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An Optimal Operation of Prosumer Microgrid Considering Demand Response Strategies and Battery Life

H.A. Muqeet[1], A.Ahmed[2]

[1,2]Department of Electrical Engineering, University of Engineering & Technology, Taxila, Pakistan

[1] abdul.muqeet@uettaxila.edu.pk

Abstract- Existing energy supply systems are facing many problems such as increasing energy prices, depletion of fossil fuels and greenhouse gas (GHG) emissions. These problems seriously affect all the stakeholders of power systems such as customers/prosumers, utility and microgrid operators. Such issues can be resolved by renewable energy integration and various energy management strategies like demand response (DR), demand-side management (DSM), etc. Among various consumers, campus microgrids are one of the major energy consumers facing high energy costs. This paper proposes a novel energy management system (EMS) for an institutional campus having onsite PV and ESS in grid exchange environment using a nonlinear mathematical model which also considers degradation cost of ESS and DR. The proposed EMS not only reduces the energy consumption cost by extending storage life but also ensures grid stability by curtailing and shifting the loads through incentive-based and price-based DR schemes. ESS is used as a stationary energy reserve which ensures stable operation of microgrid and also supports the grid network in case of contingencies. The proposed model is solved using a quadratic programming technique in MATLAB. Results show that the proposed EMS reduces the operational cost of the prosumer by increasing its self-consumption, reduces its peak load demand from the grid network and will be enticing the campus owners and energy managers to invest in distributed generation (DG) and large-scale ESS installations.

Keywords- Demand response, distributed generation, energy storage system, prosumer, renewable energy resources, smart campus microgrid

I. NOMENCLATURE

ACRONYM

$BESS$	Battery energy storage system
Cap^s	Rated capacity of storage (kWh)
DG	Distributed generation
DSM	Demand-side management
ESS	Energy storage system
EMS	Energy management system
GHG	Greenhouse gas emission
QP	Quadratic programming
$RERs$	Renewable energy resources
UET	University of engineering & technology
SG	Smart grid

VARIABLES AND PARAMETERS

$DR\ (t)$	Demand response value at time t.
$\Delta DR^{\max}$	Maximum allowable range of demand response value at time t.
$\Delta DR^{\min}$	Minimum allowable range of demand response value at time t
I	Solar irradiance
J	Weighting factor of ESS
Net_e	Net energy exchange with grid (kWh)
$P^{PV}(t)$	Output power of solar PV (kW)
$P^s(t)$	Output power of storage system (kW)
$P^s_{max}(t)$	Maximum output power of storage system (kW)
$P^s_{min}(t)$	Minimum output power of storage system (kW)
$P^C(t)$	Contracting power of neibour consumer (kW)
$K_b(t)$	Buying price of electrical energy ($)
$Q_s(t)$	Selling price of electrical energy ($)
$Net_{e,exp}$	Energy export to the grid (kWh)
$Net_{e,imp}$	Energy import from the grid (kWh)
$P^g(t)$	Output power of grid (kW)
$P^L(t)$	Energy demand of prosumer (kW)
$SOE(t)$	State of charge at time t (%).
P^g_{min}	Minimum exchange power of grid (kW)
P^g_{max}	Maximum exchange power of grid (kW)
SOE_{max}	Maximum state of charge (%)
SOE_{min}	Minimum state of charge (%)
SOE_0	Initial level of state of charge (%)
η_{pv}	Solar panel efficiency
β_{pv}	Solar panel area

II. Introduction

In the field of smart grid, one of the key challenges is the energy management system (EMS) for end-users. The smart grid comprises the interconnection of microgrids and hence, energy exchange among them provides a promising potential to reduce microgrid operation cost and could result in the decrease of required load- shedding amount by using different programs[1].

Among other programs such as demand-side management, demand response, energy storage system (ESS) participation in the electricity market, virtual power plants are a few of them [2]. Other benefits a microgrid has distributed generations (DGs) with ESS, a secure energy supply, reliable system that maximizes the profit of active consumers by participating in the electricity market, can operate in grid-connected and islanded mode [3], [4]. Different types of renewable generations such as solar PV, wind turbine, biomass and geothermal are used in microgrids. Whereas the energy storage technologies provide smooth and reliable energy supply during peak hours [5]. The energy storage system like the battery has many applications in energy resource management, such as isolated microgrid [6], backup energy for critical load [7]. On the other hand, the lifetime of storage depends on the many operational and calendrical aging factors such as internal resistance, the surrounding temperature, depth of discharge and terminal voltages [8].

The prosumers are such type of grid-connected customers that can sell their surplus energy with the utility or nearby customers [9]. To provide the economical energy supply, renewable energy integration with the conventional power grid is the emerging trend in developing and developed countries [10]. In developing regions, such as South Asia, Latin America, and Africa, energy prices are increasing with time especially due to uncertain political situations creating 'electricity short-fall' in some areas of the world. Pakistan is also a developing country and facing severe energy shortfall by 32% [11], which is an alarming situation for decision-makers. The grid outage also an alarming event which is still existing about 6-8 hours and a problem of the local region [12]. In large scale consumers, institutional microgrids such as campus prosumers are an emerging part of the power system having various types of customer categories such as residential, commercial and office buildings [13].

Numerous literature reports and studies exist on the proposed topic, for example, the authors in [14], analyzed the campus microgrid Aligarh Muslim University (AMU). The HOMER software-based solution was presented for various distributed generation. In [15], the authors presented the scheduling of PV-storage using a mixed integer-based solution of real campus microgrid. However, the uncertainty of DGs and load were ignored. In [16], the authors presented the economic analysis of the grid-connected system for the Pakistani environment. Payback period and net present values were calculated however, they ignored the energy storage system. While in [17], the authors presented the pricing and cost model for peer to peer prosumers. The proposed model reduced the cost and increased the profit of PV prosumers as compared the energy trading without scheduling. However, ignored the in-depth analysis of the energy storage system. In [18], the Korean campus microgrid was devised to investigate the financial feasibility. The proposed model was solved using MDSTool considering various economic concerns. In [19], the authors investigated the cost-benefit analysis of the PV alone and PV- storage system of 369 customers considering feed-in tariff (FIT) in US regions. The analysis revealed that the system with PV only was efficient at present but lack of self-sufficiency facility which was the main factor to participate in the electricity market. The only PV-storage system feasibility was determined if the retail electricity prices above \$0.4/kWh and feed-in tariff below \$0.05/kWh. A PSO based two-stage scheduling for cost minimization solution was presented in [20]. Different cases were analyzed to investigate the ESS role for microgrid operation. The results discovered the significant role of ESS for economical operation as compared to other resources. In [21], presented the model for operational cost reduction with energy purchasing from the grid. The energy storage cost and power loss also reduced for optimal microgrid energy management.

In [22], the authors devised a PV-storage μG scheduling framework taking into account the battery running and degradation costs. The model reduced the energy cost, peak demand violation penalty, and battery degradation cost. Flexible assignment method (FAM) with RTCS2 was applied for the state of charge (SOC) management and cost was reduced from 36,286,370 KRW to 34,354,995 KRW. In [23], the authors presented a grid load reduction model for residential applications considering the grid availability using linear programming in MATLAB. Different scenarios of load shedding were analyzed and it was deduced that 8 hours load shedding could save up to 1000kWh for a typical household of 1200W. Furthermore, the authors found that a scenario with 4 hours of load shedding reduces the monthly consumption cost by 16%.

Yu Zheng et al. presented the battery energy storage modeling for DISCOs profit enhancement [24]. The Natural Aggregation (NA) and Conic relaxation techniques were implemented for bidding strategy and cost reduction. Integration of BESS reduced the energy cost from \$448.49 to \$433.63 in the day-ahead (DA) market. In [25], the authors scheduled multiple μGs to form a virtual power plant (VPP) using a binary backtracking algorithm (BBSA). The fitness function of the proposed model was much better as compared to binary particle swarm optimization. Reductions in operating cost and power losses while enhancing reliability were found. The savings by the proposed method were increased from 187926.386 to 222246.9262 RM (Malaysian Ringgit). Dahraie et al. [26] devised a two-stage stochastic model for the simultaneous benefits supply and demand entities considering the frequency security provision cost was reduced from \$835.52 to \$773.75 in the proposed model using the incentive-based DR.

Demand Response is the rising area of research, which can be defined as the changes in consumer electric energy usage patterns by changes the unit price of electricity to reduce the system peaks, and instability. It also supports the system reliability by customer participation in the electricity market [27]. There are two types of demand response such as price-based, and incentive-based demand response. Furthermore, the price based can be divided into a time of use (TOU), critical peak pricing (CPP) and real-time pricing (RTP) [28]. The community energy sharing in a multi-microgrid environment considering the demand response was investigated in[29].

Pakistan has great potential for solar PV, which has the potential to diminish the current energy shortage [30]. On the other hand potential of wind power cannot be ignored, but it is limited to some specific regions –[31]. In a smart microgrid system, passive consumers are transitioning to prosumers, which sells its surplus energy to the national utility grid or nearby contracted customers. Different types of microgrid models are introduced in the existing literature to improve resilience and reduced the operational cost. A general proposed model of the microgrid system is given in Fig. 1 which elaborates on the microgrid energy and information flow system.

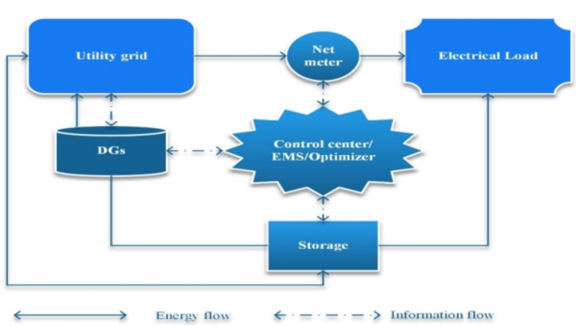

Fig. 1. General system architecture

A literature survey shows that microgrid energy management has many issues such as energy consumption cost reduction, maximize the profit of the utility grid. So, a resilient smart microgrid is a potential solution for developing countries [23]. In South Asia, Pakistan has great potential for solar PV and other renewable energy resources (RERs) [32], as discussed earlier. Net metering was launched in 2016 that promoted the passive consumer to active prosumer. In this work, an institutional microgrid has been devised for optimal energy exchanges between a university campus building and the national grid. Although, the existing literature addressed the microgrid considering uncertainties but ignored the battery life which is very important factor. Optimal energy management system considered the mixed price-based/incentive-based demand response, and ESS life are incorporated in our proposed system.

A. Contribution

Some other contribution of our work can be summarized as:

- Designed a nonlinear real-time model of the grid-connected PV-energy storage system with battery degradation cost for the campus prosumer community.
- Analyzed the proposed system with incentive and price-based demand response for cost estimation.
- Grid support and grid outage-based modes are also considered for emergency operations to analyze the effect on operational cost.

The remaining paper is comprised of the following sections: In Section III, the proposed system model is Presented. In Sections IV and V problem formulation of day-ahead scheduling and results are given, while Section VI concludes the findings of this paper.

III. SYSTEM MODEL

Renewable energy integration with the classic power grid is the emerging trend in developing countries. Pakistan has much potential for solar PV and needs proper planning to promote green energy. The system architecture of the proposed model is given in Fig. 2. University campus UET Taxila is selected as testbed which is situated in Punjab province of Pakistan and has the latitude and longitude as 33.7^0 and 72.84^0 respectively. The input data of solar PV irradiance and loads are received in the scheduler. This scheduler generates the decision signal after optimizing the available resources. The system is comprised of the battery bank and AC loads. These loads can be categories into critical and non-critical loads. The controller actively operates the ESS in case of different scenarios. The storage battery bank charge only in off-peak hours or from the solar PV panels, while discharge at peak hours. The proposed campus microgrid has a

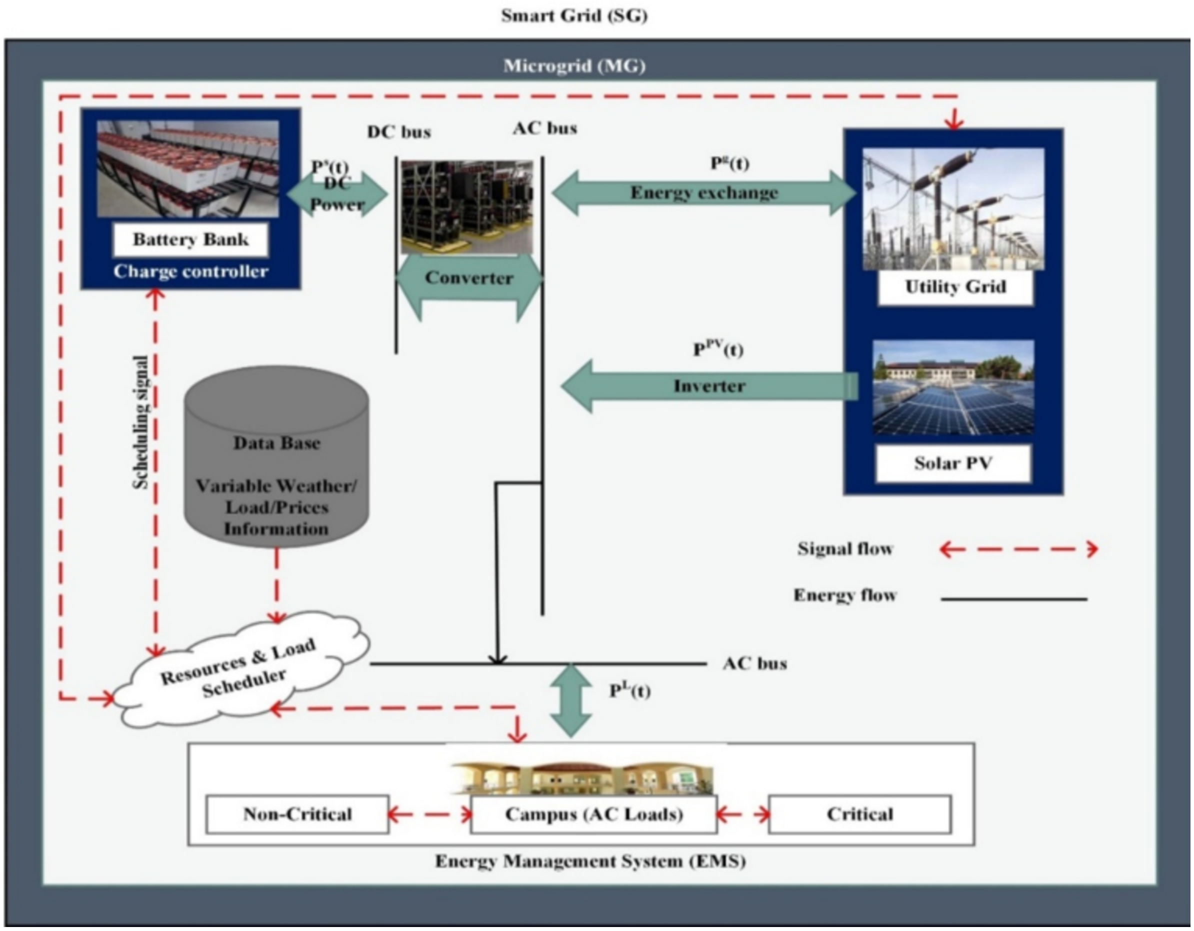

Fig. 2. Proposed system architecture

resource scheduler for optimal energy sharing operation and management, while the basic parameters of the proposed model are given in Table 1.

TABLE 1. TECHNO-ECONOMIC PARAMETERS OF THE PROPOSED MODEL

Parameters	Value	Parameters	Value
Cap^s	2000 kWh	P^g_{min}	-4000 kW
P^g_{max}	4000 kW	$P^{PV}{}_{rated}$	2000 kW
P^s_{max}	800 kW	P^s_{min}	-800kW
SOE_{max}	90%	SOE_{min}	10%
SOE_0	50%	1$	159PKR
J	weighting factor	J	0.5

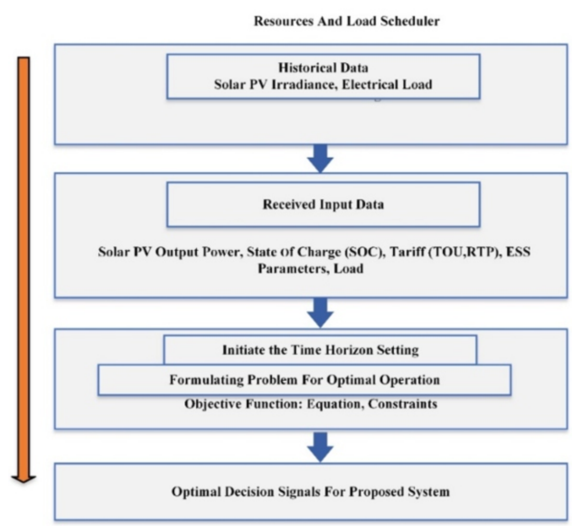

Fig. 3. Proposed scheduling steps for optimal operation

This scheduler received the signals from the database and generates a decision signal. The decision signal optimally operates the PV-storage system according to the price-based variation. Feed-in-tariff (FIT) is an important factor in energy sharing willingness. Here we assumed that the selling and purchasing energy prices are the same, which motivates the prosumers to sells their surplus energy to the national grid. The detailed layered structure of the proposed scheduler is resented in Fig. 3 with its functions.

IV. Problem Formulation of Day Ahead Scheduling

In this section, a mathematical model of day-ahead scheduling is presented. A deterministic model is analyzed for a proposed system with an objective function and related constraints.

A. Objective Function

In order to optimize the proposed model in expression (1), a nonlinear objective function is modeled and solved using quadratic programming.

$$min \sum_{t=1}^{24} \left\{ \begin{matrix} (P^g(t)K_b(t) - P^g(t)Q_s(t)) \\ +J.\left(SOE(t) - SOE(t-1)\right)^2 \end{matrix} \right\} \quad \forall t \tag{1}$$

Exchange power with the grid is expressed as $P^g(t)$ while the unit prices buying and selling rates $K_b(t)$, $Q_s(t)$ while the unit prices buying and selling rates (SOE) shows the battery energy state in percentage concerning its total capacity, while J as a weighting factor for the whole operation. The value of weieting factor is assumed as 0.5, which calculates the degradation cost.

B. Power Balance Equation

The energy exchange with the utility grid is showing in the following Eq. (2).

$$P^g(t) + P^s(t) = P^L(t) + P^C(t) - P^{PV}(t) \tag{2}$$

The output power of storage $P^s(t)$ and the grid should be equal to the sum of all powers in the right-hand side, such as prosumer load, contracted power $P^L(t)$, $P^C(t)$, and the output power of solar PV $P^{PV}(t)$, respectively. The positive and negative storage output power have expressed the discharge and charging of battery system respectively.

C. Prosumer Model Constraints

Prosumer can sell its surplus energy to the utility grid, especially in contracted hours. In emergency cases, grid support mode is also carried out for peak shaving.

$$Net_e = \sum_{t=1}^{t=24} P^g(t) \times t \tag{3}$$

Total selling and buying power are presented by the Eq. (3), whereas the export and import of energy is expressed in Eqs. (4)-(5). The limit on grid power is expressed in (6).

$$Net_{e,exp} = \sum_{t=1}^{t=24} P^g(t) \times t \quad \forall \ P^g(t) > 0 \tag{4}$$

$$Net_{e,imp} = \sum_{t=1}^{t=24} P^g(t) \times t \quad \forall \ P^g(t) < 0 \tag{5}$$

$$P^g_{min} \le P^g(t) \le P^g_{max} \tag{6}$$

As the length of complete transmission lines is short, so considering only active power and neglected the line losses.

D. Constraints of Battery Storage

Energy storage has some upper and lower bounds for smooth operation. As the life of the battery depends on many factors as discussed earlier, its output power also controlled by following constraints (7), and (8) to prevent sudden charging and discharging.

$$\frac{SOE(t-1) - SOE_{max}}{100} Cap^s \le P^s(t) \tag{7}$$

$$P^s(t) \le \frac{SOE(t-1) - SOE_{min}}{100} Cap^s \tag{8}$$

The capacity of storage system Cap^s is given by the manufacturer. Three modes of batteries are usually observed, charging state, discharging state, and standby position.

$$SOE(t) = SOE(t-1) - \frac{100.P^s_t}{Cap^s} \tag{9}$$

$$SOE_{24} = SOE_0 \tag{10}$$

The current state of energy is determined by Eq. (9), while the starting and end of operation are controlled using Eq. (10) for next-day energy participation. Besides other benefits of this assumption, on starting the next day, the prosumer can participate in the energy exchange programs especially in the day-ahead energy management system.

$$-\Delta P^s(t) \le (P^s_t - P^s_{t+1}) \le \Delta P^s(t) \tag{11}$$

In a one-time step, a specific amount of power can charge and discharge from the battery storage system, which expressed in expression (11) as a gradient of power, that restricts the output power of ESS from sudden fully charge and discharge the storage system. Limits are given in expressions (12)-(13), while the output power of solar PV is calculated in Eq. (14).

$$P^s_{min} \le P^s(t) \le P^s_{max} \tag{12}$$

$$SOE_{min} \leq SOE(t) \leq SOE_{max} \quad (13)$$

$$P^{PV}(t) = \eta_{pv}\beta_{pv}I \quad (14)$$

Where $\eta_{pv,j}$ is the efficiency of installed solar PV panels, β_{pv} is the covered rooftop area (m^2) of solar PV panels whereas I is the irradiance of solar (kW/m^2) respectively.

E. Demand Response Constraints

Demand response is the branch of smart grid energy management, that optimally reduces the peak load demand by involving the customers in the electricity market. For system reliability, it is necessary to consider here.

a) Incentive-Based Demand Response (IBDR)

In real-time pricing, the retail prices of electricity vary during the day and effect on the customer consumption cost. In our study, 0% and 20% DR are analyzed using the optimal load curtailment, considering the following Eq. (15). The 20% is the flexible range to shift the load from peak hours to off-peak hours, where the DR(t) is the load pattern after 20% IBDR is applied. From the two assumptions i.e. 0% and 20%, IBDR is not consider when applied the 0% as given in case 1.

$$\Delta DR(t) = \sum_{t=1}^{24} DR(t) \quad (15)$$

$$\Delta DR^{min} \leq \Delta DT(t) \leq \Delta DR^{max} \quad (16)$$

Where the expression (16), handle the load curtailment in the normal range (20%).

b) Price-Based Demand Response

Price based demand response have three types of tariff i.e. i) Time of use ii) Critical peak pricing and iii) Real time pricing. Real time pricing (RTP) is considered in our proposed analysis.

F. Solution Methodology

The proposed system is a single nonlinear objective, with linear constraints. So quadratic programming (QP) is using to solve the model. This technique generates an exact solution with some other features. The general expression of QP is given in the Eq. (17).

$$Minimize\ f(x) = C^T x + \frac{1}{2} * x^T Dx \quad (17)$$

Subject to

$$A_1 x = B \quad (18)$$

$$A_2 x \leq C \quad (19)$$

$$x \geq 0 \quad (20)$$

Where the A_1 and B in Eq. (18) are vectors of different linear equality constraints, while the constants A_2 and C in expression (19) are vectors of inequality constraint. The solver interior-point convex technique is used in MATLAB to solve the proposed system. In the next section, obtained results and discussion are presented.

V. Results & Discussion

Optimal scheduling of reserves is analyzed to utilize the dispatchable and non-dispatchable energy resources. A load of the campus is taken from grid station and designed a model as presented above. The prosumer energy demand which is average load demand of winter season is taken for analysis as shown in Fig. 6. The month of January is taken as a peak consumption month of the winter season. Peak load day from this month is taken as a typical day for analyzing to cover the worst-case scenario. Selecting the worst case for the cost analysis gives careful judgment about cost savings. We are underestimating the savings using the peak load. When the load is less, most of the generated electricity from PV will be exported to the grid resulting in more savings. Demand response programs such as incentive and price based are analyzed. The exponential increasing energy consumption cost of the existing campus is elaborated in Fig. 5.

The case study has been carried out to investigate the real-time pricing (RTP) along with the incentive demand response. The exchange energy with the grid is based on problem formulation presented in expressions (1)-(16).

A. Case Studies

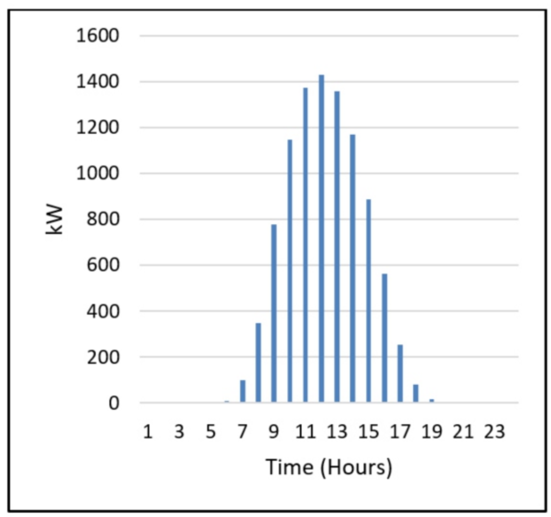

Fig. 4. Solar PV output power

In this case study, two cases are analyzed to determine the effects of different scenarios. The grid outage is also the problem of developing countries like Pakistan, so it also considered here along with a grid support case.

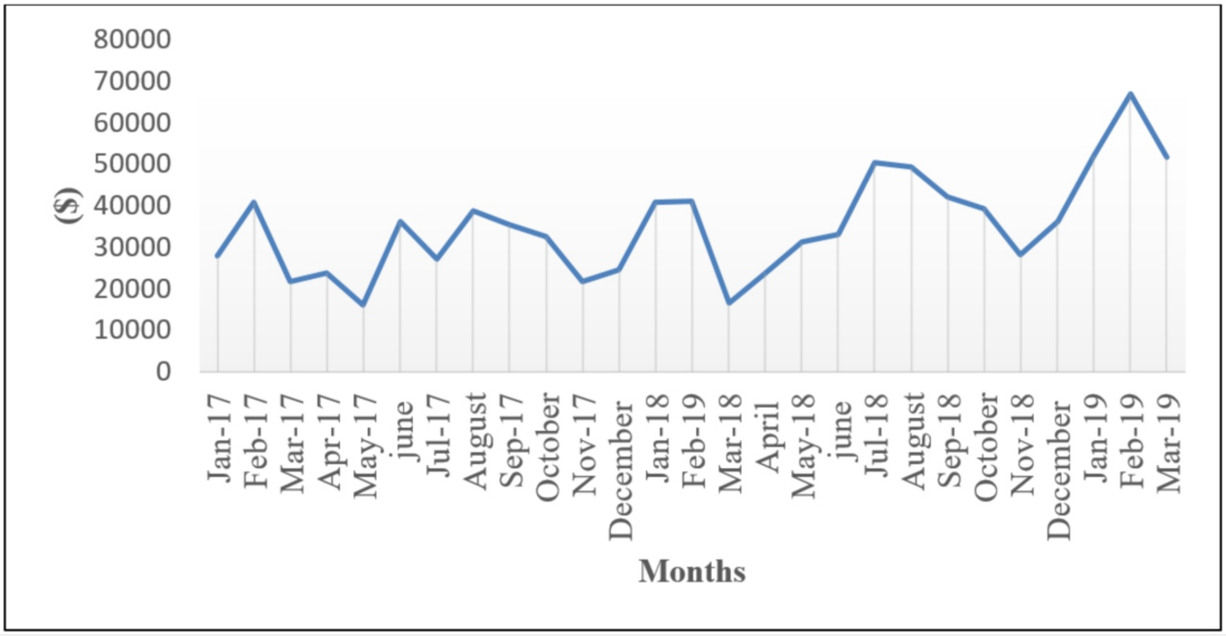

Fig. 5. Monthly energy consumption cost (Bill) of the existing campus

Here we suppose that the energy exchange with the grid at the same unit prices. The solar PV output power and prosumer energy demand are expressed in Fig. 4 and Fig. 6 respectively. Details of all case studies are elaborated in Table 2, which shows the subcases of both strategies. In case 1, price-based DR will be analyzed, while case 2 contains the hybrid DR Analysis.

AC loads are attached and are composed of air conditions, lighting, fans, and PCs. Furthermore, loads are divided into critical and non-critical loads. The critical loads that cannot curtail and are must run loads [33]

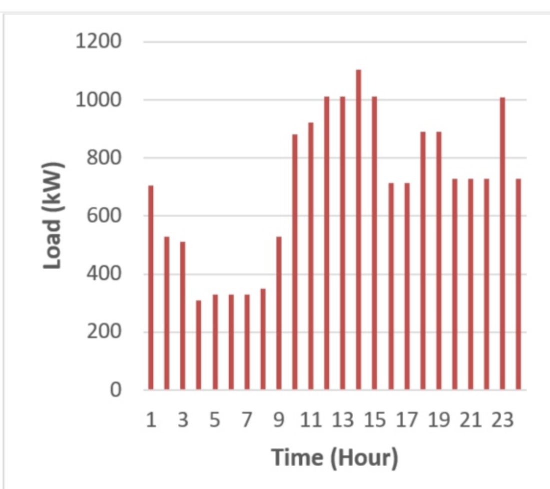

Fig. 6. Prosumer energy demand

A. CASE 1: Price Based Demand Response Analysis

In this case, price-based analysis is carried out to investigate the effects of various scenarios on the operational cost of the prosumer community.

Case 1(a): In this scenario, the energy demand is provided through the grid only. The campus has only one energy source to supply the energy and operate all its loads. The total operational cost of this case is \$2422.2 which will be considered as a base case.

Case 1(b): In this case, DG solar PV and ESS are utilized without any schedule. The result obtained is \$1349.9. The installation and replacement costs are not included in this case.

Case 1(c): In this case, the scheduled outage of the grid is analyzed as shown in Fig. 7. The operational one-day cost is obtained \$1354.3. The predefined outage is compensated by BESS and solar PV. The solar PV is available and smooth the whole system assisted with ESS. While the charging and discharging power of ESS represent by the red line.

Case 1(d): In this case, the consumer received a signal from the grid to support the grid. So, the consumer act as an energy importer to the grid through an aggregator. The operational cost, in this case, is \$1332.4, as shown in Fig.8.

Case 1(e): In this case, available resources are utilized optimally through price-based scheduling. The contracted neighbor of prosumer power is also supplied from 15:00 to 16:00 for two hours, as shown in Fig. 9. The total cost reduced about 65.3 % as compared to the base case as expressed in Table. 3.

Case 1(f): In this case the storage degradation cost is ignored and observed the cost reduction as compared to the previous case 1(e). The cost reduced from \$840 to \$754. By ignoring the storage degradation cost, it effects the life of storage system.

TABLE 2. PROFILE OF ALL CASE STUDIES

Case 1 Price Based Demand Response Analysis		Case 2 Hybrid Demand Response Analysis	
Case 1(a)	Grid available mode	Case 2 (a)	Grid available mode
Case 1(b)	Operational cost without scheduling	Case 2(b)	Operational cost without scheduling
Case 1(c)	Grid outage mode	Case 2(c)	Grid outage mode
Case 1(d)	Grid support mode	Case 2(d)	Grid support mode
Case 1(e)	Proposed scheduling mode considering storage degradation cost	Case 2(e)	Proposed scheduling mode considering storage degradation cost
Case 1(f)	Proposed Scheduling mode ignored storage degradation cost	Case 2(f)	Proposed Scheduling mode ignored storage degradation cost

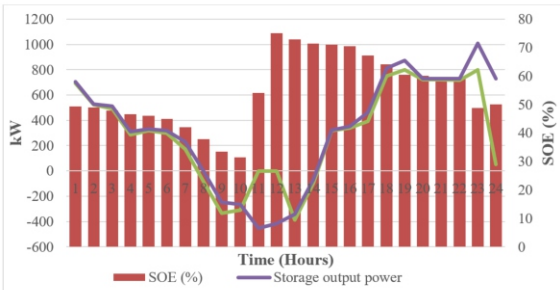

Fig. 7. Case 1(c): Grid outage for two hours

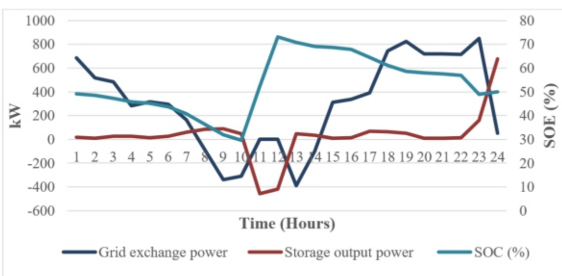

Fig. 8 Case 1(d): Grid support case

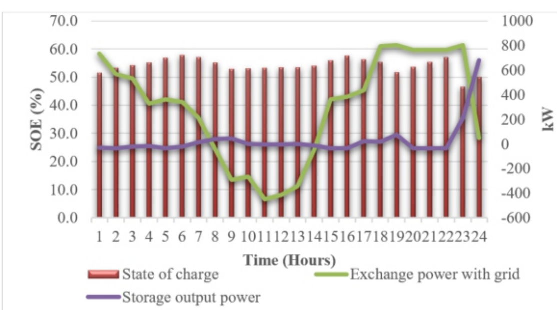

Fig. 9 Case 1(e): Proposed scheduling mode

B. CASE 2: Hybrid Demand Response Analysis

In this case, consumer shifts its load to the off-peak hours and incentivized from the national grid. This case is the combination of incentive and price-based demand response, with a 20% load curtailment during the high-cost hours. The real time pricing and load pattrn of IBDR are given in Fig. 10, Fig. 11 respectively.

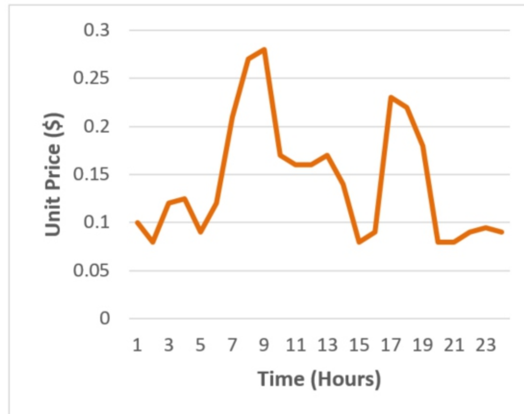

Fig. 10 Real time pricing

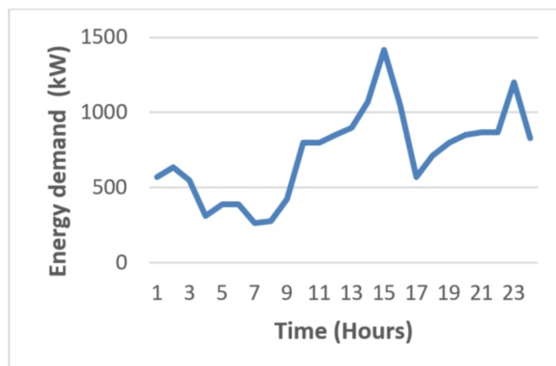

Fig. 11 Load pattern (20% IBDR)

Case 2(a): In the base case, the only grid is available as an energy source and witnessed a result of $2290.5. The difference between the above case 1(a) is significant and reduced from 2442.6 to 2290.5 which is 6%.

Case 2(b): In this case, the total operational cost is reduced to $1017.8 as compared to case 2(a) due to the solar PV and ESS. The output power of solar PV and ESS utilized randomly without considering any constraints schedule.

Case 2(c): In grid support mode cost reduced from $1332 to $809.2. The storage output power supports the grid from 10:00 to 11:00 for two hours. The state of energy shifts in discharging mode until the request completes.

TABLE 3. RESULTS OF BOTH CASES

Cases	(a)	(b)	(c)	(d)	(e)	(f)	Saving recorded ($)	Percentage benefits (%)	GHG (Carbon) Reduction (kg/day)		
									Total load (kWh/day)	Energy generated by solar PV (kWh/day)	GHG Reduction Observed (kg/day)
Case 1	2422.6	1349.9	1354.3	1332.4	840.3	754.25	1582.2	65.3	16996	9515	5709
Case 2	2290.5	1017.8	1137.5	809.2	673.2	594.23	1617.2	70.6			

TABLE 4. COMPARISON OF PROPOSED METHOD WITH EXISTING WORK

Ref.	Year	Technique	Application	Remarks	Savings
[22]	2018	MILP	Campus μG	Peak demand, ESS, degradation cost	5.32%
[23]	2019	LP	Residential μG	Grid outage	16%
[24]	2018	NA and Conic Technique	IEEE 15-Bus system	Financial feasibility	3.3%
[25]	2017	BBSA	IEEE 14 Bus system	Power losses, reliability	18.26%
[26]	2018	MILP	Residential level	Frequency regulation	7%
Proposed Model	2020	QP	Campus μG	DR, self-consumption, ESS degradation	65%, 70%

Case 2(d): In grid outage that is due to the energy shortfall, scheduled grid outage occurs at the same time any day from 10:00 to 11:00. The cost reduced from \$1354.3 to \$1137.5, due to load curtailment during these hours.

Case 2(e): In this case, the scheduler considered the available resources and loads and generate a controlled signal for optimal operation. In this case, significant cost reduced from \$2290.5 to \$673.2, which is about 70.6% as compared to the base case. Similarly, the whole process with defined parameters is shown in Fig. 12 and the results presented in Table 3.

Case 2(f): In this case, the storage degradation cost not consider to observe the effect on operational cost. The cost reduced from \$673 to \$594.

C. DISCUSSION

Form the above analysis, it is deduced that, both price based, and incentive-based demand response strategies are beneficial for the customer in the electricity market. The analysis is carried out for the Pakistani environment, which is a developing country. The renewable integration with the existing grid with optimally scheduling the available resources are analyzed and found a significant reduction in scheduled utilization. So, a microgrid scheduler is necessary for smooth and economical operation.

While the existing work is compared with the literature in Table 4. The effect of solar PV and ESS in the proposed hybrid DR based scheduling are calculated and results are given in the end columns of Table 3. More than five thousand kg/day of carbon emission has been decreased by proposed scheduling.

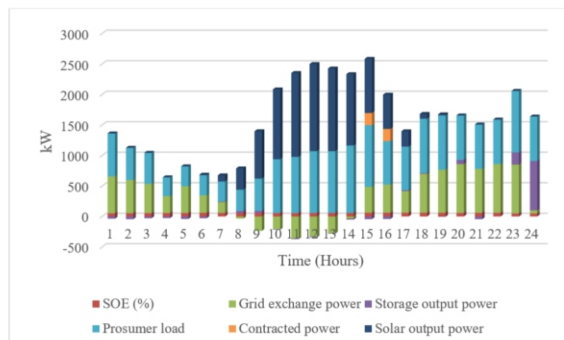

Fig. 12. Case 2 (e): Proposed scheduling mode

VI. CONCLUSION

Institutional campuses are the major energy consumers liable to pay high energy costs to utility companies. This work suggests the installation of onsite DGs and ESS with their optimal scheduling through EMS in an energy exchange environment with the grid network. The effects of ESS degradation and DR schemes are also considered in the proposed EMS model. As ESS behavior is nonlinear, therefore a nonlinear model is solved using quadratic programming in MATLAB. The prosumer also contracts some fixed power with the utility and neighbor customer for a specific duration. The proposed EMS not only reduces the energy consumption cost by extending storage life but also ensures grid stability through DR schemes. Two types of DR schemes have been analyzed: (i) Price-based DR using RTP (ii) Hybrid of Price-based and Incentive-based DR.

Results reveal that operational cost and peak load on the grid are more reduced by applying EMS in hybrid DR scheme as compared to its application in Price-based DR using RTP and observed the savings 65.3% , 70.6% in Case 01 and case 02 respectively. Furthermore, the islanded mode of a microgrid is analyzed by considering the grid outage. It is observed that the microgrid can operate its critical loads on ESS for a short-term basis until the grid is restored. The judicious choice of a critical load is left on the energy manager of the campus microgrid. Future extensions of the work can consider different types of DGs like wind, biomass, fuel cell, etc. along with mobile ESSs in the form of electric vehicles (EVs) at the parking area of the campus. Random presence of grid, DGs, EV arrival and departure, SOCs of mobile ESSs, etc. can also be incorporated using stochastic approaches in the future.

REFERENCES

[1] F. Khavari, A. Badri, and A. Zangeneh, "Energy management in multi-microgrids considering point of common coupling constraint," *Int. J. Electr. Power Energy Syst.*, vol. 115, no. June 2018, p. 105465, 2020.

[2] F. Xu, W. Wu, F. Zhao, Y. Zhou, Y. Wang, and Wu, "A micro-market module design for university demand-side management using self-crossover genetic algorithms," *Appl. Energy*, vol. 252, no. January, p. 113456, 2019.

[3] J. Shen, C. Jiang, Y. Liu, and X. Wang, "A Microgrid Energy Management System and Risk Management under an Electricity Market Environment," *IEEE Access*, vol. 4, pp. 2349–2356, 2016.

[4] H. A. Muqeet, A. Ahmad, I. A. Sajjad, and J. M. G. Ali, Saqib, "Optimal Operation of Enegy Storage System for a Prosumer Microgrid Considering Economical and Environmental Effects," in *International Symposium on Recent Advance on Electrical Engineering*, 2019.

[5] L. Kasprzyk, "Modelling and analysis of dynamic states of the lead-acid batteries in electric vehicles," *Eksploat. i Niezawodn. - Maint. Reliab.*, vol. 19, no. 2, pp. 229–236, 2017.

[6] Y. Li, Z. Yang, G. Li, D. Zhao, and W. Tian, "Optimal Scheduling of an Isolated Microgrid with Battery Storage Considering Load and Renewable Generation Uncertainties," *IEEE Trans. Ind. Electron.*, vol. 0046, no. c, 2018.

[7] T. Weitzel and C. H. Glock, "Scheduling a storage-augmented discrete production facility under incentive-based demand response," *Int. J. Prod. Res.*, vol. 57, no. 1, pp. 250–270, 2019.

[8] C. Bordin, H. O. Anuta, A. Crossland, I. L. Gutierrez, C. J. Dent, and D. Vigo, "A linear programming approach for battery degradation analysis and optimization in offgrid power systems with solar energy integration," *Renew. Energy*, vol. 101, pp. 417–430, 2017.

[9] S. Cui, Y. W. Wang, J. W. Xiao, and N. Liu, "A Two-Stage Robust Energy Sharing Management for Prosumer Microgrid," *IEEE Trans. Ind. Informatics*, vol. 15, no. 5, pp. 2741–2752, 2019.

[10] M. Nasir, S. Iqbal, and H. A. Khan, "Optimal Planning and Design of Low-Voltage Low-Power Solar DC Microgrids," *IEEE Trans. Power Syst.*, vol. 33, no. 3, pp. 2919–2928, 2018.

[11] N. Arshad and U. Ali, "An analysis of the effects of residential uninterpretable power supply systems on Pakistan's power sector," *Energy Sustain. Dev.*, vol. 36, pp. 16–21, 2017.

[12] A. Ahmad, M. Asghar, S. Abdul, and R. Kashif, "Impact of wide-spread use of uninterruptible power supplies on Pakistan ' s power system," *Energy Policy*, vol. 98, pp. 629–636, 2016.

[13] S. Bracco, F. Delfino, P. Laiolo, and M. Rossi, "The Smart City Energy infrastructures at the Savona Campus of the University of Genoa," *AEIT 2016 - Int. Annu. Conf. Sustain. Dev. Mediterr. Area, Energy ICT Networks Futur.*, 2016.

[14] F. Ahmad and M. S. Alam, "Optimal Sizing and Analysis of Solar PV, Wind, and Energy Storage Hybrid System for Campus Microgrid," *Smart Sci.*, vol. 6, no. 2, pp. 150–157, 2018.

[15] B.-C. Jeong, D.-H. Shin, J.-B. Im, J.-Y. Park, and Y.-J. Kim, "Implementation of Optimal Two-Stage Scheduling of Energy Storage System Based on Big-Data-Driven Forecasting—An Actual Case Study in a Campus Microgrid," *Energies*, vol. 12, no. 6, p. 1124, 2019.

[16] T. J. Soleja, M. F. Siddiqui, M. Kashan, and A. Waseem, "Economic feasibility analysis of on-grid PV system without battery storage for a commercial building in Karachi, Pakistan," *Proc. 2018 5th Int. Symp. Environ. Energies Appl. EFEA 2018*, pp. 1–4, 2019.

[17] N. Liu, M. Cheng, X. Yu, J. Zhong, and J. Lei, "Energy-Sharing Provider for PV Prosumer Clusters: A Hybrid Approach Using Stochastic Programming and Stackelberg Game," *IEEE Trans. Ind. Electron.*, vol. 65, no. 8, pp. 6740–6750, 2018.

[18] M. Husein and I. Y. Chung, "Optimal design and financial feasibility of a university campus microgrid considering renewable energy incentives," *Appl. Energy*, vol. 225, no. April, pp. 273–289, 2018.

[19] E. Barbour and M. C. González, "Projecting battery adoption in the prosumer era," *Appl. Energy*, vol. 215, no. January, pp. 356–370, 2018.

[20] C. D. Rodriguez-Gallegos, O. Gandhi, D. Yang, M. S. Alvarez-Alvarado, and Zhang, "A Siting and Sizing Optimization Approach for

PV-Battery-Diesel Hybrid Systems," *IEEE Trans. Ind. Appl.*, vol. 54, no. 3, pp. 2637–2645, 2018.

[21] N. Liu and J. Wang, "applied sciences Energy Sharing for Interconnected Microgrids with a Battery Storage System and Renewable Energy Sources Based on the Alternating Direction Method of Multipliers," 2018.

[22] H. C. Gao, J. H. Choi, S. Y. Yun, H. J. Lee, and S. J. Ahn, "Optimal scheduling and real-time control schemes of battery energy storage system for microgrids considering contract demand and forecast uncertainty," *Energies*, vol. 11, no. 6, pp. 1–15, 2018.

[23] M. Nasir, H. A. Khan, I. Khan, N. ul Hassan, and N. A. Zaffar, "Grid load reduction through optimized PV power utilization in intermittent grids using a low-cost hardware platform," *Energies*, vol. 12, no. 9, 2019.

[24] Y. Zheng *et al.*, "Optimal Operation of Battery Energy Storage System Considering Distribution System Uncertainty," *IEEE Trans. Sustain. Energy*, vol. 9, no. 3, pp. 1051–1060, 2018.

[25] M. G. M. Abdolrasol, M. A. Hannan, A. Mohamed, U. A. U. Amiruldin, I. Z. Abidin, and M. N. Uddin, "An optimal scheduling controller for virtual power plant and microgrid integration using binary backtracking search algorithm," *2017 IEEE Ind. Appl. Soc. Annu. Meet. IAS 2017*, vol. 2017-Janua, no. 3, pp. 1–8, 2017.

[26] M. Vahedipour-Dahraie, H. Rashidizadeh-Kermani, A. Anvari-Moghaddam, and J. M. Guerrero, "Stochastic Frequency-Security Constrained Scheduling of a Microgrid Considering Price-Driven Demand Response," *SPEEDAM 2018 - Proc. Int. Symp. Power Electron. Electr. Drives, Autom. Motion*, pp. 716–721, 2018.

[27] "Reports on Demand Response & Advanced Metering," *FERC*, 2019. [Online]. Available: https://www.ferc.gov/industries/electric/indus-act/demand-response/dem-res-adv-metering.asp. [Accessed: 22-Aug-2019].

[28] X. Yan, Y. Ozturk, Z. Hu, and Y. Song, "A review on price-driven residential demand response," *Renew. Sustain. Energy Rev.*, vol. 96, no. August, pp. 411–419, 2018.

[29] V. Bui, S. Member, A. Hussain, and S. Member, "A Multiagent-Based Hierarchical Energy Management Strategy for Multi-Microgrids Considering Adjustable Power and Demand Response," *IEEE Trans. Smart Grid*, vol. 9, no. 2, pp. 1323–1333, 2018.

[30] M. Nasir, H. A. Khan, A. Hussain, L. Mateen, and N. A. Zaffar, "Solar PV-based scalable DC microgrid for rural electrification in developing regions," *IEEE Trans. Sustain. Energy*, vol. 9, no. 1, pp. 390–399, 2018.

[31] M. Kamran, "Current status and future success of renewable energy in Pakistan," *Renew. Sustain. Energy Rev.*, vol. 82, no. October 2017, pp. 609–617, 2018.

[32] A. K. Shukla, K. Sudhakar, and P. Baredar, "Resource-Efficient Technologies Renewable energy resources in South Asian countries : Challenges , policy and recommendations ☆," *Resour. Technol.*, vol. 3, no. 3, pp. 342–346, 2017.

[33] A. Paudel, K. Chaudhari, C. Long, and H. B. Gooi, "Peer-to-peer energy trading in a prosumer-based community microgrid: A game-theoretic model," *IEEE Trans. Ind. Electron.*, vol. 66, no. 8, pp. 6087–6097, 2019.