273994.

[21] J. H. Angelim, "Energy Management on University Campus with Photovoltaic Generation and BESS using Simulated Annealing," *2018 IEEE Texas Power Energy Conf.*, pp. 1–6, 2018, doi: 10.1109/TPEC.2018.8312112.

[22] F. Xu *et al.*, "A micro-market module design for university demand-side management using self-crossover genetic algorithms," *Appl. Energy*, vol. 252, no. June, p. 113456, 2019, doi: 10.1016/j.apenergy.2019.113456.

[23] M. Nazir, "Hybrid Microgrid Controller Analysis and Design for a Campus Grid," *2019 IEEE 10th Int. Symp. Power Electron. Distrib. Gener. Syst.*, pp. 958–963, 2019.

[24] N. S. Savi and V. A. Kati, "Techno-economic and environmental analysis of a microgrid concept in the university campus," 569 no. Dc, 2018.

[25] M. Approach, "A Comparative Design of a Campus Microgrid Considering a Multi-Scenario and Multi-Objective Approach," 571 pp. 1–20, 2021.

[26] H. Abd, U. L. Muqeet, S. Member, and A. Ahmad, "Optimal Scheduling for Campus Prosumer Microgrid Considering Price Based Demand Response," *IEEE Access*, vol. PP, p. 1, 2020, doi: 10.1109/ACCESS.2020.2987915.