Pakistan Journal of Engineering and Technology, PakJET
ISSN (p): 2664-2042, ISSN (e): 2664-2050
Volume: 6, Number: 1, Pages: 51- 56, Year: 2023

Energy Hub Planning and Operation Optimization by Applying Demand Side Management Using GAMS

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Received: 01/11/2022, Revised: 20/02/2023, Accepted: 1/03/2023

Abstract- Energy hub planning and optimization considering various constraints is an emerging domain of research due to the scarcity of conventional energy resources. Strategic integration of multi-energy sources is a dominant region of research as it provides better efficiency and cost savings. Various uncertainties due to the changing electric, heating, and cooling load demand are increasing the complexity of the system. The paper investigates the effectiveness of Demand Side Management (DSM) programs by analyzing the operation of domestic Energy Hub. The paper proposes two stages for optimal energy hub planning and operation optimization and GAMS mathematical modeling is used to deduce the results. The paper provides the analysis of a two-stage optimization model using the approach of modeling uncertainties and constraints. The process of energy hub designing has been carried out by the help of PSO algorithm by considering continuous capacities of various components of energy hub. The research regarding optimal energy hub operation is modelled in GAMS and the approach of mixed-integer non-linear programming (MINLP) has been used to evaluate the results. The framework provides the energy hub model and also provided the verification of model effectiveness and efficiency.

Index Terms-- DSM, GAMS, Energy Hub, and Optimization of Hub.

I. INTRODUCTION

Depleting fossil fuel reserves and increasing pollution indexes globally are increasing the utilization of renewable energy resources. The integrated use of natural gas and electricity is becoming a domain of high interest because it provides many cost benefits and enhances the system's efficiency [1, 2].It could be concluded that the design and optimization of the energy hub, including natural gas and electricity sources, would be more complicated than separate systems.

The energy hub is the approach used for the simultaneous supply and transmission of electric and heating demand of loads [3-6]. The multi-carrier energy system would allow the users to transmit and convert different forms of energy effectively. The system of multicarrier energy resources would include various components, including the PV system, turbines, CHP, Electric Heat Pump, and different loads (Cooling, Heating, and Electric) in coordination with each other[7-11]. The energy hub is referred to in the literature as the "Input-Output Dual-Port Model", which explains the supply, conversion, and storage of multiple categories of loads and demands. Energy hub is a growing research domain, and many researchers have focused on optimizing various components of the energy hub. Energy hub optimization provides benefits like minimizing energy consumption and enhancing of reliability of the system by offering an incentive for better energy management [12-18]. The energy hub design optimization process would include the stages of optimal sizing of assets of the energy hub along with their interconnection. The energy hub design and optimization would be based on the process of meeting the demands of heating, cooling, and electric loads, which vary considerably [5]. The prediction of the exact pattern of user demand in the future is impossible because the load is an uncertain quantity. Multiple uncertainty constraints are involved in the process of optimal design and operations of the energy hub. Incorporating renewable energy resources would further complicate the optimal modeling problem of the multiple energy career systems as it would include further constraints in the research. The multiple types of loads could be managed by applying the approach of Demand Side Management as it would facilitate effective energy utilization. DSM approaches are referred to as innovative strategies that could be used to inspect and schedule the consumption pattern of the users [17]. DSM approaches help the users shift the load in off-peak hours so that the balance between the supply and the demand of the system can be achieved. The operational cost of the system is also minimized by adjusting the placement of the load by performing the optimal scheduling of demand and the resources available [19-22].

Following are the key contributions of the paper:

- The proposed framework would analyze two sections of energy hub planning: energy hub design and operation.
- The current research on energy hubs would provide the optimal design and solution for the operation of energy hubs by considering various sorts of uncertainties.
- The problem of design and operational optimization problem of the energy hub contains many constraints and is modeled in GAMS (General Algebraic Modeling System) Software. GAMS is a high-level modeling tool used for solving diverse equations with multiple constraints [2]. The problem has been solved using the CPLEX solver, and multiple uncertainties are modeled efficiently by GAMS.

II. LITERATURE REVIEW

With the development of renewable technology, Energy Hubs have emerged as one of the most promising areas of the current power industry [1,2]. Rastegar et al. [3] offered a household energy hub plan for a smart home to reduce customer payments, which included a PHEV (plug-in hybrid electric vehicle) and CHP. In the domestic energy hub concept, Rastegar et al. [4] explored heat storage units & solar panels in addition to CHP and PHEV to reduce customers' energy expenses. Brahman et al. [5] have designed efficient electrical and thermal energy management for a typical home energy hub to minimize overall energy costs while considering customer preferences. The suggested model considered various storage components, such as thermal energy or PHEV storage. However, the initial study [5,3,4] only investigated the situation of a single EV connecting to the system, and large-scale EV deployment in the energy hub needed to be modeled.

A review article is presented in [6] to study the possible function of an energy hub as an integrated energy management system in addressing the major energy market problem. This study focuses on the profits obtained by combining choices like demand-side management, renewable energy resources, distributed energy resources, storage systems, and multi-generation systems, and leveraging smart technologies by presenting the notion of smart energy hubs. Authors in [7] proposes a linear model of hub-coordinated energy management with storage and active loads RES as the hub scheme in the DA market.

Linear coordinated energy management issue in this process has a single linear objective function that maximizes hub profit in the DA market while considering linear networks and hub restrictions. However, while using renewable energy, it is vital to analyze the influence of uncertainty. The ideal scheduling of energy hubs is described in [8] to reduce operational expenses. The effects of different uncertainties are studied using the fuzzy sets approach, and a sensitivity analysis on the influence of unknown parameters is performed.

As significant as the cost problem is in installing an energy hub, the emission pollution issue is equally critical [9,10] different nonrenewable sources, including CHP and heat sources, have been used to meet energy demand and maximize the efficiency of the operating EH (boiler). As a result, the use of renewable resources has a significant influence on increasing the operation of the energy hub and reducing emission concerns. The multi-objective coordinated energy dispatch & voyage scheduling strategy for a multi-energy ship micro-grid was reported in [11]. The effect of employing adequate energy storage hub energy performance was then investigated. However, the amount of energy provided by renewable sources is yet unknown.

Javadi et al. [12] analyzed the energy hub performance employing several energy carriers of hub systems based on operating cost reduction. Aside from financial considerations, environmental degradation is a significant element in power systems. As a result, in [13], the performance of EH has been assessed by reducing emission concerns.

A unique optimization approach for an EH was proposed in [13] to calculate the ideal size of candidate DERs & analyze EH's environmental and economic consequences. Numerous aspects were studied to establish the economic and environmental consequences. To produce accurate findings and satisfy demand, it is critical to evaluate the uncertainty elements and their influence on the operation of the energy hub. There are several techniques for investigating the effects of uncertainty on system performance. Dolatabadi and Ivatloo [15] used scenario-based stochastic scheduling to simulate risk-based stochastic programming of EH in the existence of WT, heat storage, electrical storage, and an electricity market.

III. MATERIALS AND METHODS

The main approach that has been used in energy hub modeling is to propose the optimal planning and operation of an energy hub incorporating basic components. The domestic model of energy hub is used in the problem and includes components CHP, Chillers, EHP, boiler, PV, and electric heater. The problem provides a solution to the capacities of various assets of the hub in such a manner that the total investment and operating costs are minimized.

The approach used for planning of energy hub is the PSO algorithm and the second section provides an overview of the energy hub's operational optimization. The overall objective function of the system proposed in the research is shown in (1) where TIC donates "Total Investment Cost" and "Total Operational Cost".

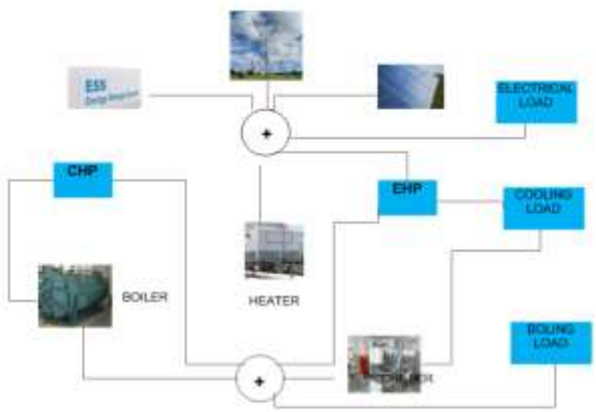

FIGURE 1: Energy Hub Design

A.MATHEMETICAL EVALUATION

The overall objective function of the paper comprises of two key variables that include the total investment cost and total operational cost.

$$Z = Min(TIC + TOC) \quad (1)$$

The total investment cost of the system could be defined by equation (2) and the factor "Cap" indicate the capacity of the CHP, Chillers, EHP, Boiler, PV, and heater respectively. The factor of "CRF" depicts Cornerstone Total Return Fund Inc. (CRF) and it has been evaluated by using the equation in [16]

$$TIC = CRF((F^{CHP}(Cap^{CHP}) + (F^{Chiller}(Cap^{Chiller}) + (F^{EHP}(Cap^{EHP}) + (F^{Boiler}(Cap^{Boiler}) + (F^{PV}(Cap^{PV}) +)\left(F^{Heater}(Cap^{Heater})\right) \quad (2)$$

The total operational cost of the model is evaluated by incorporating the flow of power in the grid and power flowing out of the grid respectively [8]. The factor of "P_ENS" indicates the power that is not supplied by the grid and the equation includes that factor as well. Total operational cost is modeled by the following equation:

$$TOC = sum\left((P_{G2H} * Lambda_{BUY}) - (P_{H2G} * Lambda_{BUY})\right) + OC_{CHP} + OC_{BOILER} + OC_{CHILLER} + OC_{HEATER} + (P_{ENS} * DEL_T * Lambda_{ENS}); \quad (3)$$

The model includes the model of PV and the constraints of PV are also included in the model of the energy hub considering the irradiance and other factors [7]. The equation for the addition of the PV module in the energy hub is indicated below in equation (4):

$$Pv(t) = Npv * SS * I * (1 - 0.005 * tout - 25) \quad (4)$$

The irradiance of the sun is used to evaluate the output of the PV in the above equation.

There are various sorts of operational costs associated with each asset used in the energy hub and the research focuses on including these factors in problem solutions to increase the accuracy effectively. The equations of the operational cost of CHP, EHP, Heater, Chiller, and Boiler are stated below:

$$OC\_CHP(t) = \left(a_{CHP} * \left(P_{CHP(t)} * DEL_T\right)^2\right) + b\_CHP * (P\_CHP(t) * DEL\_T) + \left(C_{CHP(t)} * \left(H_{CHP(t)} * DEL_T\right)^2\right) + d\_CHP * \left(H_{CHP(t)} * DEL_T\right) + +e\_CHP * \left(P_{CHP(t)} * DEL_T\right) * \left(H_{CHP(t)} * DEL_T\right) + f\_CHP; \quad (5)$$

$$OC\_Boiler(t) = data(t,' Lamd'_{gas}) * \left(\left(\frac{H_{Boiler(t)} * DEL_T}{EFF_{Boiler}}\right)\right. \quad (6)$$

$$OC\_Chiller(t) = a\_Chiller * (C\_Chiller(t) * DEL\_T) + b\_Chiller \quad (7)$$

$$OC_{EHP(t)} = a_{EHP} * \left(\left(\left(\left(H_{EHP(t)} * DEL_T\right) + \left(C_{EHP(t)} * DEL_T\right)\right)\right)^2\right) + b_{EHP\left(\left(H_{EHP(t)} * DEL_T\right) + \left(C_{EHP(t)} * DEL_T\right)\right)} + c_{EHP} \quad (8)$$

$$OC_{Heater(t)} = a_{Heater} * \left(H_{Heater(t)} * DEL_T\right) + b_{Heater} \quad (9)$$

Following are expressions of important constraints that are considered while modeling various components in Energy Hub:

$$H_{Boiler(t)} =< Cap_{boiler} * I_{boiler(t)}; \quad (10)$$
$$C_{Chiller(t)} =< Cap_{Chiller} * I_{Chiller(t)}; \quad (11)$$
$$C_{Chiller(t)} = H_{Chiller(t)} * COP_{Chiller} \quad (12)$$
$$C_{EHP(t)} =< Cap_{EHP} * IC_{EHP(t)} \quad (13)$$
$$H_{EHP(t)} =< Cap_{EHP} * IH_{EHP(t)} \quad (14)$$

Following are the expressions for power demand, heat demand, and cooling demand in the Energy hub:

$$P_{G2H(t)} + Pdis_{EES(t)} + P_{CHP(t)} + P_{PV(t)} \quad (15)$$
$$= P_{ENS(t)} + P_{H2G(t)} + Pch_{EES(t)} + P_{EHP(t)} + P_{Heater(t)} \quad (16)$$
$$H_{CHP(t)} + H_{EHP(t)} + H_{Heater(t)} + H_{Boiler(t)} = H_{D(t)} + H_{Chiller(t)}; \quad (17)$$
$$C_{D(t)} = C_{EHP(t)} + C_{Chiller(t)} \quad (18)$$

B. SOLUTION APPROACH

Two fundamental stages are modeled for solving the problem of energy hub optimization. The first stage involved the process of formulation of the sizing problem and it has been evaluated by using the MINLP framework. The first stage provides the results of the capacities of various assets of the energy hub and these capacities are used in the operational optimization of the energy hub. The second stage provides the solution to operational constraints by optimizing the cost using GAMS software. The data of the energy hub is taken from [16] and the data of four seasons have been evaluated and the results are deduced logically as well. The research uses the demand side strategy of real-time pricing and peak shaving has been used in the solution of the problem. The results have been deduced by providing a comparison of the demand-time curves of various seasons. The capacities of various components including CHP, EHP, and Boiler have been taken differently for different seasons according to the load curves [4].

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VI. RESULTS AND DISCUSSION

The results of the problem have been concluded by using PSO for obtaining the solution of the optimal value of PV, CHP, Boiler, EES, Chiller, EHP, and Heater. The investment costs have been obtained by using equations of its constraints and cost factor depicted in [23].

The scenarios of four seasons have been taken in the problem and results are presented in Table I and Table II.. The results depict that application of the approach of real-time pricing and peak shaving of DSM have resulted in better optimization of the energy hub as shown in Fig. 2, Fig. 3, Fig. 4 and Fig. 5. Total Investment Cost remains the same for all seasons and has been listed in the table separately. The demand (KW) varies according to the consumption pattern of the users and the historic data has been taken from [23].

Table I: Optimal values.

Asset	Size	Investment cost
PV	100.88	15776.85
CHP	290	38127.39
Boiler	402	26294.75
EES	200	26295.88
Chiller	260	12654.66
EHP	95	6508
Heater	0	0

Table 2: Optimal values for each season.

Asset	Spring	Summer	Fall	Winter
CHP	808.9	1149	1182.27	1420.25
Boiler	162	88.2	452.9	851.3
Chiller	0.309	0.94	0	0
EHP	0	6.801	0	0.521
Heater	0	0	0	0
TOC	1430	2325.7	1640	1827
TIC	125657.5			

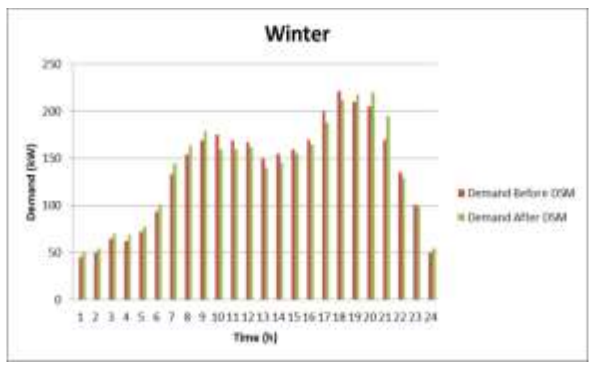

FIGURE 2: Winter histogram.

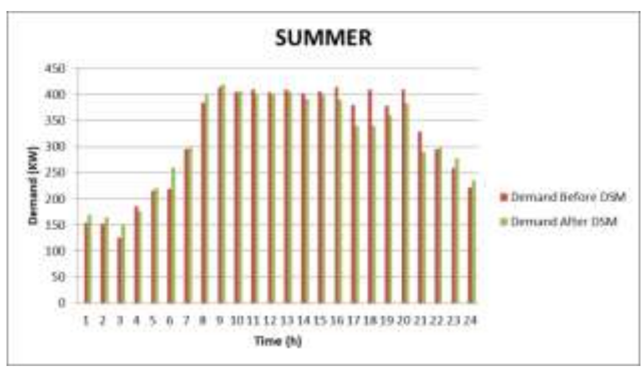

FIGURE 3: Summer histogram.

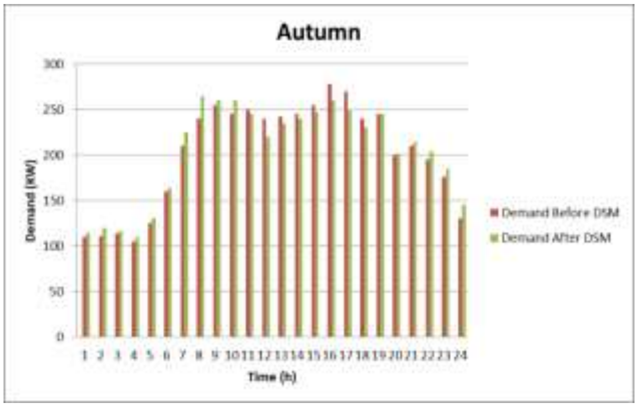

FIGURE 4: Autumn histogram.

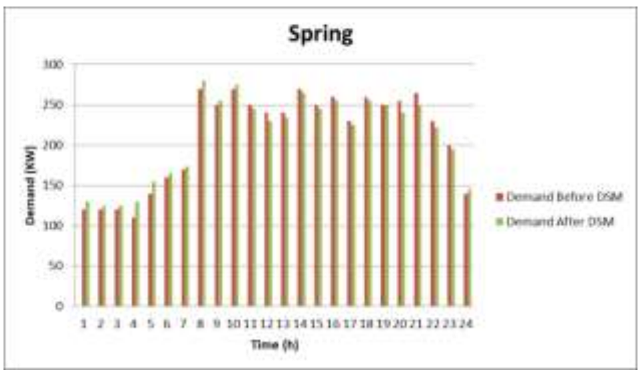

FIGURE 5: Spring histogram.

The results depict that energy hub operations could be best optimized by using the approaches of demand-side management. Effective management of the load would result in cost saving for the customers as it would help in the peak shaving of adjustable loads. The approaches of DSM have been used because only 2% of the total load could be shifted from peak to off-peak hours.

V. CONCLUSION

Energy hub planning and optimization considering various constraints is an emerging domain of research due to the scarcity of conventional energy resources. The paper provides a detailed analysis of the solution of Energy Hub by considering various constraints of capacity and operational costs. The paper provides the analysis of a two-stage optimization model using the approach of modeling uncertainties and constraints. The results of the problem have been concluded by using PSO for obtaining the solution of the optimal value of PV, CHP, Boiler, EES, Chiller, EHP, and Heater. The investment costs have been obtained by using equations of its constraints and cost factor depicted and the scenarios of four seasons have been taken into the problem. The proposed framework provides a comprehensive overview of energy hub planning using multiple constraints. Total investment cost that has been derived for the current paper is 125657.5. Total operational costs for summer, spring, fall and Autumn have been computed as 1430, 2325.7, 1640 and 1827 respectively. The results depict that the use of DSM approaches of real-time data and peak shaving play a vital role in reducing the cost of operation of the energy hub.

FUNDING STATEMENT

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

CONFLICT OF INTEREST

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REFERENCES

[1] Liu Z, Wu Q, Huang S, Wang L, and Xue Y. Shahidehpour M, "Optimal day-ahead charging scheduling of electric vehicles through an aggregative game model," *IEEE Trans Smart Grid*, vol. 9, p. 5173–84, 2017.

[2] Gross G. Guille C, "A conceptual framework for the vehicle-to-grid (V2G) implementation," *Energy Pol* , vol. 37, p. 4379–90, 2009.

[3] Fotuhi-Firuzabad M, Lehtonen M. Rastegar M, "Home load management in a residential energy hub," *Electr Power Syst Res*, vol. 119, p. 322–8, 2015.

[4] Fotuhi-Firuzabad M, Zareipour H, Moeini-Aghtaieh M. Rastegar M, "A probabilistic energy management scheme for renewable-based residential energy hubs," *IEEE Trans Smart Grid*, vol. 8, p. 2217–27, 2016.

[5] Honarmand M, Jadid S. Brahman F, "Optimal electrical and thermal energy management of a residential energy hub, integrating demand response and energy storage system," *Energy Build*, vol. 90, p. 65–75, 2015.

[6] Y. Noorollahi, B. Mohammadi-ivatloo, M. Hosseinzadeh, H. Yousefi, S.T. Khorasani M. Mohammadi, "Optimal management of energy hubs and smart energy hubs–a review," *Renewable and Sustainable Energy Reviews*, vol. 89, p. 33–50, 2018.

[7] S. Pirouzi, M. Norouzi, M. Lehtonen A. Dini, "Grid-connected energy hubs in the coordinated multi-energy management based on day-ahead market framework," *Energy*, vol. 188, p. 116055, 2019.

[8] Y. Noorollahi, B. Mohammadi-ivatloo M. Mohammadi, "Fuzzy-based scheduling of wind integrated multi-energy systems under multiple uncertainties," *Sustainable Energy Technologies and Assessments*, vol. 37, pp. 1-11, 2020.

[9] S. He, A. Alizadeh, S. Nojavan, K. Jermsittiparsert Z. Yuan, "Probabilistic scheduling of power-to-gas storage system in renewable energy hub integrated with demand response program," *Journal of Energy Storage*, vol. 29, pp. 1-15, 2020.

[10] A.H. Mirzahosseini, F. Faghihi, M. Panahi F. Jamalzadeh, "Optimal operation of energy hub system using hybrid stochastic-interval optimization approach," *Sustainable Cities and Society*, vol. 54, p. 19, 2020.

[11] Y. Xu, S. Fang, Y. Wang, X. Zheng, Z. Li, "Multi objective coordinated energy dispatch and voyage scheduling for a multienergy ship microgrid," *IEEE Transactions on Industry Applications*, vol. 56, p. 989–999, 2019.

[12] M.S., Lotfi, M., Nezhad, A.E., Anvari-Moghaddam, A., Guerrero, J.M. and Catalão, J.P. Javadi, "Optimal Operation of Energy Hubs Considering Uncertainties and Different Time Resolutions," *IEEE Transactions on Industry Applications*, vol. 56, no. 5, pp. 5543-5552, 2020.

[13] A. Mahmoudi, M. Aghamohamadi, "From bidding strategy in smart grid toward integrated bidding strategy in smart multi-energy systems, an adaptive robust solution approach," *Energy*, vol. 183, p. 75–91, 2019.
[14] S. Nojavan, M. Majidi, and and K. Zare, "Optimal scheduling of heating and power hubs under economic and environmental issues in the presence of peak load management," *Energy Conversion and Management*, vol. 156, p. 34–44, 2018.
[15] B. Mohammadi-Ivatloo A. Dolatabadi, "Stochastic risk-constrained scheduling of smart energy hub in the presence of wind power and demand response," *Applied Thermal Engineering*, vol. 123, pp. 40-49, 2017.
[16] Uddin, Moslem, et al. "A novel peak shaving algorithm for islanded microgrid using battery energy storage system." Energy vol. 196, p. 117084, 2020.
[17] Rajamand, Sahbasadat. "Effect of demand response program of loads in cost optimization of microgrid considering uncertain parameters in PV/WT, market price and load demand." Energy vol. 194, p. 116917, 2020.
[18] Shafiee, Mehdi, MasoudRashidinejad, and Amir Abdollahi. "A novel stochastic framework based on PEM-DPSO for optimal operation of microgrids with demand response." Sustainable Cities and Society vol. 72, p. 103024, 2021.
[19] Nayak, Aanchit, AvirupMaulik, and Debapriya Das. "An integrated optimal operating strategy for a grid-connected AC microgrid under load and renewable generation uncertainty considering demand response." Sustainable Energy Technologies and Assessments vol. 45, p. 101169, 2021.
[20] AbdulMuqeet, Hafiz, et al. "Optimal Operation of the Campus Microgrid considering the Resource Uncertainty and Demand Response Schemes." Mathematical Problems in Engineering vol. 2021, 2021.
[21] Dai T, Qiao W. Trading wind power in a competitive electricity market using stochastic programming and game theory. IEEE Trans Sustain Energy vol. 4, p. 1–6, 2013.
[22] Khare V, Nema S, Baredar P. Game theory based cournot's model of solar wind hybrid renewable energy system. In: Proceedings of ICRESE-IEEE; 2013. p. 7–11.
[23] Brahman F, Honarmand M, Jadid S. Optimal electrical and thermal energy management of a residential energy hub, integrating demand response and energy storage system. Energy Build vol. 90, p. 65e75, 2015. https://doi.org/10.1016/ j.enbuild.2014.12.039