Fog as-a-Power Economy Sharing Service

Rasool Bukhsh [1, *], Nadeem Javaid[2,*], Asma Rafique[3, †]
*COMSATS University, Islamabad 44000, Pakistan
† Department of Computer Engineering, School of Sciences, Karabuk University, Turkey
Email:Rasool Bukhsh [1](rasoolbax.rb@gmail.com), Asma Rafique [3](asmamscs@gmail.com)
[2]Correspondence: www.njavaid.com, nadeemjavaidqau@gmail.com

***Abstract*—Smart grid technologies ensures reliability, availability and efficiency of energy which contribute in economic and environmental benefits. On other hand, communities have smart homes with private energy backups however, unification of these backups can beneficial for the community. A community consists of certain number of smart homes (SH) which have their own battery based energy storage system. In this paper, 12 smart communities are connected with 12 fog computing environment for power economy sharing within the community. Each community has 10 smart homes with battery bases energy storage system. These communities are evaluated for load and cost profiles with three scenarios; SHs without storage system, SHs with storage system for individual SH requirements and SHs with unified energy storage system (unified-ESS). Unified-ESS is formed with the help of home and fog based agents. Simulations show that, unfied-ESS is efficient to have reduced cost for SHs within the community.**

***Index Terms*—Battery based Energy Storage System (BESS), unified Energy Storage System (unified-ESS), Economy sharing, Smart community**

I. Introduction

In addition to complex and expensive process of electricity production environmental pollution is the serious matter for ecological and geopolitical concerns. Increased demand increases the power production which causes more carbon emission in the environment. Two parallel strategies can very helpful for reduction and eradication of such pollution. First, optimized utilization of power such that peak of demand is shifted. Second, Use renewable energy source for power production. Renewable energy sources are expensive and difficult to maintain.

Production or supply side companies are encouraged to use renewable energy resources instead of conventional fossil fuel based power generation [1]. Moreover, 65% of produced power is wasted during generation, transmission and distribution [2] because of unidirectional communication e.g. from utility to consumer. Bidirectional communication prevails power saving and reduced bills for consumers. Encouraging renewable energy source for production and educating consumers for efficient power consumption help to efficient power production and utilization.

However, optimization techniques compromise the user satisfaction, for the reason users prefer personal micro-grids to utilize during on-peak hours to avoid high bills and over loading on supply side is avoided. Micro-grids with renewable energy sources are intermittent in nature, expensive and difficult for maintenance. Energy Storage System (ESS) is a rational solution to cope the challenges. ESSs are cheaper and require less maintenance compared to renewable energy sources.

During the course of last few decades, energy storage companies are developing systems for dynamic requirements of consumers however, battery based ESS (BESS) provides resilient and affordable power infrastructure for residential users [3]. BESS is flexible to integrate with existing power setup with high reliability. BESS provides promising solution to avoid peaks and minimize expensive power consumption from utilities [4] - [6]. BESS in a SH can be charged during low pricing (off-peak) hours and utilize during high pricing (on-peak) hours. With the help of demand side management BESS reduces significant electricity bills [7]- [9]. If maximum residential consumers tend to use BESS it can help to reduce power generation and save the environment.

However, every consumer has different consumption requirements which can shift the power consumption from BESS to utility while, a neighbor can have excessive storage specially during on-peak hours. This excessive power can be utilized for consumer to avoid power consumption from utility. The challenge is to develop a unified-ESS in which every BESS of a community is utilized within the community and avoid utility power consumption at maximum. In this paper, fog-cloud based unified-ESS have been proposed for 12 communities in which, fog serve as “power economy sharing”.

In next section, Related Work is discussed. In section II proposed System Model, section IV Mapping of Multiple Agents, section V Results and Discussion and in last section Conclusion is discussed.

II. Related Work

In [10], authors conducted a survey to study BESS is a complete solution. Case studies are discussed in to prove that BESS are better than renewable energy sources due to portability, heavy maintenance and intermittent nature. BESS are suitable for commercial appliances. Future research required to overcome technology maturity, complexity and economical problems. Authors in [11], electric vehicles based optimal charging of batteries with energy transportation.

Research in BESS is immature and need special attention due to potential to replace renewable energy resources in some applications, portability and complete solution tool for other cases. The unification of multiple batteries makes it flexible to scale energy according to requirements. Authors in [9], proposed unified-BESS for a community to share the benefits. No-profit-no-loss based sharing of battery based ESS convinced the consumers to avoid utility power and rely on unified-ESS.

Authors in [9], pointed limitation of the work which are resolvable. Research is expendable for wide scale communities. There is need to process multiple requests on different level to tackle the number of communities with SHs. One of the hot solution is to put BESS on fog or cloud computing environment. Many related solution have been proposed with fog, cloud or fog-cloud based computing environment. Authors in [12], proposed cloud based smart grid application with secure data processing and physical control from the remote location. Proposed scheme is secure and robust for smart grid.

Cloud based information infrastructure for next generation smart grid is proposed in [13]. Huge data from maximum population is processed on cloud based physical system. Proposed system is capable to provide maximum benefits using visualization. However, cloud and fog computing environment offer their sub-services e.g. as-a-storage, as-a-infrastructure and as-a-software etc. Authors in [14], experimented and implemented various application for city aware issues using fog computing. A city aware applications produce huge amount data that should be responded in near-real time. In [15], free market concept is proposed using fog computing environment.

Fog and cloud computing environments provide efficient, robust and secure processing for huge data. These computing environments are also feasible for energy management in smart grid. The proposed research of [9] is also scalable using fog and cloud computing. In this paper, system model is proposed with fog and cloud based computing environments to facilitate a community with their own resources. BESS of SHs in a community is unified and shared economically for mutual benefits.

III. System Model

There are three levels in proposed system model Fig.1. On top level there is a cloud which communicates with utility and n number of fogs. Cloud receives current pricing signals from utility and shares among fog nodes. Cloud permanently stores necessary data received from fog, in this paper, cloud-as-a-storage service is used. The stored data is processed and analyzed for future use like prediction and statistical analysis for forthcoming projects. There are n number of fogs computing on middle level which communicate with respective communities. Fogs are brains for energy distribution within the community and used a “Fog -as-a-Power Economy Service”. For the purpose, fogs have Power Distribution Agents (PDAs) to ensure smooth power supply. Energy Storage Agent (ESA) serves between the fog and the community. The community consist of 10 Smart Homes (SHs), each has own Batter based Energy Storage System (BESS). Home Agent (HA) resides in Smart Meter (SM) of SH and calculates the power consumption from utility, BESS and updates the ESA.

Three scenarios are implemented; $i)$ SHs of communities without BESS, $ii)$ SHs of communities with stand alone BESS, and $iii)$ SHs of communities with shared BESS.

A. Scenario-1

There are n SHs in a community which consume power from smart grid at some tariff. The electricity tariff has two major stages; price on on-peak “P^on’ hours and price on off-peak “P^off” hours as illustrated in Fig.**??**. SHs without ESS buy electricity from utility however, reduced cost is attained when appliances load of SHs are shifted from on-peak to off-peak hours. There are intelligent algorithms which assist to shift loads from on-peak hours to off-peak hours. However, whole load can not be avoided from on-peak hours. A SH h in a community x with m number of appliances has power consumption for 24 hours. The total power consumption T_{Pc_h} is the sum of power consumption in on-peak Pc^t_{on} and off-peak hours Pc^t_{off},

$$T_{Pc_h} = Pc^t_{on} + Pc^t_{off}. \tag{1}$$

Power consumption of all n SH is calculated;

$$PC_n = \sum_{1}^{n} T_{PC}. \tag{2}$$

Power consumption pattern of a SH differs from other as well as from day to day hence, average of collective consumption of n SH in a community is calculated in Eq.3

$$AvgPC_n = \frac{\sum_1^n T_{PC}}{n}. \tag{3}$$

The cost of power consumption C_{PC} in given time is the product of power consumption PC_t and tariff rate EP_t at given time t, as shown in Eq. 4,

$$C_{PC} = PC_t \times EP_t. \tag{4}$$

B. Scenario-2

In this scenario, SHs depends on their own BESS however, if BESS falls short then utility power is consumed at the rates of utility at that time. Appliances of the SHs are scheduled however used according to user’s own will when shifted to BESS. BESS charges the batteries using utility power hence, when power is consumed from BESS it carries the cost. A SH h which consumes power from BESS and utility in a day then total cost is the sum of power consumption cost from BESS and utility as shown in Eq. 5,

$$C_{total} = \sum(PC^t_{BESS} \times EP^t_{BESS}) + \sum(PC^t_{Ut.} \times EP^t_{Ut.}),. \tag{5}$$

Where PC^t_{BESS} is power consumed from BESS and EP^t_{BESS} is electricity price of BESS in given time t. Similarly, $PC^t_{Ut.}$ is power consumption from utility and $EP^t_{Ut.}$ is the electricity price for given time t. Power consumption of utility during on-peak hours increases the overall cost rather decreasing. User comfort is achieved by 100% however the cost is compromised when utility power is consumed.

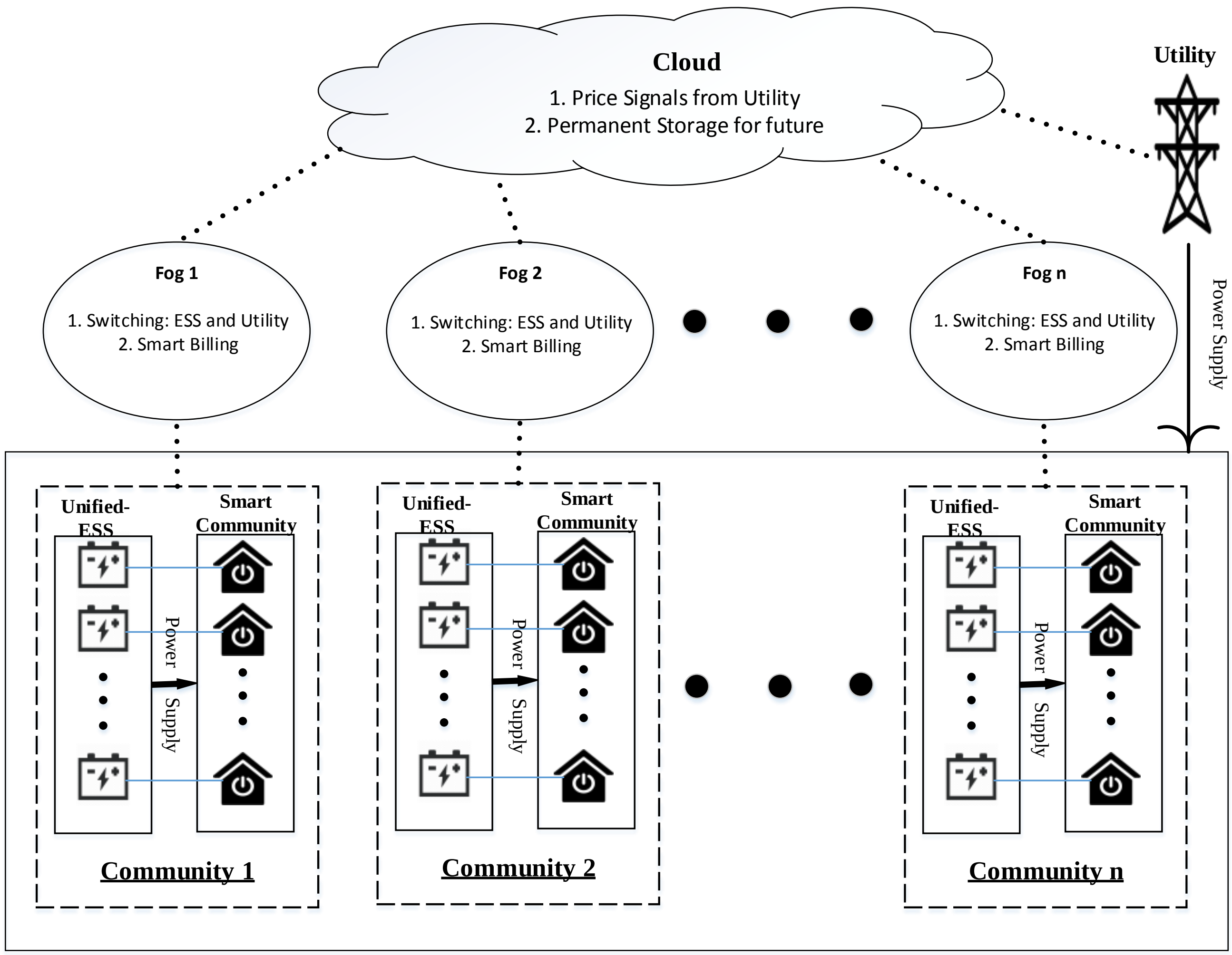

Fig. 1. System Model

C. Scenario-3

In scenario-2, each home has own BESS however, when BESS falls short SHs have to buy power from utility which is costly. If the BESS of a SH h falls short and SH g in the same community has more storage and can be shared with h. In this scenario, BESS of whole community is unified and shared among other SHs if they required rather buying expensive power from the utility. Suppose, n SHs agree to share their BESS for economical benefits. The appliances are scheduled according to utility pricing signals however, when user want to operate appliances with his own will it operates on unified ESS. The pricing of unified-ESS is lesser than utility.

Each SH has Home Agent (HA) which keeps the calculation of storage capacity of BESS and requirement of SH. HAs of all SHs communicate with ESA where decision is made for specific SH to consume power from utility or from unified-ESS. The BESS of SHs store energy from utility during off-peak hours and excessive energy is not sold back rather used within the community. Hence, when user disturbs the scheduled appliances power consumption starts from unified-ESS which has reduced cost compared to utility and purpose is to avoid utility power consumption at maximum. HA, PDA and ESA perform to fulfill the purpose.

Every SH has its own behavior of power consumption with different number of appliances of different power ratings. For the scenario, following assumptions are made,

- Selection of BESS is made on the bases of demand of that SH.
- Every SH has unique power consumption pattern with number of appliances and their power ratings.
- Different investments are made on respective BESSs.
- There is fixed cost for all BESS.
- PDA makes decision for SH power consumption from utility or unified-ESS.

Objective function for daily cost of n SHs of community is shown in Eq. 6,

$$Cost_n = \sum_{i=1}^{n} (PC_{ESS}^{i} \times EP_{ESS}^{t} + PC_{ut.}^{i} \times EP_{ut.}^{t}). \quad (6)$$

Where PC_{ESS} is power consumption of SH i from unified-ESS and EP_{ESS} is electricity price. $PC_{ut.}$ and $EP_{ut.}$ are power consumption and electricity price of utility. Product of power consumption and electricity price of that time makes the cost of consumption.

Charging of ESS is performed during off-peak P_{off} hours and discharged during on-peak P_on hours. PDA generates signals for SH to shift from personal BESS to unified-ESS when storage left only 20% and use it until unified-ESS reaches lowest storage (20%). When unified-ESS also reaches lowest level PDA shifts SH to utility. Lowest level or "0-level" is considered when storage left with 20% and 10% is level -5 and storage with actual "0" storage is level -10.

Every user of SH invest in BESS according to own requirements. So, BESS of different storage capacities S are installed while, ESA forms unified-ESS of these BESSs with storage $S_n = (S_1 + S_2 + S_3, ...S_n)$ and charging cost of unified-ESS $(nBESSs)$ is CC_n. unified-ESS is charged during P_off, as explained earlier. If SH h demands power after consuming S_h ESA requests PDA to facilitate h from unified-ESS or from utility, depending on storage of unified-ESS. Power offered from unified-ESS has maximum price equal to P_off.

IV. Mapping of Multiple Agents

Multi-agent system is developed in adhering to system model, presented in Fig.1. Agents are standard intelligent programs which keeps the system run, maintained and self-correct. In proposed system modle, agents resides in every level for smooth operation and inter-communication. SHs with BESS are have Home Agents (HAs) which performs to store battery based energy storage during P_off and utilize during P_on. SAs resides in lowest level of system model and communicate with their upper level agents; ESA and PDA. ESA and PDA resides on fog computing. PDA maintains the smart metering between a community and fog and ensures the smooth power supply to the community. ESA communicate with BESS of SHs and forms unified-ESS with the help of HAs. It also entertain requests of SHs and responds back with desired signals e.g. shift from BESS to unified-ESS or utility. It also, communicate with PDA for the provision of smooth power supply on the requests of SHs. PDA and ESA utilize the information of utiity with the help of Cloud Agent (CA). CA carries information of utility Real Time Pricing (RTP) and request for permanent storage.

V. Results and Discussion

A smart community consists of smart homes in neighborhood which communicate with each other to attain certain mutual benefits. In the paper, 12 smart communities; each consists of 10 smart homes are considered. Each SH has different number of appliances with different power ratings. The operations of appliances are scheduled to optimize the power consumption for cost efficiency. GA, EHO and hybrid of both called EGO are implemented for load optimization in every SH. Power Distribution Agent (PDA) in fog decides either SH consume power from utility or unified ESS on the bases of information of utility from cloud and Energy Storage Agent (ESA). ESA shares the information of community with fog and respond back with decision signals. Home Agent (HA) is a local program that builds communication between home and its Battery based Energy Storage System (BESS). The proposed system model is implemented with three scenarios for each community. In first scenario, SHs do not have BESS and appliances are scheduled with scheduling algorithms for optimized power consumption. In second scenario, SHs have their own BESS and do not participate in power economy sharing, however, appliances are scheduled. In third scenario, SHs participate in power economy sharing and form unified ESS. Appliances are scheduled according to utility pricing signal however, user operates appliances according to his will when unified ESS is used. Stored energy is used when utility have peak pricing time.

In first scenario, SHs of a community do not have BESS hence, fully dependent on utility. In order to reduce the cost, appliances of SHs are scheduled for power consumption. GA, EHO and EGO scheduling algorithms are implemented however, user comfort is compromised with the scheduling. Appliance are schedule using GA, EHO and EGO algorithms which compromise the user satisfaction. In the second scenario, SHs use their own BESS without scheduling the appliances hence, has maximum user satisfaction. BESS is preferred to use when it is fully charged. On discharge of BESS SHs shift to utility for power consumption. The time length of BESS usage depends on the demands of SHs and storage capacity. In third scenario, SHs of communities agree to share their BESS on no-profit-no-loss bases. Main purpose is to avoid utility power consumption during high-peak hours and during off-peak hours BESS and SHs use utility power for storage and consumption, respectively. Appliances are scheduled according to utility pricing signal. Unified-ESS is utilized during utility on-peak hours. In Fig.2 show, power consumption profile for aforementioned scenarios using GA, EHO and GEO.

The total load of each SH remained same however, optimized shifting of appliances load in a day varied the consumption pattern. In first scenario, appliances of SHs are scheduled however, only utility power is consumed. In Fig.2 power consumption of this scenario is represented with $-+$. In second and third scenarios SH appliance are scheduled as well as they shift to BESS and unified-ESS (in figure represented as UESS) when required. This make them share the profile of power consumption however, they have different cost profiles and represented with $-o$ and $-*$.

The Fig.3 show the cost profile of 120 homes of 12 communities. Cost of SHs with first, second and third scenarios are represented with $-+$, $-*$ and $-o$. Cost with GA, EHO and EGO are closer for standalone or individualized SH with BESS. This behavior is due to closely related behavior

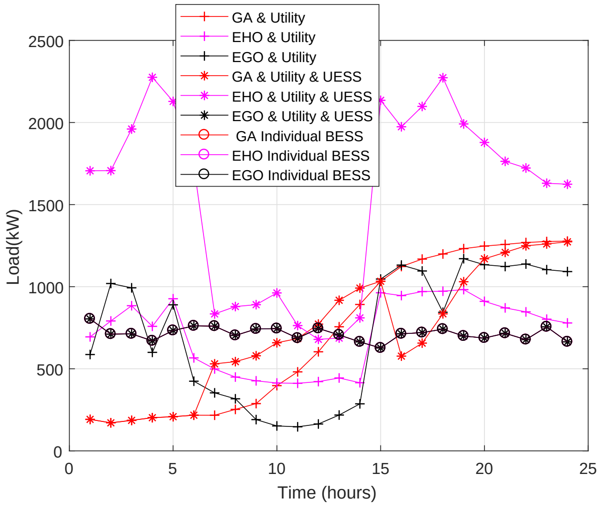

Fig. 2. Load profile of 12 communities for 24 hours

of algorithms due to randomness. However, EGO reduced maximum cost by efficient optimizing the loads.

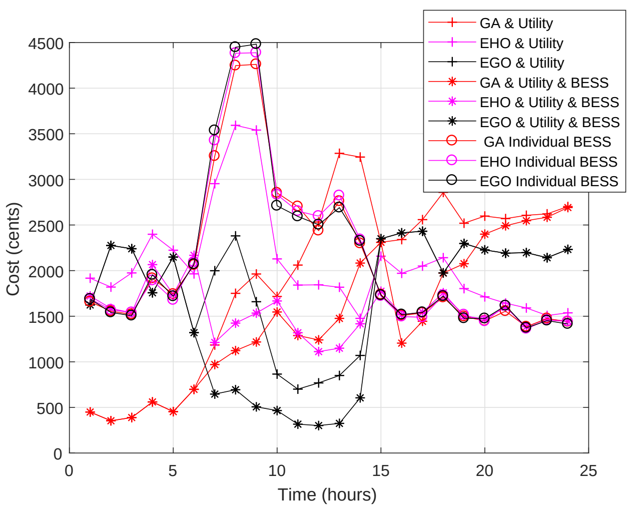

Fig. 3. Cost profile of 12 communities for 24 hours

VI. Conclusion

The proposed system extends the facilities of personal ESS for a community using economy sharing concept. Twelve smart communities are connected with fog computing to share energy information using HAs. ESAs and PDAs at fog computing make decision for any SH in the community weather, power is entertained from utility or unified-ESS of the community. Each home schedules the appliances using GA, EHO and EGO techniques. In first scenario, SHs without BESS and unified-ESS, schedule appliances and use utility electricity power. In second scenario, SHs with personal BESS and without unified-ESS, schedule SHs appliances and used utility power too have highest cost. In third scenario, SHs relied mostly on unified-ESS and avoided utility power. unified-ESS has lesser cost than utility which caused least cost for the communities.

References

[1] Aslam, Sheraz, Nadeem Javaid, Farman Ali Khan, Atif Alamri, Ahmad Almogren, and Wadood Abdul. "Towards Efficient Energy Management and Power Trading in a Residential Area via Integrating a Grid-Connected Microgrid." Sustainability 10, no. 4 (2018): 1245.
[2] Evangelisti, S., P. Lettieri, R. Clift, and Domenico Borello. "Distributed generation by energy from waste technology: a life cycle perspective." Process Safety and Environmental Protection 93 (2015): 161-172.
[3] Mahmood, Danish, Nadeem Javaid, Imran Ahmed, Nabil Alrajeh, Iftikhar Azim Niaz, and Zahoor Ali Khan. "Multiagentbased sharing power economy for a smart community." International Journal of Energy Research 41, no. 14 (2017): 2074-2090.
[4] Hassan, Naveed Ul, Yawar I. Khalid, Chau Yuen, and Wayes Tushar. "Customer engagement plans for peak load reduction in residential smart grids." IEEE Transactions on Smart Grid 6, no. 6 (2015): 3029-3041.
[5] Hassan, Naveed Ul, Yawar Ismail Khalid, Chau Yuen, Shisheng Huang, Muhammad Adeel Pasha, Kristin L. Wood, and See Gim Kerk. "Framework for minimum user participation rate determination to achieve specific demand response management objectives in residential smart grids." International Journal of Electrical Power & Energy Systems 74 (2016): 91-103.
[6] Huang, Shisheng, Wayes Tushar, Chau Yuen, and Kevin Otto. "Quantifying economic benefits in the ancillary electricity market for smart appliances in Singapore households." Sustainable Energy, Grids and Networks 1 (2015): 53-62.
[7] Marzband, Mousa, Hamed Alavi, Seyedeh Samaneh Ghazimirsaeid, Hasan Uppal, and Terrence Fernando. "Optimal energy management system based on stochastic approach for a home Microgrid with integrated responsive load demand and energy storage." Sustainable cities and society 28 (2017): 256-264.
[8] Zhang, Di, Songsong Liu, and Lazaros G. Papageorgiou. "Energy management of smart homes with microgrid." In Advances in Energy Systems Engineering, pp. 507-533. Springer, Cham, 2017.
[9] Coelho, Vitor N., Miri Weiss Cohen, Igor M. Coelho, Nian Liu, and Frederico Gadelha Guimares. "Multi-agent systems applied for energy systems integration: State-of-the-art applications and trends in microgrids." Applied energy 187 (2017): 820-832.
[10] Hidalgo-Len, Ruben, Diego Siguenza, Carola Sanchez, Jonathan Len, Pablo Jcome-Ruiz, Jinsong Wu, and Diego Ortiz. "A survey of battery energy storage system (BESS), applications and environmental impacts in power systems." In Ecuador Technical Chapters Meeting (ETCM), 2017 IEEE, pp. 1-6. IEEE, 2017.
[11] Helms, Thorsten. "Asset transformation and the challenges to servitize a utility business model." Energy Policy 91 (2016): 98-112.
[12] He, Debiao, Neeraj Kumar, Sherali Zeadally, and Huaqun Wang. "Certificateless Provable Data Possession Scheme for Cloud-Based Smart Grid Data Management Systems." IEEE Transactions on Industrial Informatics 14, no. 3 (2018): 1232-1241.
[13] Popovic, Nemanja, Dragan Popovic, and Ivan Seskar. "A Novel Cloud-Based Advanced Distribution Management System Solution." IEEE Transactions on Industrial Informatics (2017).
[14] Mohamed, Nader, Jameela Al-Jaroodi, Imad Jawhar, Sanja Lazarova-Molnar, and Sara Mahmoud. "SmartCityWare: a service-oriented middleware for cloud and fog enabled smart city services." Ieee Access 5 (2017): 17576-17588.
[15] Hung, Yi-Hsuan, and Chih-Yu Wang. "Fog micro service market: Promoting fog computing using free market mechanism." In 2018 IEEE Wireless Communications and Networking Conference (WCNC), pp. 1-6. IEEE, 2018.