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Peer-to-Peer Energy Trading in Micro/Mini-Grids for Local Energy Communities: A Review and Case Study of Nepal

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ABSTRACT Distributed Energy Resources (DERs) are being integrated into the power market by customers rather than large scale energy suppliers, thereby slowly transforming the centralized, unidirectional market to a decentralized, bidirectional market and transitioning customers into prosumers. Various system architectures are used in the real field to coordinate the energy distribution in the micro/ mini-grids integrated with DERs, all of which have their strengths, weaknesses and challenges. Peer-to-peer (P2P) is an emerging architecture in the field of electrical energy trading and Distributed Generation (DG) management that can be applied in local energy markets. This paper focuses on P2P energy trading, with an in-depth discussion on its various operating algorithms, their principles, characteristics, features and scope through state of art review on P2P. Furthermore, the energy system of Nepal is used as a case study in this paper, and the micro/mini-grids of Nepal and their associated challenges, constraints and opportunities for improvement are discussed. Finally, an energy trading model is proposed to address the problems occurring in the specific case of Nepalese energy market.

INDEX TERMS Distributed generation resources, energy trading, micro-grid, mini-grid, peer-to-peer.

I. INTRODUCTION

Globally, more than 12.62% of people still do not have access to electricity which corresponds to 22.57% of rural population and 3.01% of urban population in the world [1]. This lack of electricity access, especially in the rural areas, is attributed to the fact that in many countries, national grids have not reached these areas mostly due to the lack of funding or difficult terrains [2]. Further, most of the world's grids rely on centralized large-scale power providers for continuous power supply [3]. And as such, power trading is unidirectional in nature, i.e. centralized large scale power providers provide power to be spread out to customers [4], [5]. However, the modern power market is evolving. Power customers are growing more independent by the years and increasingly relying on the DERs and mini-grids for power [6], [7]. The power market is now evolving from a centralized system to a decentralized dynamic system [8], [9]. As of 2018, 2,258 micro grids with a total capacity of 19,575 MW has been identified [10]. Due to the developments in small/medium scale renewable energy technologies, customers now have an option to store excess power using batteries or sell them to other customers of the grid, thus transitioning from customers to prosumers [11], [12]. However, the shift of power market from the centralized to decentralized system has led to a requirement of a new energy management system, one which is based on energy trading between prosumers [13]. Development of decentralized operation has been brought forth with

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the progress made in information algorithms such as Gossip and Consensus, all of which are based on the framework provided by the advancement of Information Communication Technologies (ICT) [14], [15]. But, decentralized operation does require a precise synchronization among the prosumer units. One such approach of Customer-to-Customer energy trading is P2P [16]–[18].

P2P schemes consist of customers acting as individual energy traders, i.e. customer can consume or generate power, thereby reducing the congestions on transmission lines [19], [20]. Diversity and variability of demand, direct transactions conducted between users, and transaction terms set by the users themselves bring P2P to the forefront of information algorithm options available for decentralized operation of the grid [21]. P2P trading thus enables small suppliers to compete with large traditional suppliers [21].

Switching the focus on Nepal, 83% of the total land of Nepal is composed of hills and mountains [22]. This has led to difficulties in developing grid resulting in 60% of the total population of Nepal being deprived of access to national grid. Mid and Far-Western regions and rural areas are greatly affected by the lack of transmission lines [22]. While, even the community based isolated micro-grids are constantly affected by the unsustainable operation. Alternative Energy Production Centre (AEPC) has been actively involved in promoting and financially supporting renewable technologies for about 25% of the population [23], [24]. With the lack of access to the national grid and government-aided push towards use of renewable energy, P2P promises to be an ideal system architecture for the development of sustainable micro-grids integrated with DERs to provide electricity access to all of Nepal.

In this study, the authors aim to present the existing concepts, control architectures, approaches and the challenges in the implementation of different energy trading and controlling concepts. It is mainly focused on the review of existing techniques, available documents, and the experience of the authors, that provide an overview for a specific case study of Nepal. This study first introduces the issues and importance of reliable energy systems with their challenges in terms of locality, cost, reliability and energy characteristics. Section 2 presents an overview of different system architectures existing in the field, and their applications. Section 3 focused on the P2P concept including its operating algorithms, their principles, characteristics, features and scopes in comparative form. An overview of technologies, model and operating principle followed in Nepal is discussed in Section 4. Finally, in Section 5, conclusions are drawn and presented based on the existing constraints. Though described in detail in further chapters, the main contributions of this paper are related to:

a. Comparison between various methods and architectures to control the energy system with comparative analysis among them.
b. A detailed comparison between various operating algorithms of P2P with comparative analysis among them.
c. Look at the present energy scenario existing in Nepal along with identification of associated challenges and constraints to be improved upon.
d. The proposal of energy trading method for the implementation in the context of local mini-grids in Nepal.

II. ENERGY TRADING AND CONTROL ARCHITECTURE

With the advent of various energy generation sources as photovoltaic systems, wind turbines, and micro-hydropower stations, the energy consumers upgrade to energy prosumers, the people who consume, as well as produce energy to give back to the grid. In a complex structure with distributed energy resources at the local level, the give and take of energy without following a proper protocol will lead to an unbalanced system. Therefore, various control architectures have been proposed and used for coordinating energy distribution in micro-grids. The following subsections list the most implemented control architectures, and Table 1 provides a glance at the main features, challenges, strengths and weaknesses of the control architectures.

A. LOCAL CONTROL ARCHITECTURE

The control architecture without any communication link between any of the node existing within a micro-grid, termed as local control architecture – is fail-safe against any kind of communication disturbances within the network [25]. However, such type of network system underperforms, as parameters of either the grid or DERs cannot be known whenever required [26]. Despite inherent problems observed in this control architecture, it is beneficial for specific situations and, thus, various local control architectures have been proposed [27]. In [28], the authors proposed a localized solution to deal with voltage rise in a low voltage distribution network. Figure 1 provides a typical configuration in a local area control architecture. As illustrated in Figure 1, Local Agents (LA) within a micro-grid are electrically connected to transfer electricity, but do not have any form of communication.

B. CENTRAL CONTROL ARCHITECTURE

In a centralized control architecture, a central section called Micro-Grid Control Center (MGCC) regulates all the control operations within the nodes in the network [26], [29]. A typical centralized control architecture is shown in Figure 2. MGCC constantly monitors the active and reactive power flow in the network and by comparing the market price of the electricity and other mains of sources, and taking into account the security concern of the system and the additional need of any of the nodes in the micro-grid, decides on the need for either importing the energy for consumption from an external distribution network, or exporting the produced energy for use in any other connected grids [30], [31]. In [32], authors show the functioning of a primary AC controller that communicates with two separate secondary DC micro-grid controllers to stabilize the power in the AC multi-bus system. The main advantage of having a central controller is that, the performance of the controller is better than that of a

TABLE 1. Glance at the main features, challenges, strengths and weaknesses in the control architectures.

System Architecture	Feature	Challenges	Strengths	Weaknesses	References
Local	No controlling device	Network parameters cannot be known when required	Fail-safe against any kind of communication disturbance	Underperforming	[25, 27]
Centralized	Single controller	Stability of the network during error in controller	Performance of the controller is normally good	The downfall of the central controller leads to the collapse of the network	[26, 29, 33, 55]
Distributed	Multiple local controllers	Sharing of information requires communication protocols	Failure of a local agent does not affect any other local agents	The necessity of communication between local agents for network stability	[34, 35, 37, 76, 88, 102, 103]
Hierarchical	Chain of command for controllers	Division of tasks for different controllers	Appropriate decision can only be made by a controller with a required authority level	The traversing chain of authority takes time	[40, 47, 49, 104]
P2P	Communication of every single node with another node	Heterogeneity in a network can lead to topology mismatch	Multiple communication paths exist for resource sharing	Information of a node can be accessed by any other node	[4, 21, 58, 74, 76, 105, 106]

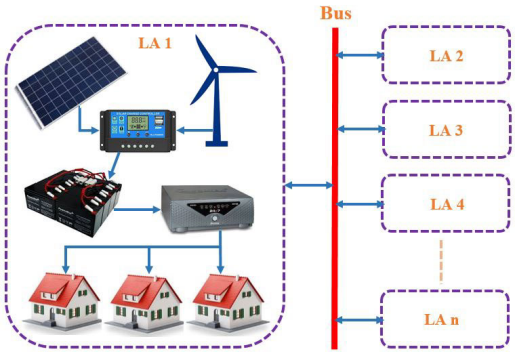


FIGURE 1. A typical local control architecture.

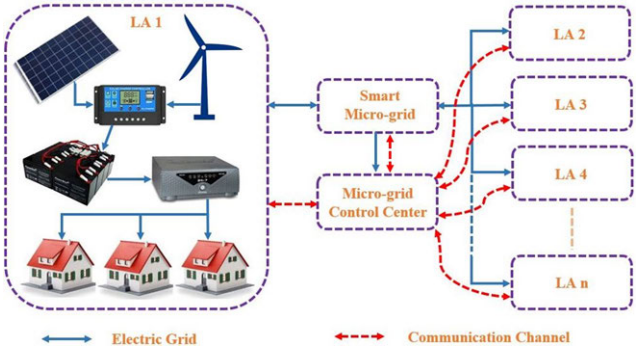


FIGURE 2. Centralized control architecture in an energy trading system.

decentralized controller, however, the higher speed and better performance comes at a price [33].

C. DISTRIBUTED CONTROL ARCHITECTURE

Unlike in central control architecture that has a central device to facilitate communication between all the nodes within a micro-grid, a distributed control architecture (CA) consists of multiple local agents within a single micro-grid [34], [35].

Each local agent houses multiple distributed generations within it, and although distributed and decentralized control architectures operate on the same principle, the fundamental difference exists in communication [36]. Unlike a

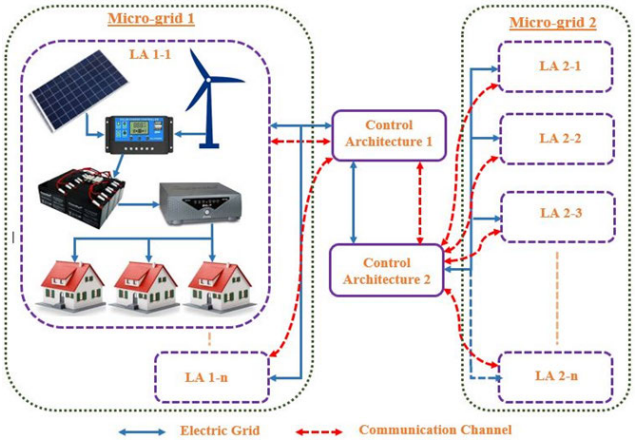


FIGURE 3. Distributed control architecture in energy trading.

decentralize control architecture that assumes the negligible communication between local agents, the local agents in a distributed control architecture share the necessary information regarding the current situation of the micro-grid that is required to keep the grid running without any operational failure. The primary motivation behind the implementation of a distributed control architecture is the unwillingness of a DG operator to share private information with other parties outside of a specific area [37].

D. HIERARCHICAL CONTROL ARCHITECTURE

The hierarchical control system is an alternative to a distributive control system [38]. It is also called tree-shaped, command/feedback control system [39], [40]. The multilayer control system where the devices and governing software is arranged in a hierarchical tree, and each link are connected through network control system [41]. The hierarchical control system has two concepts, namely multilayer and multilevel [42], [43]. In multilayer concept the control of the object is split into algorithm or layers, where each of which acts at different time interval, and in multilevel concept, the control of interconnected complex system is introduced

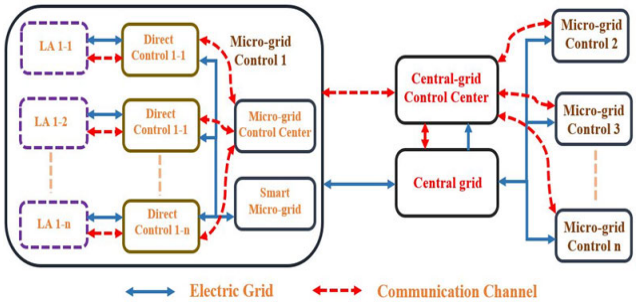


FIGURE 4. Hierarchical control architecture.

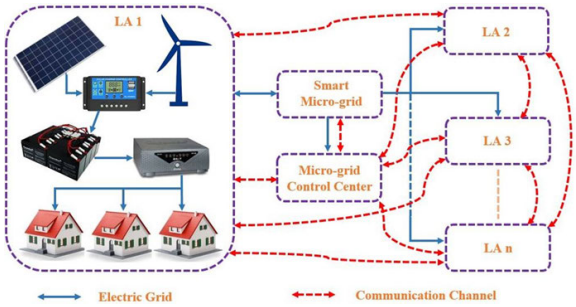


FIGURE 5. Peer to peer control architecture.

into local goals, local control units and their action is coordinated by an additional supreme unit.

The design and implementation of hierarchical architecture vary depending on the application and complexity of the system [44]. The general architecture of the hierarchical technique to control the DGRs is shown in Figure 4. Autonomous decision-making level, middle control level and reactive control level are the three major levels [45]. The controller works at all three levels with different objectives. The high-level controller takes uncertainty while determining the best action for subsystem [46]. The middle-level controller uses searching algorithms for different resources [47], [48], and the low-level controller required a rapid response which can conduct the control mechanism of the components directly [49].

E. P2P CONTROL ARCHITECTURE

A P2P system is a self-organizing system which is completely decentralized for shared usage of resource in a network environment avoiding central services [50]. It follows end to end argument where each peer utilizes the resources provided by other peers [51]. In peer to peer architecture, all the autonomous and distributed system is aggregate in a large number of heterogonous nodes called peers, which incorporate each other to fulfil some objectives [52]. P2P is more applicable in streaming because it provides bandwidth available to serve content scale with demand [53]. In P2P architecture, a given peer can play three different roles:

a. **Source:** The source peer can store the whole or a part of the content and intended to share with other peers.
b. **Intermediate:** Intermediate peer plays the role of a transport node to facilitate the streaming mechanism. It receives the given content and transmits it to the next intermediate.
c. **Destination:** It is the client peer who requests for the content. It can obtain content from one or more sender peer depending on the architecture.

The content media is distributed to the client using generally an overlay network which later rooted at the source or destination peer, depending on the source such as multiple sources or single source [53], [54]. A basic overview of a P2P control architecture is given in Figure 5. In this type of master-slave configuration of the P2P energy trading system, any kind of damage or error to the master controller results in the downfall of the entire micro-grid. Thus, any error in the server ruptures any kind of energy transfer from one node to another within or out of the network [55].

III. STATE OF ART REVIEW ON P2P CONCEPT

A new and highly interesting paradigm for communication, known as P2P, is an emerging technique in the field of energy trade and DGRs management. Any kind of distributed resources can be accessed by P2P and may offer new possibilities with various applications. This system is a self-organizing system of equal, autonomous entities (peers), which aims for the shared usage of distributed resources in an environment avoiding central services [50]. It can be seen as an organizational principle. The P2P principle is applicable to many kinds of systems such as; content distribution, communication, distributed computation, collaboration and so on. P2P distributed energy trading (DET) is an energy trading system in which entities in the power system can exchange power with each other in a peer to peer model, without the direct involvement of central entity such as utility companies [56], [57]. In the electricity trading concept, P2P refers to cases where each node of the distributed energy system is given equal responsibility and plays a role in both production and consumption of energy. Energy prosumers in the network can make their energy available to others as per their requirement. It represents direct energy trading between peers, where energy from small-scale DERs in dwellings, offices, factories, etc. is traded among local energy producers and consumers. A peer in the P2P-DET refers to one or a group of local energy customers, including generators and consumers [58].

Existing power systems were designed to accommodate large-scale generating plants, with demand traditionally considered as uncontrollable and inflexible. However, with the increasing integration of DERs, traditional energy consumers will become prosumers, who can both generate and consume energy. Generation of DERs is unpredictable and intermittent, and the prosumers have surplus energy that can either store it with energy storage devices, or supply others who are in an energy deficit, such energy trading concept among prosumers [15]. Conventional energy trading is mainly unidirectional. Electricity is usually transmitted from large-scale generators to consumers over long distances, while the cash flow goes the opposite way. On the other hand, P2P energy trading encourages multidirectional trading within a local

geographical area [58]. P2P energy trading surely has the potential to increase the benefits of all the consumers and producers, and to facilitate the balance of consumption and intermittent generation from renewable energy sources, thus being beneficial to the power system as well. P2P energy trading has a wide range of application either in micro-grid, solar power and can be used on different platforms. The system allows consumers to take advantage of other users who produce more energy than they need. Those consumers can sell their excess power for profit. Distributed energy exchange can create a competitive energy market that is not monopolized by a few utility companies, bringing profit to small scale energy producers and consumers [59].

In recent years, P2P-DET has also been investigated at the distribution network level. In [16], a paradigm of P2P energy sharing among neighbouring micro-grids was proposed for improving the utilization of local DERs and saving the energy bills for all micro-grids. There are various types of elements and technologies which are suitable for the implementation of P2P energy trading. Different energy trading arrangements for local distribution networks have been investigated. P2P energy trading cannot be applied without a software platform, which enables the information exchange among peers, and also assists the system operators (e.g. DSOs) to monitor and control the distribution network. In addition, different trading rules defined by the platform also have significant influences on the decisions made by peers when trading with other peers. Various software platforms can be designed to facilitate P2P energy trading. Trials of energy trading based on the ''P2P economy'' concept have already been carried out across the globe, for example, Piclo in the UK [4], Vandebron in the Netherlands [5], Yeloha and Mosaic in the US, and Sonnen Community in Germany [6]. These trials mainly focused on providing incentive tariffs to electricity customers from the energy suppliers' perspective. A number of trials and projects on P2P-DET have been carried out in recent years. Some of them focus on business models and platform for energy markets acting similarly to the supplier's role in the electricity sector, while some are targeted at the local control and ICT systems for micro-grids. P2P energy-trading platforms offer a new strategy for incentivizing prosumers to support the formation of micro-grids and other community energy initiatives [60]. One of the goals of the P2P energy-trading platform being developed for the Brooklyn micro- grid is to help coordinate DERs to maintain continuity of supply if the micro-grid is separated from the main grid [61], [62]. Community energy initiatives may be based around shared resource, or shared objectives, such as reducing local pollution [63]. P2P energy-trading platforms could be used as part of these initiatives to raise awareness and to incentivize local users to support the markets amenable to P2P trading, and are characterized by demand variability, diversity and low production economies of scale [64]. Transactions between prosumers offer the most value when they have complementary resources and/or preferences. P2P-DET platforms offer three distinct value-streams: (a) energy matching, (b) uncertainty reduction and (c) preference satisfaction [21].

P2P energy trading in a community based micro/mini-grid describes flexible energy trades between peers, where the excess energy from many small-scale DERs is traded among local customers [65]. Community based market design can readily be applied to micro/mini grids [66], [67] or to a group of neighbouring prosumers [67], [68] that are natural constructs due to their location (i.e. being geographically close). More generally a community is to be based on members that share common interests and goals: for instance, a group of members that are willing to share green energy, though they are not at the same location. The fact of being a more structured design allows the community manager to provide services to the grid operators as an aggregator. Hence, the community-based market design is the enhancement of involvement and cooperation between peers. Being a community based trading, it has numerous challenges such as: (a) Reaching the preferences of energy use for all community members at all time, (b) For the community manager is aggregating all members' data and managing their expectations, and (c) Having a fair and unbiased energy sharing among community members [66]–[75].

In addition, there are numerous challenges in P2P-DET. The realization of P2P-DET depends on the availability of several important aspects such as demand response optimization, power routing, public energy market, money transaction mechanisms and efficient communication networks [76]. Maintaining the balance between supply and demand is an important criterion for the security and reliability of power systems. A mismatch between supply and demand may lead to system instability and failure [77]. In existing systems, demand response optimization is usually performed through load scheduling and price optimization mechanisms under the control of one central entity [77]–[79]. In P2P-DET, power is generated in a distributed manner and is controlled by several producers. Moreover, power generation is highly unpredictable as it depends on RES that is affected by weather conditions. Therefore, achieving demand response optimization is more difficult for P2P-DET as compared to existing systems. As a result, new methods of energy scheduling and price optimization algorithms based on game theory, collaboration, incentives and centrally controlled models have been proposed by several studies [80]–[89]. It ubiquitously takes place in various scenarios such as; micro-grids, energy harvesting networks, vehicle-to-grid networks etc. However, there are common security and privacy challenges caused by untrusted and non-transparent energy markets in these scenarios [90]. Entities participating in distributed energy trading need to communicate with each other for various reasons including demand response optimization, negotiation of energy prices, publishing/invoking energy contracts and performing payment transactions [76]. It is based on a two-way communication network, which might expose the system to various types of security and privacy threats which can harm the confidentiality, integrity and reliability of the

TABLE 2. Characteristics of different approaches used in P2P energy trading.

Method	Process	Feature	Application	Pros	Cons	References
Game Theory	Formulate, analyze, understand the strategic scenarios	Cooperatives theory and non-cooperatives theory	Wide range of field including economics, law, biology etc.	Organization of knowledge on the outside world	Based on assumptions of rationality	[57, 58, 76, 105, 107-113]
Distributed Algorithm	Multiple processing, executed concurrently and coordinate the independent process for results	Leader election, distributed search, resource allocations, spanning tree	Widely used in grid computing, telecommunication, real-time process control	High-availability, lower-latency, higher-throughput	Difficulty in coordinating multiple processes	[17, 69, 76, 102, 103, 114-120]
Consensus	Put forwards a value, communicate with one another and agree on the single consensus value	All partners agree on a single value	The building block of Blockchain technology, has been intensively used in clock synchronization, smart power grids, controls system, load balancing	Highly reliable	Must be fault tolerant	[72, 74, 117, 121-125]
Multi-Market Driven	Information exchange between multiple agents present in the market	Tends to maintain market demand and supply equilibrium	Energy scheduling of micro-grids, power matching	Mitigate the negative impact of intermittent sources, minimization of buyers' power purchasing cost and the maximization of sellers' power selling benefit at the same time	Limiting factors like grid constraints could affect the model	[126-128]
Particle Swarm Optimization	Iterate problem to improve the solution with respect to the predefined measure of quality	Follows metaheuristic approach	Finding optimal location, type and size of distributed energy source	Simple, robust, few parameters to adjust, short computational time, do not overlap or mutate	Difficulty in assigning initial parameters	[128-131]
Genetic Algorithm	Problem is evolved toward a better solution	Follows metaheuristic approach	Widely used in optimization, artificial intelligence, machine learning, image processing	Faster, more efficient, always gets to the answer which gets better over time	Can be inaccurate, suggest a bad solution, can be time-consuming for large functions	[128, 129, 132-134]

system [91]–[95]. As indicated by various studies [91], [92], [96], security vulnerabilities include: (a) submission of fake contracts, (b) double spending of energy or money, (c) modification of transactions, (d) possible Denial of Service (DoS) attacks on P2P-DET systems, etc. Privacy problems on smart grid users are discussed in various studies [93], [95], [97].

P2P-DET plays a vital role in industrial IoT. There are common security and privacy challenges for general P2P energy trading scenarios: (a) It is insecure for IoT nodes to carry out large-scale decentralized energy trading in untrusted and non-transparent energy markets, (b) Industrial IoT nodes with surplus energy maybe not willing to participate as energy suppliers due to their concerns about privacy, where the energy supply and demand are unbalanced among industrial IoT nodes [98], and (c) there is an intermediary to audit and verify transaction record among industrial IoT nodes which intermediary suffers from problems such as a single point of failure and privacy leakage [92]. The other essential service required for P2P-DET is power routing [99]–[101]. This is a mechanism that allows energy routing between producers and consumers residing in different geographical locations. However, existing systems do not provide this functionality. Moreover, power routing in distributed systems is more challenging due to integration- problems as it might require power conversion from one form to another [99], [100]. Plug-in electric vehicles (PEVs) are also one of the main challenges to P2P-DET. PEVs are mobile entities which are not situated in a fixed location. Hence, they dynamically enter the market for a short period of time and leave as they move from one place to the other. Hence, appropriate authentication method and power flow control mechanism are required to allow PEVs to securely participate in the market in dynamic mode [135]–[137]. In terms of design and operation of the energy system with P2P trade model in the local energy market, a number of energy modelling techniques and approaches were practised. There are numerous methods with their own features, advantages and disadvantages. Table 2 lists the popular methods used to develop the P2P energy trading model with their comparisons. The techniques are discussed as follows:

a. **Game Theory:** Game theory is the process of modelling the strategic interactions among multiple decision-makers in a situation, where set rules and outcomes exist. Game-theoretic modelling begins by modelling some aspects of the interaction and tries to evaluate the situation based on the model and provides an output accordingly. Care is taken, however, to only feed relevant parameters to the model so as not to distort the results obtained [138]. In P2P energy

trading, many researches have carried out energy sharing management [139], [140], and real-time pricing [141], [142] using game-theoretic approaches.

b. **Distributed Algorithm:** A distributed system is an interconnection of multiple computers, processes or processors, also called nodes [143]. The algorithms used in such systems for the process and hardware management are referred to as distributed algorithms. Distributed algorithm was proposed to solve the packet drop problem in unreliable communication links [144]. The optimization problem can be solved by using the running sum method [145], [146], or a distributed algorithm that applies Newton Raphson method for energy trading can be used [147].

c. **Consensus:** A consensus, in distributed systems, is an algorithmic process for agreement on a single data value. The algorithm is designed to solve the consensus problem in multi-agent systems. In energy management, scalability of centralized method is of great concern [74] and, therefore, to address the issue of centralized energy management distributed algorithms have been proposed [148]–[150], including a distributed consensus-based algorithm [151], [152].

d. **Multi-Market Driven:** A multi-market-driven approach to energy trading facilitates multiple buyers and sellers in order to optimize the energy trading process. In [128], the authors present a multi-market-driven micro/mini-grid energy schedule that includes centralized and distributed market participation. Evolutionary multi-objective market-driven optimization techniques have been in more use in recent studies [153]–[155]. Authors in [126], tackle the power matching problem with multi-objective market-driven optimization that focuses on the hourly participation of customers.

e. **Particle Swarm Optimization:** Particle Swarm Optimization (PSO) was originally designed and introduced by Eberhart and Kennedy in [156], [157]. Based on the simulation of the social behaviour of birds, bees and a school of fishes, the PSO method is a population-based algorithm [158]. PSO is extensively used in DG locating and sizing problems [131], [159], [160]. Further, PSO is also used to improve the voltage profile [161]. Some advantages of PSO can be that it is simple to implement, have few parameters to adjust, can converge fast and have short computational time [129].

f. **Genetic Algorithm:** Genetic algorithms are search algorithms which are based on the process of natural selection and natural genetics [132]. They are used for solving both constrained and unconstrained optimization problems. In the beginning, a genetic algorithm creates a random population, where each individual is evaluated by a fitness function. The subsequent generation is all evaluated on the same basis and after a certain interval, highly fit generation evolves. Due to their evolving scheme, genetic algorithms have found usage in energy trading models. In [162], authors have used genetic algorithms for optimal micro-grid scheduling, whereas in [163], prosumers are clustered into virtual micro-grids for minimal energy trading market cost.

Apart from these, as explained in [164] the exogenous approach can be implemented in the P2P energy trading model by considering the power system limits with the minimum involvement of the system operator. Moreover, different model and standard have been introduced for the effective and optimized operation of P2P energy trading. OpenARD [165] and OASIS EMIX [166] are such research and standard development effort for energy management through communication between DSO and consumers.

Majority of the P2P techniques are found to be based on the blockchain technology, which is a public ledger that verifies the validity of the transactions, which when integrated with the peer to peer energy trading, provides a secure decentralized record of energy consumption and transaction data [4], [167], [168]. Brooklyn Micro-grid is one such project that plans to integrate blockchain with P2P, aiming to integrate P2P energy trading at Brooklyn, providing the prosumers with streamline-transparent transactions to grow the overall local energy market. This technology integrated with artificial intelligence seems to be the direction that P2P is headed in [169]. Melding artificial intelligence can help P2P optimize the overall energy trading and decentralized operation of the energy market by changing the grid parameters with respect to the change in load parameters. This has been put into practice by Siemens' Active Network Management [170]. Further, combining artificial intelligence, Internet of Things (IoT) and blockchain technologies Verv, a UK based company, has created a P2P trading platform that can give its prosumers a real-time costing of the energy trading [171].

One argument against the P2P trading scheme over centralized energy trading is the unpredictability and unassurance of the continuous energy supply between the prosumers. This however can be minimised introducing artificial intelligence into the system. Artificial intelligence can help predict the load flow and generation. This will enable the system to adjust accordingly and ensure that the grid can ensure a stable supply of electricity, given the availability of a foresight. Given these advantages provided by the integration of blockchain and the artificial intelligence in P2P energy trading schemes, many companies are currently working to make these facilities available to the prosumers. There are many projects like Power Ledger, Grib+ and LO3 Energy in the current energy market that has been actively developing the next generation of P2P energy trading, some even utilizing the blockchain technology by enabling the users to bid on the energy, thereby warranting the prosumers to control the energy cost [18], [125], [170], [172].

IV. CASE STUDY OF NEPALESE ENERGY SYSTEM

Nepal is a country with economically-viable potential of hydroelectricity generation of 42000 MW, solar generation

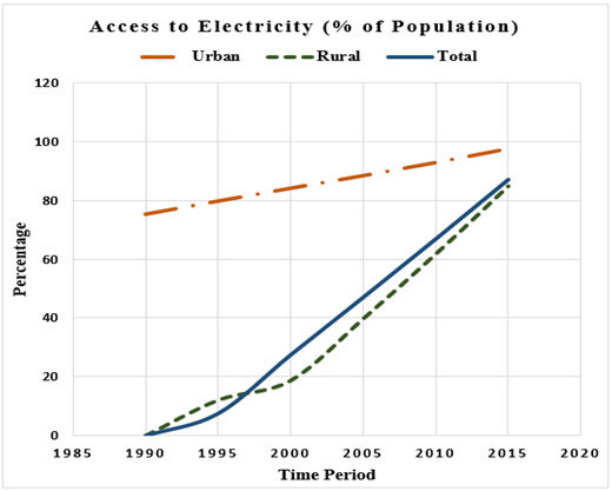


FIGURE 6. Access to electricity by percentage of Nepalese population [1].

of 3000 MW and wind generation of 2100 MW [173]–[175]. However, 9.3 % of the Nepalese population (5.5 % in urban areas and 14.8 % in rural areas) are out of reach of electricity, and even the population connected with the national grid do not have access to reliable and sufficient electricity supply [1]. The situation of power supply and electricity access was much worse a decade ago, which can be seen in Figure 6. The people connected to the national grid were forced to face up to 16 hours of load shedding in a day during the dry season [176], [177]. But the percentage of people getting access to electricity is increasing through the years and the country as a whole has been moving towards a reliable energy supply. Within the past 5 years, the Nepal Electricity Authority (NEA), the national electricity utility has succeeded to eliminate intentional load shedding, and the public is getting continuous power supply [23]. Hence, it is evident that Nepal's electricity sector has improved significantly, and has the potential to move toward a reliable and sustainable power system in the near future.

A. CURRENT PRACTICES

Majority of Nepalese living in urban areas are getting electricity through the centrally controlled national grid, but electricity penetration is hindered in rural areas because of various constraints such as: geography, technical issues, cost, sustainability etc. [23], [178], [179]. Currently, rural areas are electrified through numerous locally controlled isolated DGs and regionally controlled national grid in selected areas [23], [180]. As of 2018, 1,700 community-owned isolated micro/mini hydro projects with the total installed capacity of 30 MW were providing electricity to rural areas of Nepal, and about 600,000 solar home systems had been installed to ensure the fundamental lighting objectives under different project of Alternative Energy Promotion Center (AEPC) [180]. Similarly, NEA is providing electricity to rural areas through isolated small hydro project of 4,536 kW and 100 kW of solar plant [23]. Currently, AEPC is primarily focused on design, development and implementation of isolated hybrid energy systems including micro/mini hydro projects, wind energy systems, solar power plants, biogas plants, solar dryers and improved water mills with the objective to provide clean energy to the rural communities [181], whereas NEA is working to provide adequate and reliable electricity to the people through extension of national grid [23], [182]. Besides these projects, a number of organizations; institutions, hospitals, commercial buildings, governmental and non-governmental organizations, have installed their own energy generators, including solar PV, diesel generator sets, biomass generators etc. on their own control mechanism and model [183]. At this stage, the Nepal's electrical sectors are found to be focused on developing a reliable and continuous supply of electricity through the modernization/upgrading of existing DGs, integration of DGs to grid and extension of national grid with the parallel development of new projects [180].

Further, national utilities have started the policy of DGs integration with a net meter tariffing model. This policy is applied in the solar water pumping projects, through which, the system owner can sell the left-over energy to the utility grid. Similarly, the concept of net metering is applied to other independent power producers (IPPs). In some major cities, a new practice has been piloted, where the street lights are fed through utility's distribution system that has their own internet protocol address and controlled through a central server. Implementation of smart energy metering through web-based approaches has been installed in major cities, with proper data processing and visualization tools for primary-load-type-users, and connected with Time of Day (ToD) meter. In this system, all of the communicating mechanisms are conducted under the control of utility's central server. In addition, NEA is making detailed plans on some important projects such as; Enterprise Resource Planning (ERP) management, geographical mapping system, distribution system master plan, grid-tied-meter, substation automation system etc., which are on their finalization stage and their implementation is scheduled for the near future. NEA has also installed two micro hydropower plants that stores off-peak-energy and supplies it to the community during on-peak-hours [23].

Recently in 2017, NEA had introduced Kathmandu Valley Smart Metering Project (KVSMP), which is expected to modernize the distribution system of Kathmandu valley through the implementation of Distribution Management System (DMS) and Advanced Metering Infrastructure (AMI) [184]. After completion of this project, consumers will get the detailed information of their electricity-use-patterns and will be aligned with modern practices to get operation flexibility (time of use based tariffs), resulting in the reduction of non-technical losses of the distribution system [185].

Different energy-based organizations; governmental, non-governmental and international non-governmental organizations, are working on the development and improvement activities of the isolated renewable energy system. As of 2018, around 25% of total population were getting

electricity through different DGs developed all around the country. The isolated energy system is found to be a single solution to connect electricity in the rural area, where it is unfeasible to transmit electricity through the national grid [2], [23]. Government of Nepal has developed a number of policies and released subsidy schemes to support the isolated DGs, resulting in sharp growth of energy penetration in rural areas and economic growth of the rural population [186]–[188]. These systems are locally controlled with the help of either Electronic Load Controller (ELC) or storage devices equipped with Automatic Voltage Regulator (AVR) and these systems sell the electricity to local consumer in tariff rates defined by the project development committee. However, there are numerous challenges in isolated renewable energy systems such as high-costs, poor reliability and power quality, low load factor, periodic nature of renewable sources, problems in maintenance and monitoring activities etc. [189]–[191]. Because of the periodic nature and dependency on weather factors, the energy generated from renewable energy sources like solar and wind are variable, which can be improved upon using sufficient storage devices or by interconnecting multiple energy resources type, called optimal hybridization. An optimized hybrid energy system is a quite promising technique based on cost, power quality and system's reliability to provide electricity to such areas [192]. However, other problems such as low load factor, low diversity factor, low reliability, protection, etc. are still present in isolated energy systems, which can be resolved/ minimized through the concept of micro-grid [7], [193], [194]. Hence, the Nepal electricity sector has prioritized the development of mini-grids by interconnecting multiple power producers, and worked towards improving the overall system performance.

In Nepal, the power producers are categorized into pico (less than 5kW), micro (5-100 kW), mini (100-1000 kW) and large (higher than 1000 kW), and the community-based grid system is categorized into micro (less than 10 kW) and mini (10-1000 kW) [193], [195]. Till today, more than 17 mini-grid projects have been proposed, connecting the mini/micro/pico hydro projects in different parts of the country and few numbers of projects are in operation stage [196]. Urja Upatyaka Mini-grid, Baglung (Connecting six micro-hydro projects, 107 kW), Thingan mini-grid, Makawanpur (connecting a micro-hydro, solar PV and wind turbines, 28 kW), Khimti Rural Electric Cooperative, Dolakha-Ramechaap (connecting two mini-hydro projects, 1035 kW) etc. are some successful micro/mini-grids found in Nepal [190], [192], [195], [197]. Figure 7 shows an example of micro-grid developed by interconnecting different types of DGs at Thingaan and Kolkhop villages of Makawanpur district. This system includes a 20 kW micro-hydro, installed at Kolkhap village, and a hybrid system of 5 kW solar and 3 kW wind power plant at Thingan village [192]. These two systems are connected through a 7 kilometres long 11 kV transmission line and the project supplies power to 232 households, one police station, one health post, two schools, eleven commercial farms, one

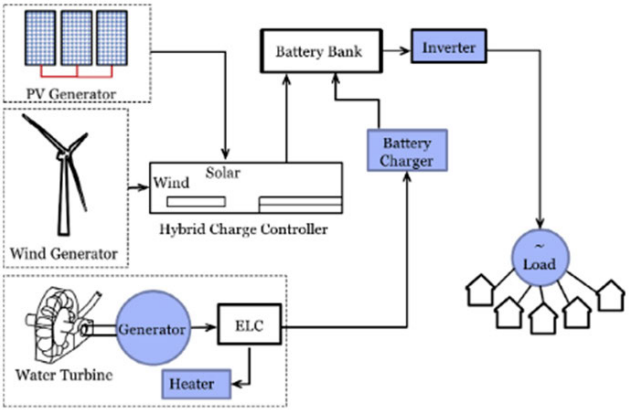


FIGURE 7. Block diagram of the solar-wind-micro hydro tri-hybrid system developed at Thingan and Kolkhop villages, Makawanpur [192].

chicken farm, one library and one church at the voltage level of 220 V [198].

Basically, the power plants are found to be operated with the modality of IPP, and controlled by a central body within the system or distributed controller as per their design in a micro/mini-grid. ELC with micro-controller-based grid-synchronizer is widely used to regulate and control the system in present context, but the concept of central ELC is also found to be used in numerous cases. Generally, the projects are considered as an IPP, managed by a respective cooperative committee and sell the electricity as per their tariff rate, fixed during power purchase agreement (PPA). In most of the micro/mini-grid under operation, the following particulars are very important [195]:

a. **Operation schedule:** As per the demand, plants are scheduled to operate manually in coordination between plant operators by accounting the power generated and load demanded, for different periods of time.
b. **Black start mechanism:** In case of system blackout, the largest system is so designed to operate first, and bootstrap the whole grid.
c. **Complete grid shutdown:** All DGs are shut down for a small period of time during the occurrence of a fault in the main grid.
d. **Partial grid shutdown/ islanding:** When a problem has occurred in a single power plant, DGs are operated in islanding mode and provide continuous electricity to local feeder.
e. **Communication mechanism**: Mobile phone is one of the major options for communication purpose.
f. **Component failure:** Major failures occur in automatic synchronizer, semi-conductors in control panel, micro-controller and load monitoring systems. Absence of skilled/ experienced technician in some specific place leads to frequent shut-down of plants.
g. **Tariff rate:** Based on two factors; Consumer ability to pay, and regulated tariff guideline. It may be power-based, energy-based or flat.
h. **Trading platform:** Generally, power producers sell the electricity to the mini/micro-grid with a fixed PPA, and

the mini/micro-grid cooperative sell the electricity to the local communities based on its tariff rate.

B. ASSOCIATED CHALLENGES AND CONSTRAINTS

As discussed in section IV (A), there are numerous challenges in isolated energy systems as well as in micro/mini-grids. In the specific case of the Nepalese energy system, the plant utilization factor and the load factor of isolated DGs are found to be very low, since the local communities have load demand for a certain period of time (especially morning and evening). The following challenges and constraints have been identified to be improved upon, for improving the isolated energy systems and micro/ mini-grids of Nepal:

1) TECHNICAL ISSUES

Generally, P-F control system, Q-V control system, switchgear and protection system, measurement and instrumentation system, grid synchronization etc. are the technical aspects in a micro/ mini-grid system. The mini-grids present here in Nepal are currently facing the following technical issues [180], [181], [195], [196], [199], [200]:

a. **Lack of central control and monitoring unit:** Grid operators should know continuously about the generation and loading condition, to maintain the balanced condition. However, in the existing system, the grid operators are unknown to what is happening in the system. Similarly, independent DGs are controlled by separate operators with their mutual understanding, through mobile communications that lead to delay and difficulties in load management.
b. **Lack of a suitable and reliable communication mechanism:** Mobile communication is only the means of communication between grid and plant operators in rural Nepal. It is very difficult to deliver continuous, reliable and accurate information through such techniques. There are lots of cases in which communication network issues have led to many sensitive loads being stopped for a longer time period.
c. **Issues on the active power-sharing:** In the micro/ mini-grid, active power-sharing is proportional to the capacity of the ballast load; power-sharing is affected by the ballast size. During the operation of a micro-hydro plant at lower rating, there may be a possibility of back feeding by the grid to the ballast (i.e. dump load) of that plant, which is an undesirable condition.
d. **Issues on the reactive power sharing:** Reactive power must be shared in proportion to the kVA rating of the generator. Although reactive voltage droop is created, due to the difficulties in proper droop setting, the reactive power is found to be not shared in accordance with this statement. In addition, the reactive power sharing is affected by the open-circuit voltage, which can be affected by the voltage adjustment with panel mounting potentiometer. It is impossible to find the correct excitation point by manual tuning. Hence, there is always mismatch in reactive power, causing the flow of circulating current. These current increases the system loss. In extreme condition, if the excitation is too low the system voltage becomes low, causing voltage instability and if the excitation is higher, the rotor may be overheated resulting in insulation failure of the rotor winding.
e. **Lack of operating and maintenance guideline**: Technology provider does not provide any operating and maintenance guidelines. So, it is very difficult for proper operation and maintenance of equipment inside the control panel.
f. **Lack of synchronization check:** In the existing condition, plant operator of a plant is unfamiliar with the synchronization status of another plant, which leads the system instability as a result of a misunderstanding between the operators.
g. **Expensive technology and lack of skilled personnel:** The concept of mini-grid was replicated from other countries, and is more expensive than the older system. Since there are no local suppliers, manufacturers, service providers, it is very expensive and tedious to maintain the system after system break. Maintenance and up-gradation of defected equipment cannot be computed by the local technician, resulting in high cost, longer shut down, and lack of preventive and protective maintenance even for minor problems.
h. **Lack of data recording devices:** There are not any data recording devices in existing plants. In order to analyze the performance and current status, different information are required, which is impossible to take at an instant. So, it is very difficult to study what is actually happening in the system. It is seen that the accuracy and reliability of indicating devices are below the acceptable level, and it is very difficult to take action without a detailed analysis.
i. **Lack of guideline in the protection system:** Protection system is the primary requirement of the power system. For the protection of power system equipment and personal, various protection equipment's are provided in the existing control panels. Automatic fault clearances play a vital role in the protection scheme of switch gears, and these are rather not preferred in the current scenario and manual fault clearances are done. During the system blackout state, the fault clearances in multiple zones are conducted manually, that requires more technical manpower and create significant delays in system recovery.

2) OTHER ISSUES

Asides from technical issues, several management issues play an important role to degrade the performance of existed energy system. The following are the noticeable issues of the current management model (IPP Model) [180], [181], [193], [195], [196]:

a. **Gap creation between plant functional group and co-operative body:** In a straightforward way, both of these are two separate business groups so, both of them

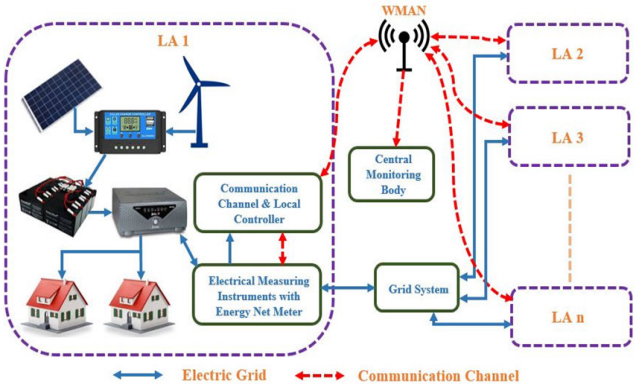


FIGURE 8. Block diagram of the proposed model for micro/mini-grid in rural Nepal.

try to generate more revenue from the common source of income (i.e. electricity) creating a dispute between them. Plant functional group tries to make higher PPA rate and lower tariff structure for the consumer, which is not in favour of the mini-grid. The hidden fact is that, staff within both groups are internally unsatisfied with the other regarding the scope of work, facilities etc. which affects the management of the existing system.

b. **Delay in problem-solving:** In the existing model, the plant functional groups do not have authority over the distribution system up to end-user. During the occurrence of problems in distribution line and consumer connection, large time is taken to solve even simple problems because of the large coverage area, limited staffs and long management procedures.

c. **High financial burden over the mini-grid:** According to the IPP model, the distribution line is operated under the mini-grid. With the passing of time, operating and maintenance cost increase. Moreover, to operate the whole distribution system, a co-operative body either has to hire additional staff or use plant operators by paying an extra charge. Due to these difficulties, all of the distribution lines are looked after by the plant functional group in isolated mode.

d. **Difficulty in community mobilization:** Lack of ownership feelings for mini-grid, local political interference and individual biases of local people, lack of unity among different communities, lack of awareness about renewable energies and the understanding of how micro/ mini-grid systems work are among the major factors that contribute to the system failure. It is indisputable that a system that is not understood cannot be managed. The awareness about renewable energy-based grids needs to go beyond mere optimism that such technologies promise for increasing the electricity access rate in the country.

As the management of a local grid with several IPPs is a complex task as compared to an isolated energy system, orientation and outlook of people affiliated with isolated plants need to be changed pursuing the vision. This requires continuous support in technical, management, operation area for an extended period of time. Conflict among plant operational groups and mini-grid cooperative groups has hampered these sort of projects from planning stage to the implementation stage. An example of Baglung mini-grid can be taken to generalize the problems associated with the local energy system in Nepal. The co-existing IPPs are now on the verge of separation and are trying to operate in isolated mode. The main reason for this clash is conflict among the existing groups for some issues such as transparency and transection modality. The technical viability and capacity to operate the mini-grid system is found to be good, but the system's sustainability is in danger because of the financial conflict and improper management. Especially, distribution of total revenue, transparency, sharing of operating and maintenance cost of mini-grid are the major issues to be solved in Nepal's energy system. Similarly, lack of ownership feeling, local political interference are some of the social issues. Hence, a unique technique, which is more focused on trade and proper control of the system, is required. The technique should be controlled in advanced form, mainly focusing on the electricity trade and their transparency. For such a case, a simple model as shown in Figure 8 can be implemented.

As shown in Figure 8, the proposed model simply consists of multiple local systems operating under their own functional group. Individual plants are responsible to produce electricity and feed the connected community (i.e. prosumers). All of the individual plants are connected to the grid system through a net energy meter that is equipped with advanced measurement tools. There are communication channel and local controller at each local producer, whose main objective is to communicate with other plants and trade energy with them as per the mutual understanding. All of the plants are connected with a commutation system and monitored by a central monitoring body, which is directly associated with a banking system whose transaction based on net energy trade. Communication networks are required in order to exchange data between transmitters and receivers located in different places either in proximity or separated by geographical areas. These communication networks, which can use either wired or wireless channels to communicate between each device in the network, can be categorically divided into three topologies; Local Area Network (LAN), Metropolitan Area Network (MAN) and Wide Area Network (WAN). The LAN architecture can be used when the distance between the communicating devices is within a closed environment like a house or an office building. The MAN architecture can facilitate the connection of devices that span a large geographic region in the range of 1 km to 100 km [201], [202], for example, several company buildings within a city [203]. WAN architecture has the widest network range and can span the entire country or even the globe [204].

Wireless version of the metropolitan area network-based network architecture is the most suitable for the proposed peer-to-peer energy trading model. The Wireless MAN (WMAN) architecture is approved by IEEE 802.16

committee for standardization [205]. The upper-level control in the MAN topology is facilitated by a centralized switching method, whereas the lower level utilizes a distributed switching technique [206]. Figure 8 provides a general block diagram for the architecture to be used in the proposed model. The advantage of WMAN in this particular model is the use of a central tower that facilitates the communication between local towers in each micro-hydro. This method of communication is dependable for providing uninterrupted interaction between each node in the grid network even in case of actual power transmission line being affected by natural phenomena. Furthermore, a single MAN can connect more than 500 devices with support for a data transfer rate of at least 100 Mbps [207]. This feature in particular allows for real-time control of existing nodes and expansion of the micro/ mini-grid to numerous alternative generation sources.

V. DISCUSSION AND CONCLUSION

Due to rising concerns around carbon footprints and increasing availability of renewable energy over the last several years, we have witnessed a rapid growth of the number of installed various DERs, such as solar power plants, wind power generations, and micro/mini hydro generation systems around the world. This paper provides a detailed discussion of P2P energy trading in micro/mini-grids, using the country of Nepal as a case study. P2P is a network, in which the members or peers of the network share a part of their own resources and information to facilitate certain applications. Each peer is both a provider and receiver of the resource and can directly communicate with the rest of the peers of the network, without the intervention of any intermediate node. The production of energy takes place within each house or nearby to reduce transmission losses and utilize cogeneration, if possible. When a prosumer has surplus energy, it can either store this energy within its storage device, if there is any, or distribute the energy among other peers within the network to avoid having wasted energy. P2P approaches have the potential to reduce the costs of electric power, increase accessibility to power markets, and encourage further proliferation of renewable generation. It is considered as a potential solution to this misalignment, as it can provide a price signal for better coordination of local generation and consumption.

The P2P concept is also expected to become an integral part of the energy systems in rural areas. It promises to provide various benefits such as reducing power outages, increasing the overall efficiency of the power system and providing an alternative source of energy, according to user choice. Similarly, it can help to mitigate the problems associated with the rural micro/mini-grid arises from numerous technical, managerial, social issues in developing countries like Nepal. However, this technology can only be realized through addressing challenges such as security and scalability in P2P systems, if services such as power routing, reliable communication networks, and appropriate security and privacy measures are available. Through addressing such challenges, it is will be possible to enable future P2P-DET systems like Energy Internet, SDN and Blockchain. Although the concept of P2P energy trading has already been demonstrated in small-scale trials, much more research is needed in order to realize its potential benefits. Significant future research work should focus on the development of algorithms and platforms for co-operative electricity trading and energy IoT systems, and in the testing and validation of these approaches in the field.

P2P energy trading provides local and regional energy providers with options to trade energy fairly within the neighbourhood, within the community and within the vicinity in the distribution system. P2P designs invite the use of distributed optimization techniques that respect the privacy of every peer, and future work should aim to improve the negotiation processes. Arguably, scalability when reaching a large number of peers is a current challenge. Sparsification of communication and negotiation graphs will be fundamental to reduce exchanges among peers with residual effect on the optimality of resource allocation and pricing outcomes. The research of methods to handle asynchronous communication is also a relevant future work [208].

Nepal is a developing country, where the electricity sector is found to be improved significantly in the last few years. Within the period of five years, the Nepalese electricity authority has eliminated the intentional load shedding from a previous situation, where there were 16 hours load shedding per day at dry season. This success was achieved via numerous steps, among which, the role of DGs, demand-side management, upgraded electrical system and their effective management were applied. Currently, the Nepalese people are getting continuous power supply, and the utility is improving their system toward a reliable, sustainable and advanced form. Hence, Nepal can be taken as an example of a rapidly developing nation in the electrical sector. In a present context, more than 25% of population is getting electricity through the isolated energy systems. However, the concepts of isolated energy system and micro/mini-grid are still an emerging topic in case of Nepal.

In current scenario, private companies are interested in investing in such projects, while policies are not clearly defined by the governing bodies. Clarity in policies and regulation such as outlining rights of mini-grid operators, grid connection, regulatory approvals, tariff setting, and standards should be drafted well and implemented from the Government's side. Widespread applications of microgrid systems are achieved in developed countries as well as in some developing countries through effective policy frameworks. It is impossible to achieve sustainable micro/mini-grids in the absence of appropriate policy measures. Such policies work together with other aspects such as social, technical, economic factors to achieve the desired results. Examples of existing policies in other parts of the world are Feed-in-Tariffs (FiTs), Feed-in-Premiums (FiPs), net metering/net billing and tax credits/incentives. Therefore, the lack of effective policies and system model are some of

the major factors that have led to the failure of micro/mini-grids projects in Nepal.

Being specific in terms of associated problems, the Nepalese technologies are viable, and have the capacity to operate the micro/mini-grid system smoothly, but the system is found to be unstable, because of the financial conflict and improper management. Lack of ownership feeling, local political interference, difficulty in community mobilization, lack of unity in different communities etc. are some of the social issues. In addition, lack of awareness about renewable energies and the understanding of how micro/mini-grid systems contribute to increase the system's reliability and performance. Hence a unique solution, such as the model for micro/mini-grids in rural Nepal proposed in this paper, is required. The implementation of future micro/mini-grids should in such rural areas focus on ensuring the transparency and security of local electricity trades, and on enabling a more coordinated, system-level control and optimization.

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REFERENCES

[1] SE4ALL. (Apr. 19, 2019). *Access to Electricity (of Population)*. [Online]. Available: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS

[2] A. Shrestha, L. B. Rana, A. Singh, S. Phuyal, A. Ghimire, R. Giri, R. Kattel, K. Karki, and S. K. Jha, "Assessment of electricity excess in an isolated hybrid energy system: A case study of a Dangiwada village in rural Nepal," *Energy Procedia*, vol. 160, pp. 76–83, Feb. 2019.

[3] J. Martin, "Distributed vs. centralized electricity generation: Are we witnessing a change of paradigm," in *An Introduction to Distributed Generation*. 2009.

[4] M. Andoni, V. Robu, D. Flynn, S. Flynn, S. Abram, D. Geach, D. Jenkins, P. McCallum, and A. Peacock, "Blockchain technology in the energy sector: A systematic review of challenges and opportunities," *Renew. Sustain Energy Rev.*, vol. 100, pp. 143–174, Feb. 2019.

[5] C. Papadimitriou, A. Anastasiadis, C. Psomopoulos, and G. Vokas, "Demand response schemes in energy hubs: A comparison study," *Energy Procedia*, vol. 157, pp. 939–944, Jan. 2019.

[6] P. Shrestha, A. Shrestha, and B. Adhikary, "Comparative analysis of grid integration on distributed energy system," presented at the 5th Int. Conf. Develop. Renew. Energy Technol., Kathmandu, Nepal, 2018.

[7] V. Bhandari, R. Dahal, B. Adhikary, R. K. Maskey, and N. Shrestha, "MiniGrid: Design and development of mini-grid for efficient use of distributed hydropower systems-experience from the first year of the project," in *Proc. Rentech Symp. Comendium*, 2012, vol. 1, no. 1, p. 4.

[8] B. Astarios, A. Kaakeh, M. Lombardi, and J. Scalise, "The future of electricity: New technologies transforming the grid edge," World Econ. Forum, Cologny, Switzerland, Tech. Rep., 2017.

[9] S. Howell, Y. Rezgui, J.-L. Hippolyte, B. Jayan, and H. Li, "Towards the next generation of smart grids: Semantic and holonic multi-agent management of distributed energy resources," *Renew. Sustain. Energy Rev.*, vol. 77, pp. 193–214, Sep. 2017.

[10] (Apr. 19, 2019). *Microgrid Deployment Tracker 4Q18*. [Online]. Available: https://www.navigantresearch.com/reports/microgrid-deployment-tracker-4q18

[11] S. Aslam, N. Javaid, F. Khan, A. Alamri, A. Almogren, and W. Abdul, "Towards efficient energy management and power trading in a residential area via integrating a grid-connected microgrid," *Sustainability*, vol. 10, no. 4, p. 1245, 2018.

[12] S. E. Alam, R. Shorten, F. Wirth, and J. Y. Yu, "Distributed algorithms for Internet-of-Things-enabled prosumer markets: A control theoretic perspective," 2018, *arXiv:1812.07636*. [Online]. Available: https://arxiv.org/abs/1812.07636

[13] N. Wang, X. Zhou, X. Lu, Z. Guan, L. Wu, X. Du, and M. Guizani, "When energy trading meets blockchain in electrical power system: The state of the art," *Appl. Sci.*, vol. 9, no. 8, pp. 1–32, 2019.

[14] L. Meng, E. R. Sanseverino, A. Luna, T. Dragicevic, J. C. Vasquez, and J. M. Guerrero, "Microgrid supervisory controllers and energy management systems: A literature review," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 1263–1273, Jul. 2016.

[15] C. Zhang, J. Wu, C. Long, and M. Cheng, "Review of existing peer-to-peer energy trading projects," *Energy Procedia*, vol. 105, pp. 2563–2568, May 2017.

[16] T. Liu, X. Tan, B. Sun, Y. Wu, X. Guan, and D. H. K. Tsang, "Energy management of cooperative microgrids with P2P energy sharing in distribution networks," in *Proc. IEEE Int. Conf. Smart Grid Commun. (SmartGridComm)*, Nov. 2015, pp. 410–415.

[17] A. Pouttu, J. Haapola, P. Ahokangas, Y. Xu, M. Kopsakangas-Savolainen, E. Porras, J. Matamoros, C. Kalalas, J. Alonso-Zarate, F. D. Gallego, J. M. Martín, G. Deconinck, H. Almasalma, S. Clayes, J. Wu, M. Cheng, F. Li, Z. Zhang, D. Rivas, and S. Casado, "P2P model for distributed energy trading, grid control and ICT for local smart grids," in *Proc. Eur. Conf. Netw. Commun. (EuCNC)*, 2017, pp. 1–6.

[18] E. Mengelkamp, B. Notheisen, C. Beer, D. Dauer, and C. Weinhardt, "A blockchain-based smart grid: Towards sustainable local energy markets," *Comput. Sci.-Res. Develop.*, vol. 33, nos. 1–2, pp. 207–214, 2018.

[19] N. Wang, W. Xu, Z. Xu, and W. Shao, "Peer-to-peer energy trading among microgrids with multidimensional willingness," *Energies*, vol. 11, no. 12, p. 3312, 2018.

[20] C. Zhang, "Peer-to-peer energy trading in electrical distribution networks," Cardiff Univ., Wales, U.K., Tech. Rep., 2017.

[21] T. Morstyn, N. Farrell, S. J. Darby, and M. D. McCulloch, "Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants," *Nature Energy*, vol. 3, no. 2, p. 94, 2018.

[22] Central Bureau of Statistics, Government of Nepal, Kathmandu, Nepal. (2011). *National Population and Housing Census 2011 (National Report)*. [Online]. Available: https://unstats.un.org/unsd/demographic-social/census/documents/Nepal/Nepal-Census-2011-Vol1.pdf

[23] NEA, Kathmandu, Nepal. (2018). *NEA Annual Report 2074/75*. [Online]. Available: http://www.nea.org.np/annual_report

[24] National Planning Commission, Government of Nepal, Kathmandu, Nepal. (2018). *Universalizing Clean Energy in Nepal: Sustainable Distributed Generation and Grid Access to All (SUDIGGAA) by 2022*. [Online]. Available: https://www.npc.gov.np/images/category/SUDIGGAA_final_version1.pdf

[25] A. Bani-Ahmed, L. Weber, A. Nasiri, and H. Hosseini, "Microgrid communications: State of the art and future trends," in *Proc. Int. Conf. Renew. Energy Res. Appl. (ICRERA)*, 2014, pp. 780–785.

[26] H. Almasalma, J. Engels, and G. Deconinck, "Peer-to-peer control of microgrids," 2017, *arXiv:1711.04070*. [Online]. Available: https://arxiv.org/pdf/1711.04070.pdf

[27] S. Weckx, C. Gonzalez, and J. Driesen, "Combined central and local active and reactive power control of PV inverters," *IEEE Trans. Sustain. Energy*, vol. 5, no. 3, pp. 776–784, Jul. 2014.

[28] G. Mokhtari, A. Ghosh, G. Nourbakhsh, and G. Ledwich, "Smart robust resources control in LV network to deal with voltage rise issue," *IEEE Trans. Sustain. Energy*, vol. 4, no. 4, pp. 1043–1050, Oct. 2013.

[29] N. D. Hatziargyriou, A. Dimeas, A. G. Tsikalakis, J. P. Lopes, G. Karniotakis, and J. Oyarzabal, "Management of microgrids in market environment," in *Proc. Int. Conf. Future Power Syst.*, 2005, p. 7.

[30] N. Hatziargyriou, *Microgrids: Architectures and Control*. Hoboken, NJ, USA: Wiley, 2014.

[31] K. Hashmi, M. M. Khan, J. Xu, M. U. Shahid, S. Habib, M. T. Faiz, and H. Tang, "A quasi-average estimation aided hierarchical control scheme for power electronics-based islanded microgrids," *Electronics*, vol. 8, no. 1, p. 39, 2019.

[32] A. Mohamed, A. Ghareeb, T. Youssef, and O. A. Mohammed, "Wide area monitoring and control for voltage assessment in smart grids with distributed generation," in *Proc. IEEE PES Innov. Smart Grid Technol. (ISGT)*, Feb. 2013, pp. 1–6.
[33] S. Sojoudi, J. Lavaei, and A. G. Aghdam, "Robust control of LTI systems by means of structurally constrained controllers," in *Structurally Constrained Controllers*. Springer, 2011, pp. 139–150.
[34] T. L. Nguyen, Q.-T. Tran, R. Caire, C. Gavriluta, and V. H. Nguyen, "Agent based distributed control of islanded microgrid—Real-time cyber-physical implementation," in *Proc. IEEE PES Innov. Smart Grid Technol. Conf. Eur. (ISGT-Eur.)*, Sep. 2017, pp. 1–6.
[35] P. Gupta and M. Duchon, "Developing self-similar hybrid control architecture based on SGAM-based methodology for distributed microgrids," *Designs*, vol. 2, no. 4, p. 41, 2018.
[36] M. van Steen and A. S. Tanenbaum, "A brief introduction to distributed systems," *Computing*, vol. 98, no. 10, pp. 967–1009, 2016.
[37] M. Yazdanian and A. Mehrizi-Sani, "Distributed control techniques in microgrids," *IEEE Trans. Smart Grid*, vol. 5, no. 6, pp. 2901–2909, Nov. 2014.
[38] A. Paudel and G. H. Beng, "A hierarchical peer-to-peer energy trading in community microgrid distribution systems," in *Proc. IEEE Power Energy Soc. General Meeting (PESGM)*, Aug. 2018, pp. 1–5.
[39] W. Jing, "Review of dynamic hierarchical management system of project managers in construction enterprise," *Value Eng.*, vol. 32, p. 066, 2013.
[40] A. Bidram and A. Davoudi, "Hierarchical structure of microgrids control system," *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 1963–1976, Dec. 2012.
[41] A. T. Jones and C. R. McLean, "A proposed hierarchical control model for automated manufacturing systems," *J. Manuf. Syst.*, vol. 5, no. 1, pp. 15–25, 1986.
[42] W. Findeisen, F. N. Bailey, M. Brdys, K. Malinowski, P. Tatjewski, and A. Wozniak, *Control and Coordination in Hierarchical Systems*. Hoboken, NJ, USA: Wiley, 1980.
[43] T. L. Vandoorn, B. Zwaenepoel, J. D. De Kooning, B. Meersman, and L. Vandevelde, "Smart microgrids and virtual power plants in a hierarchical control structure," in *Proc. 2nd IEEE PES Int. Conf. Exhib. Innov. Smart Grid Technol.*, Dec. 2011, pp. 1–7.
[44] C. X. Dou and B. Liu, "Multi-agent based hierarchical hybrid control for smart microgrid," *IEEE Trans. Smart Grid*, vol. 4, no. 2, pp. 771–778, Jun. 2013.
[45] A. D. Bintoudi, L. Zyglakis, T. Apostolos, D. Ioannidis, S. Al-Agtash, J. L. Martinez-Ramos, A. Onen, B. Azzopardi, L. Hadjidemetriou, N. Martensen, C. Demoulias, and D. Tzovaras, "Novel hybrid design for microgrid control," in *Proc. IEEE PES Asia–Pacific Power Energy Eng. Conf. (APPEEC)*, Nov. 2017, pp. 1–6.
[46] K. Rohloff, J. Ye, J. Loyall, and R. Schantz, "A hierarchical control system for dynamic resource management," Dept. Comput. Sci., Univ. York, York, U.K., Tech. Rep. 398, 2006, pp. 37–72.
[47] T. L. Vandoorn, J. C. Vasquez, J. D. Kooning, J. M. Guerrero, and L. Vandevelde, "MicroGrids: Hierarchical control and an overview of the control and reserve management strategies," *IEEE Ind. Electron. Mag.*, vol. 7, no. 4, pp. 42–55, Dec. 2013.
[48] J. Borges de Sousa, K. H. Johansson, J. Silva, and A. Speranzon, "A verified hierarchical control architecture for co-ordinated multi-vehicle operations," *Int. J. Adapt. Control Signal Process.*, vol. 21, nos. 2–3, pp. 159–188, 2007.
[49] Y. Li and D. Mavris, "A hierarchical control architecture for resource allocation," in *Proc. 12th Int. Conf. Control Autom. Robot. Vis. (ICARCV)*, 2012, pp. 955–959.
[50] R. Steinmetz and K. Wehrle, "2. What is this *'peer-to-peer'* about?" in *Peer-to-Peer Systems and Applications*. Springer, 2005, pp. 9–16.
[51] H. Balakrishnan, M. F. Kaashoek, D. Karger, D. Karger, R. Morris, and I. Stoica, "Looking up data in P2P systems," *Commun. ACM*, vol. 46, no. 2, pp. 43–48, 2003.
[52] D.-E. Meddour, M. Mushtaq, and T. Ahmed, "Open issues in P2P multimedia streaming," in *Proc. IEEE ICC Workshop Multimedia Commun. Workshop (MultiCom)*, Jun. 2006, pp. 43–48.
[53] V. N. Padmanabhan, H. J. Wang, and P. A. Chou, "Resilient peer-to-peer streaming," in *Proc. 11th IEEE Int. Conf. Netw. Protocols*, Nov. 2003, pp. 16–27.
[54] R. Rejaie and A. Ortega, "PALS: Peer-to-peer adaptive layered streaming," in *Proc. 13th Int. Workshop Netw. Oper. Syst. Support Digit. Audio Video*, 2003, pp. 153–161.
[55] R. H. Lasseter, "Smart distribution: Coupled microgrids," *Proc. IEEE*, vol. 99, no. 6, pp. 1074–1082, Jun. 2011.
[56] C. Park and T. Yong, "Comparative review and discussion on P2P electricity trading," *Energy Procedia*, vol. 128, pp. 3–9, Sep. 2017.
[57] W. Tushar, C. Yuen, H. Mohsenian-Rad, T. Saha, H. V. Poor, and K. L. Wood, "Transforming energy networks via peer to peer energy trading: Potential of game theoretic approaches," 2018, *arXiv:1804.00962*. [Online]. Available: https://arxiv.org/abs/1804.00962
[58] C. Zhang, J. Wu, Y. Zhou, M. Cheng, and C. Long, "Peer-to-peer energy trading in a microgrid," *Appl. Energy*, vol. 220, pp. 1–12, Jun. 2018.
[59] E. Mengelkamp, J. Gärttner, K. Rock, S. Kessler, L. Orsini, and C. Weinhardt, "Designing microgrid energy markets: A case study: The Brooklyn microgrid," *Appl. Energy*, vol. 210, pp. 870–880, Jan. 2018.
[60] T. Morstyn, A. Teytelboym, and M. D. McCulloch, "Bilateral contract networks for peer-to-peer energy trading," *IEEE Trans. Smart Grid*, vol. 10, no. 2, pp. 2026–2035, Mar. 2019.
[61] M. B. Sands. (2018). *The Brooklyn Microgrid: Blockchain-Enabled Community Power*. [Online]. Available: https://www.siew.sg/newsroom/articles/detail/2018/01/12/the-brooklyn-microgrid—blockchain-enabled-community-power
[62] L. Orsini, B. Collins, M. Webb, C. Montgomery, B. Conte, M. Adamson, P. Heitmann, S. Kessle, and M. Brown. *EXERGY Business Whitepaper: Introduction to EXERGY*. [Online]. Available: https://lo3energy.com/wp-content/uploads/2018/04/Exergy-BIZWhitepaper-v11.pdf
[63] A. Smith, T. Hargreaves, S. Hielscher, M. Martiskainen, and G. Seyfang, "Making the most of community energies: Three perspectives on grassroots innovation," *Environ. Planning A*, vol. 48, no. 2, pp. 407–432, 2016.
[64] L. Einav, C. Farronato, and J. Levin, "Peer-to-peer markets," *Annu. Rev. Econ.*, vol. 8, pp. 615–635, Oct. 2016.
[65] C. Long, J. Wu, C. Zhang, M. Cheng, and A. Al-Wakeel, "Feasibility of peer-to-peer energy trading in low voltage electrical distribution networks," *Energy Procedia*, vol. 105, pp. 2227–2232, May 2017.
[66] M. Akter, M. Mahmud, and A. M. Oo, "A hierarchical transactive energy management system for microgrids," in *Proc. IEEE Power Energy Soc. General Meeting (PESGM)*, Jul. 2016, pp. 1–5.
[67] P. Olivella-Rosell, G. Viñals-Canal, A. Sumper, R. Villafafila-Robles, B. A. Bremdal, I. Ilieva, and S. Ø. Ottesen, "Day-ahead micro-market design for distributed energy resources," in *Proc. IEEE Int. Energy Conf. (ENERGYCON)*, Apr. 2016, pp. 1–6.
[68] R. Verschae, T. Kato, and T. Matsuyama, "Energy management in prosumer communities: A coordinated approach," *Energies*, vol. 9, no. 7, p. 562, 2016.
[69] N. Liu, X. H. Yu, C. Wang, C. J. Li, L. Ma, and J. Y. Lei, "Energy-sharing model with price-based demand response for microgrids of peer-to-peer prosumers," *IEEE Trans. Power Syst.*, vol. 32, no. 5, pp. 3569–3583, Sep. 2017.
[70] B. P. Hayes, S. Thakur, and J. G. Breslin, "Co-simulation of electricity distribution networks and peer to peer energy trading platforms," *Int. J. Elect. Power Energy Syst.*, vol. 115, Feb. 2020, Art. no. 105419.
[71] I. Ilieva, B. Bremdal, S. Ottesen, J. Rajasekharan, and P. Olivella-Rosell, "Design characteristics of a smart grid dominated local market," in *Proc. CIRED Workshop*, 2016, pp. 1–4.
[72] J. Kang, R. Yu, X. Huang, S. Maharjan, Y. Zhang, and E. Hossain, "Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains," *IEEE Trans. Ind. Informat.*, vol. 13, no. 6, pp. 3154–3164, Dec. 2017.
[73] F. Moret and P. Pinson, "Energy collectives: A community and fairness based approach to future electricity markets," *IEEE Trans. Power Syst.*, vol. 34, no. 5, pp. 3994–4004, Sep. 2018.
[74] T. Morstyn and M. D. McCulloch, "Multiclass energy management for peer-to-peer energy trading driven by prosumer preferences," *IEEE Trans. Power Syst.*, vol. 34, no. 5, pp. 4005–4014, Sep. 2018.
[75] W. Tushar, B. Chai, C. Yuen, S. Huang, D. B. Smith, H. V. Poor, and Z. Yang, "Energy storage sharing in smart grid: A modified auction-based approach," *IEEE Trans. Smart Grid*, vol. 7, no. 3, pp. 1462–1475, May 2016.
[76] J. Abdella and K. Shuaib, "Peer to peer distributed energy trading in smart grids: A survey," *Energies*, vol. 11, no. 6, p. 1560, 2018.
[77] A. Malik and J. Ravishankar, "A review of demand response techniques in smart grids," in *Proc. IEEE Elect. Power Energy Conf. (EPEC)*, Oct. 2016, pp. 1–6.
[78] F. Yingdan and A. Xin, "The review of load scheduling model research based on demand response method," in *Proc. IEEE PES Asia–Pacific Power Energy Eng. Conf. (APPEEC)*, Dec. 2013, pp. 1–5.

[79] I. Koutsopoulos and L. Tassiulas, "Challenges in demand load control for the smart grid," *IEEE Netw.*, vol. 25, no. 5, pp. 16–21, Sep./Oct. 2011.

[80] Y. Wu, X. Tan, L. Qian, and D. H. K. Tsang, "Optimal management of local energy trading in future smart microgrid via pricing," in *Proc. IEEE Conf. Comput. Commun. Workshops (INFOCOM WKSHPS)*, Apr./May 2015, pp. 570–575.

[81] Y. Wu, X. Tan, L. Qian, D.-K. Tsang, W.-Z. Song, and L. Yu, "Optimal pricing and energy scheduling for hybrid energy trading market in future smart grid," *IEEE Trans. Ind. Informat.*, vol. 11, no. 6, pp. 1585–1596, Dec. 2015.

[82] H. Wang, J. X. Zhang, and F. Li, "Incentive mechanisms to enable fair renewable energy trade in smart grids," in *Proc. 6th Int. Green Comput. Conf. Sustain. Comput. Conf. (IGSC)*, Apr./May 2015, pp. 1–6.

[83] G. Tabibnia and M. D. Lieberman, "Fairness and cooperation are rewarding," *Ann. New York Acad. Sci.*, vol. 1118, no. 1, pp. 90–101, 2007.

[84] K. Zhang, Y. Mao, S. Leng, S. Maharjan, Y. Zhang, A. Vinel, and M. Jonsson, "Incentive-driven energy trading in the smart grid," *IEEE Access*, vol. 4, pp. 1243–1257, Apr. 2016.

[85] Y. Wu, X. Sun, X. Tan, L. Meng, L. Yu, W.-Z. Song, L. Yu, W.-Z. Song, and D. H.-K. Tsang, "Cooperative distributed energy generation and energy trading for future smart grid," in *Proc. 33rd Chin. Control Conf. (CCC)*, 2014, pp. 8150–8157.

[86] J. Xu and R. Zhang, "Cooperative energy trading in CoMP systems powered by smart grids," *IEEE Trans. Veh. Technol.*, vol. 65, no. 4, pp. 2142–2153, Apr. 2015.

[87] A. Mondal and S. Misra, "Game-theoretic energy trading network topology control for electric vehicles in mobile smart grid," *IET Netw.*, vol. 4, no. 4, pp. 220–228, Jul. 2015.

[88] J. Lee, J. Guo, J. Choi, and M. Zukerman, "Distributed energy trading in microgrids: A game-theoretic model and its equilibrium analysis," *IEEE Trans. Ind. Electron.*, vol. 62, no. 6, pp. 3524–3533, Jun. 2015.

[89] H. Wang, T. Huang, X. Liao, H. Abu-Rub, and G. Chen, "Reinforcement learning in energy trading game among smart microgrids," *IEEE Trans. Ind. Electron.*, vol. 63, no. 8, pp. 5109–5119, Aug. 2016.

[90] Z. Li, J. Kang, R. Yu, D. Ye, Q. Deng, and Y. Zhang, "Consortium blockchain for secure energy trading in industrial Internet of Things," *IEEE Trans. Ind. Informat.*, vol. 14, no. 8, pp. 3690–3700, Aug. 2018.

[91] F. Aloul, A. Al-Ali, R. Al-Dalky, M. Al-Mardini, and W. El-Hajj, "Smart grid security: Threats, vulnerabilities and solutions," *Int. J. Smart Grid Clean Energy*, vol. 1, no. 1, pp. 1–6, 2012.

[92] N. Z. Aitzhan and D. Svetinovic, "Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams," *IEEE Trans. Dependable Secure Comput.*, vol. 15, no. 5, pp. 840–852, Sep./Oct. 2018.

[93] T. Dimitriou and G. Karame, "Privacy-friendly tasking and trading of energy in smart grids," in *Proc. 28th Annu. ACM Symp. Appl. Comput.*, 2013, pp. 652–659.

[94] W. Han and Y. Xiao, "Privacy preservation for V2G networks in smart grid: A survey," *Comput. Commun.*, vol. 91, pp. 17–28, 2016.

[95] S. Wicker and R. Thomas, "A privacy-aware architecture for demand response systems," in *Proc. 44th Hawaii Int. Conf. Syst. Sci. (HICSS)*, 2011, pp. 1–9.

[96] K. Shuaib, E. Barka, N. A. Hussien, M. Abdel-Hafez, and M. Alahmad, "Cognitive radio for smart grid with security considerations," *Computers*, vol. 5, no. 2, p. 7, 2016.

[97] Y. He and J. Wei, "A game-theoretic model for energy trading of privacy-preserving microgrid social networks," in *Proc. IEEE Int. Conf. Smart Grid Commun. (SmartGridComm)*, Nov. 2016, pp. 388–394.

[98] J. Matamoros, D. Gregoratti, and M. Dohler, "Microgrids energy trading in islanding mode," in *Proc. IEEE 3rd Int. Conf. Smart Grid Commun. (SmartGridComm)*, Nov. 2012, pp. 49–54.

[99] R. Abe, H. Taoka, and D. McQuilkin, "Digital grid: Communicative electrical grids of the future," *IEEE Trans. Smart Grid*, vol. 2, no. 2, pp. 399–410, Jun. 2011.

[100] W. Zhong, R. Yu, S. Xie, Y. Zhang, and D. H. K. Tsang, "Software defined networking for flexible and green energy Internet," *IEEE Commun. Mag.*, vol. 54, no. 12, pp. 68–75, Dec. 2016.

[101] A. Reyna, C. Martín, J. Chen, E. Soler, and M. Díaz, "On blockchain and its integration with IoT. Challenges and opportunities," *Future Gener. Comput. Syst.*, vol. 88, pp. 173–190, Nov. 2018.

[102] T. Liu, X. Tan, B. Sun, Y. Wu, and D. H. Tsang, "Energy management of cooperative microgrids: A distributed optimization approach," *Int. J. Elect. Power Energy Syst.*, vol. 96, pp. 335–346, Mar. 2018.

[103] O. M. Longe, K. Ouahada, S. Rimer, H. C. Ferreira, and A. J. H. Vinck, "Distributed optimisation algorithm for demand side management in a grid-connected smart microgrid," *Sustainability*, vol. 9, no. 7, p. 1088, 2017.

[104] Z. Du, "The hierarchical control method for coordinating a group of connected vehicles on urban roads," Clemson Univ., Clemson, SC, USA, Tech. Rep., 2017.

[105] 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, Aug. 2018.

[106] R. Steinmetz and K. Wehrle, *Peer-to-Peer Systems and Applications*. Springer, 2005.

[107] R. W. Ferrero, S. M. Shahidehpour, and V. C. Ramesh, "Transaction analysis in deregulated power systems using game theory," *IEEE Trans. Power Syst.*, vol. 12, no. 3, pp. 1340–1347, Aug. 1997.

[108] J. S. Hong and M. Kim, "Game-theory-based approach for energy routing in a smart grid network," *J. Comput. Netw. Commun.*, vol. 2016, Dec. 2016, Art. no. 4761720.

[109] M. Iqbal, M. Azam, M. Naeem, A. Khwaja, and A. Anpalagan, "Optimization classification, algorithms and tools for renewable energy: A review," *Renew. Sustain. Energy Rev.*, vol. 39, pp. 640–654, Nov. 2014.

[110] O. Jogunola, A. Ikpehai, K. Anoh, B. Adebisi, M. Hammoudeh, S.-Y. Son, and G. Harris, "State-of-the-art and prospects for peer-to-peer transaction-based energy system," *Energies*, vol. 10, no. 12, p. 2106, 2017.

[111] H. Singh, "Introduction to game theory and its application in electric power markets," *IEEE Comput. Appl. Power*, vol. 12, no. 4, pp. 18–20, Oct. 1999.

[112] N. Capodieci, "P2P energy exchange agent platform featuring a game theory related learning negotiation algorithm," M.S. thesis, 2011.

[113] W. Tushar, T. K. Saha, C. Yuen, T. Morstyn, M. D. McCulloch, H. V. Poor, and K. L. Wood, "A motivational game-theoretic approach for peer-to-peer energy trading in the smart grid," *Appl. Energy*, vol. 243, pp. 10–20, Jun. 2019.

[114] N. A. Lynch, *Distributed Algorithms*. Amsterdam, The Netherlands: Elsevier, 1996.

[115] O. Jogunola, B. Adebisi, K. Anoh, A. Ikpehai, M. Hammoudeh, G. Harris, and H. Gacanin, "Distributed adaptive primal algorithm for P2P-ETS over unreliable communication links," *Energies*, vol. 11, no. 9, p. 2331, 2018.

[116] K. Aberer, P. Cudré-Mauroux, A. Datta, Z. Despotovic, M. Hauswirth, M. Punceva, and R. Schmidt, "P-grid: A self-organizing structured P2P system," *SIGMOD Rec.*, vol. 32, pp. 29–33, 2003.

[117] S. Noor, W. Yang, M. Guo, K. H. van Dam, and X. Wang, "Energy demand side management within micro-grid networks enhanced by blockchain," *Appl. Energy*, vol. 228, pp. 1385–1398, Aug. 2018.

[118] J. Guerrero, A. C. Chapman, and G. Verbič, "Decentralized P2P energy trading under network constraints in a low-voltage network," *IEEE Trans. Smart Grid*, vol. 10, no. 5, pp. 5163–5173, Sep. 2018.

[119] H. Nabati and J. Y. Yu, "Distributed, private, and derandomized allocation algorithm for EV charging," in *Proc. IEEE Int. Smart Cities Conf. (ISC2)*, Sep. 2018, pp. 1–8.

[120] S. E. Alam, R. Shorten, F. Wirth, and J. Y. Yu, "Communication-efficient distributed multi-resource allocation," in *Proc. IEEE Int. Smart Cities Conf. (ISC2)*, Sep. 2018, pp. 1–8.

[121] E. Sorin, L. Bobo, and P. Pinson, "Consensus-based approach to peer-to-peer electricity markets with product differentiation," *IEEE Trans. Power Syst.*, vol. 34, no. 2, pp. 994–1004, Mar. 2018.

[122] D. Mingxiao, M. Xiaofeng, Z. Zhe, W. Xiangwei, and C. Qijun, "A review on consensus algorithm of blockchain," in *Proc. IEEE Int. Conf. Syst., Man, (SMC)*, Oct. 2017, pp. 2567–2572.

[123] C. Pop, T. Cioara, M. Antal, I. Anghel, I. Salomie, and M. Bertoncini, "Blockchain based decentralized management of demand response programs in smart energy grids," *Sensors*, vol. 18, no. 1, p. 162, Jan. 2018.

[124] R. Chitchyan and J. Murkin, "Review of blockchain technology and its expectations: Case of the energy sector," 2018, *arXiv:1803.03567*. [Online]. Available: https://arxiv.org/abs/1803.03567

[125] F. Casino, T. K. Dasaklis, and C. Patsakis, "A systematic literature review of blockchain-based applications: Current status, classification and open issues," *Telematics Inform.*, vol. 36, pp. 55–81, Mar. 2018.

[126] A. G. Azar, M. Afsharchi, M. Davoodi, and B. S. Bigham, "A multi-objective market-driven framework for power matching in the smart grid," *Eng. Appl. Artif. Intell.*, vol. 70, pp. 199–215, Apr. 2018.

[127] B. Skantze, M. Ilic, and J. Chapman, "Stochastic modeling of electric power prices in a multi-market environment," in *Proc. IEEE Power Eng. Soc. Winter Meeting. Conf.*, vol. 2, Jan. 2000, pp. 1109–1114.

[128] J. Yue, Z. Hu, A. Anvari-Moghaddam, and J. M. Guerrero, "A multi-market-driven approach to energy scheduling of smart microgrids in distribution networks," *Sustainability*, vol. 11, no. 2, p. 301, 2019.

[129] Z. Abdmouleh, A. Gastli, L. Ben-Brahim, M. Haouari, and N. A. Al-Emadi, "Review of optimization techniques applied for the integration of distributed generation from renewable energy sources," *Renew. Energy*, vol. 113, pp. 266–280, Dec. 2017.

[130] F. Wang, L. Philip, and D. W. Cheung, "Combining technical trading rules using particle swarm optimization," *Expert Syst. Appl.*, vol. 41, no. 6, pp. 3016–3026, 2014.

[131] V. R. Pandi, H. H. Zeineldin, and W. Xiao, "Determining optimal location and size of distributed generation resources considering harmonic and protection coordination limits," *IEEE Trans. Power Syst.*, vol. 28, no. 2, pp. 1245–1254, May 2013.

[132] D. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning*. Boston, MA, USA: Addison-Wesley, 2012.

[133] S. G. Koo, C. G. Lee, and K. Kannan, "A genetic-algorithm-based neighbor-selection strategy for hybrid peer-to-peer networks," in *Proc. 13th Int. Conf. Comput. Commun. Netw.*, Oct. 2004, pp. 469–474.

[134] J. H. Choi, H. Ahn, and I. Han, "Utility-based double auction mechanism using genetic algorithms," *Expert Syst. Appl.*, vol. 34, no. 1, pp. 150–158, 2008.

[135] K. Shuaib, E. Barka, J. A. Abdella, F. Sallabi, M. Abdel-Hafez, and A. Al-Fuqaha, "Secure plug-in electric vehicle (PEV) charging in a smart grid network," *Energies*, vol. 10, no. 7, p. 1024, 2017.

[136] K. Shuaib, E. Barka, J. A. Abdella, and F. Sallabi, "Secure charging and payment protocol (SCPP) for roaming plug-in electric vehicles," in *Proc. 4th Int. Conf. Control, Decis. Inf. Technol. (CoDIT)*, Apr. 2017, pp. 173–178.

[137] M. A. Mustafa, N. Zhang, G. Kalogridis, and Z. Fan, "Roaming electric vehicle charging and billing: An anonymous multi-user protocol," in *Proc. SmartGridComm*, 2014, pp. 939–945.

[138] M. J. Osborne, *An Introduction to Game Theory*. New York, NY, USA: Oxford Univ. Press, 2004, no. 3.

[139] S. Park, J. Lee, S. Bae, G. Hwang, and J. K. Choi, "Contribution-based energy-trading mechanism in microgrids for future smart grid: A game theoretic approach," *IEEE Trans. Ind. Electron.*, vol. 63, no. 7, pp. 4255–4265, Jul. 2016.

[140] B. Celik, R. Roche, D. Bouquain, and A. Miraoui, "Coordinated neighborhood energy sharing using game theory and multi-agent systems," in *Proc. IEEE Manchester PowerTech*, Jun. 2017, pp. 1–6.

[141] A. Khalid, N. Javaid, M. Ilahi, T. Saba, and A. Rehman, A. Mateen, "Enhanced time-of-use electricity price rate using game theory," *Electronics*, vol. 8, p. 48, Jan. 2019.

[142] T. Ma, J. Wu, L. Hao, H. Yan, and D. Li, "A real-time pricing scheme for energy management in integrated energy systems: A Stackelberg game approach," *Energies*, vol. 11, no. 10, p. 2858, 2018.

[143] G. Tel, *Introduction to Distributed Algorithms*. Cambridge, U.K.: Cambridge Univ. Press, 2000.

[144] L. Su, "On the convergence rate of average consensus and distributed optimization over unreliable networks," in *Proc. 52nd Asilomar Conf. Signals, Syst., Comput.*, 2018, pp. 43–47.

[145] A. D. Dominguez-Garcia, C. N. Hadjicostis, and N. H. Vaidya, "Resilient networked control of distributed energy resources," *IEEE J. Sel. Areas Commun.*, vol. 30, no. 6, pp. 1137–1148, Jul. 2012.

[146] C. N. Hadjicostis, N. H. Vaidya, and A. D. Domínguez-García, "Robust distributed average consensus via exchange of running sums," *IEEE Trans. Autom. Control*, vol. 61, no. 6, pp. 1492–1507, Jun. 2016.

[147] R. Carli, G. Notarstefano, L. Schenato, and D. Varagnolo, "Analysis of Newton-Raphson consensus for multi-agent convex optimization under asynchronous and lossy communications," in *Proc. 54th IEEE Conf. Decis. Control (CDC)*, Dec. 2015, pp. 418–424.

[148] H. Dagdougui and R. Sacile, "Decentralized control of the power flows in a network of smart microgrids modeled as a team of cooperative agents," *IEEE Trans. Control Syst. Technol.*, vol. 22, no. 2, pp. 510–519, Mar. 2014.

[149] A. Cortés and S. Martínez, "On distributed reactive power and storage control on microgrids," *Int. J. Robust Nonlinear Control*, vol. 26, no. 14, pp. 3150–3169, 2016.

[150] M. Kraning, E. Chu, J. Lavaei, and S. Boyd, "Dynamic network energy management via proximal message passing," *Found. Trends Optim.*, vol. 1, no. 2, pp. 73–126, 2014.

[151] G. Hug, S. Kar, and C. Wu, "Consensus + innovations approach for distributed multiagent coordination in a microgrid," *IEEE Trans. Smart Grid*, vol. 6, no. 4, pp. 1893–1903, Jul. 2015.

[152] T. Morstyn, B. Hredzak, and V. G. Agelidis, "Network topology independent multi-agent dynamic optimal power flow for microgrids with distributed energy storage systems," *IEEE Trans. Smart Grid*, vol. 9, no. 4, pp. 3419–3429, 2016.

[153] A. G. Azar and R. H. Jacobsen, "Appliance scheduling optimization for demand response," *Int. J. Adv. Intell. Syst.*, vol. 9, nos. 1–2, pp. 50–64, 2016.

[154] B. Chai, Z. Yang, K. Gao, and T. Zhao, "Iterative learning for optimal residential load scheduling in smart grid," *Ad Hoc Netw.*, vol. 41, pp. 99–111, May 2016.

[155] D. Jornada and V. J. Leon, "Robustness methodology to aid multiobjective decision making in the electricity generation capacity expansion problem to minimize cost and water withdrawal," *Appl. Energy*, vol. 162, pp. 1089–1108, Jan. 2016.

[156] R. Eberhart and J. Kennedy, "Particle swarm optimization," in *Proc. IEEE Int. Conf. Neural Netw.*, vol. 4, Nov./Dec. 1995, pp. 1942–1948.

[157] R. Eberhart and J. Kennedy, "A new optimizer using particle swarm theory," in *Proc. MHS 6th Int. Symp. Micro Mach. Hum. Sci.*, 1995, pp. 39–43.

[158] E. Cuevas, M. Cienfuegos, D. Zaldívar, and M. Pérez-Cisneros, "A swarm optimization algorithm inspired in the behavior of the social-spider," *Expert Syst. Appl.*, vol. 40, no. 16, pp. 6374–6384, 2013.

[159] A. M. El-Zonkoly, "Optimal placement of multi-distributed generation units including different load models using particle swarm optimisation," *IET Gener., Transmiss. Distrib.*, vol. 5, no. 7, pp. 760–771, Jul. 2011.

[160] A. Singh, A. Shrestha, S. Phuyal, B. Adhikari, and A. Papadakis, "Particle swarm optimization approach for distributed generation allocation planning for voltage profile improvement," presented at the 11th Int. Conf. Deregulated Eng. Market Issues South Eastern Eur., Nicosia, Cyprus, 2018.

[161] S. Kansal, V. Kumar, and B. Tyagi, "Optimal placement of different type of DG sources in distribution networks," *Int. J. Elect. Power Energy Syst.*, vol. 53, pp. 752–760, Dec. 2013.

[162] C. Changsong, D. Shanxu, C. Tao, L. Bangyin, and Y. Jinjun, "Energy trading model for optimal microgrid scheduling based on genetic algorithm," in *Proc. IEEE 6th Int. Power Electron. Motion Control Conf.*, May 2009, pp. 2136–2139.

[163] D. J. Vergados, I. Mamounakis, P. Makris, and E. Varvarigos, "Prosumer clustering into virtual microgrids for cost reduction in renewable energy trading markets," *Sustain. Energy, Grids Netw.*, vol. 7, pp. 90–103, Sep. 2016.

[164] T. Baroche, P. Pinson, and H. B. Ahmed, "Exogenous approach to grid cost allocation in peer-to-peer electricity markets," 2018, *arXiv:1803.02159*. [Online]. Available: https://arxiv.org/abs/1803.02159

[165] openADR. (Apr. 15, 2019). *Connecting Smart Energy to the Grid*. [Online]. Available: https://www.openadr.org/

[166] OASIS. (Apr. 15, 2019). *Open Standards-Open Source*. [Online]. Available: https://www.oasis-open.org/

[167] Y. Yu, Y. Guo, W. Min, and F. Zeng, "Trusted transactions in micro-grid based on blockchain," *Energies*, vol. 12, no. 10, p. 1952, 2019.

[168] M. S. Tundal, "Utilizing blockchain technology for settlement in a micro-grid," NTNU, Ålesund, Norway, Tech. Rep., 2018.

[169] J. Sagisi. (Mar. 26, 2019). *Trading Energy: Will Blockchain Disrupt the Energy Industry?* [Online]. Available: https://hackernoon.com/trading-energy-will-blockchain-disrupt-the-energy-industry-34a6a9e90112

[170] A. Pellegrini, *5 Examples How AI and Blockchain Will Change Energy Industry*.

[171] VERV. (2019). *Unlocking Unique Energy Insights With AI*. [Online]. Available: https://verv.energy/

[172] A. Reed. (Aug. 12, 2019). *P2P Energy Trading on the Blockchain*. [Online]. Available: https://medium.com/wolverineblockchain/p2p-energy-trading-on-the-blockchain-db61fa2c8caf

[173] C. Schillings, E. B. Pereira, R. Perez, R. Meyer, F. Trieb, and D. Renné, "High resolution solar energy resource assessment within the UNEP-project SWERA," in *Proc. World Renew. Energy Congr. VII*, Cologne, Germany, vol. 29, 2002.

[174] R. P. Bhatt, "Hydropower development in Nepal-climate change, impacts and implications," in *Renewable Hydropower Technologies*. Rijeka, Croatia: IntechOpen, 2017.

[175] Alternative Energy Promotion Center, Kathmandu, Nepal. (2014). *Project Inception Report: Renewable Energy for Rural Livelihoods (RERL)*. [Online]. Available: https://www.google.com.np/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&cad=rja&uact=8&ved=0ahUKEwihlubT7YnYAhVDv48KHVgiC70QFghDMAU&url=https%3A%2F%2Finfo.undp.org%2Fdocs%2Fpdc%2FDocuments%2FNPL%2FInception%2520Report_RERL_Final_13%2520Mar%25202015.docx&usg=AOvVaw1bN_VRdCUtDrc6KJcGu6v2

[176] R. S. Shrestha, "Electricity crisis (load shedding) in Nepal, its manifestations and ramifications," *Hydro Nepal, J. Water, Energy Environ.*, vol. 6, pp. 7–17, Jan. 2010.

[177] Energypedia. *Nepal Energy Situation*. [Online]. Available: https://energypedia.info/wiki/Nepal_Energy_Situation

[178] A. Shrestha, "Planning, design and optimization of distribution system for affected area of upper Karnali hydropower project," M.S. thesis, Dept. Mech. Eng., Kathmandu Univ., Kathmandu, Nepal, 2017.

[179] A. Shrestha, B. B. Shah, B. R. Gautam, and S. K. Jha, "Optimal grid network for rural electrification of Upper Karnali hydro project affected area," presented at the IEEE Region 10 Humanitarian Technol. Conf., Agra, India, 2017.

[180] Ministry of Energy, Water Resources and Irrigation, Government of Nepal, Kathmandu, Nepal. (2018). *Environmental and Social Management Framework for Nepal: Private Sector-Led mini-Grid rnergy Access Project*. [Online]. Available: https://www.aepc.gov.np/uploads/docs/final-esmf-nepal-minigrid-project-1545296018.pdf

[181] AEPC. *Mission, Vision and Strategy*. [Online]. Available: https://www.aepc.gov.np/mission-vision-and-strategy

[182] NEA, Kathmandu, Nepal. (1993). *Electricity Regulation, 2050*. [Online]. Available: http://www.nea.org.np/images/supportive_docs/Electricity_Regulation_2050-english.pdf

[183] B. R. Poudel, S. Shrestha, S. Kandel, and K. C. Das, *Solar Pico PV Market Potential in Nepal: Current Trend and Future Perspective*. Patan, Nepal: SNV Neatherlands Development Organisation, 2014.

[184] (2017). *Design, Supply and Installation of Advanced Metering Infrastructure (Smart Meters and Associated Facilities) System*. [Online]. Available: https://www.nea.org.np/admin/assets/uploads/supportive_docs/1505294924_KVSMP%20Vol-2.pdf

[185] ADB, NEPAL, Power Transmiss. Distrib. Efficiency Enhancement Project. (2017). *Project Administration Manual*. [Online]. Available: https://www.adb.org/sites/default/files/project-documents/50059/50059-002-pam-en.pdf

[186] AEPC, Ministry of Population and Environment, Lalitpur, Nepal. (2016). *Renewable Energy Subsidy Policy, 2073 BS (Unofficial Translation)*. [Online]. Available: https://www.aepc.gov.np/uploads/docs/2018-06-19_RE%20Subsidy%20Policy,%202073%20(English).pdf

[187] B. Mainali and S. Silveira, "Renewable energy markets in rural electrification: Country case Nepal," *Energy Sustain. Develop.*, vol. 16, no. 2, pp. 168–178, 2012.

[188] M. Adhikari, B. R. Pahari, and R. Shrestha, "Impact of renewable energy subsidy policy in rural electrification," in *Proc. IOE Graduate Conf.*, Lalitpur, Nepal, vol. 5, 2017.

[189] S. Sah, A. Shrestha, and A. Papadakis, "Cost-effective and reliable energy system for Kathmandu University complex," presented at the 11th Int. Conf. Deregulated Eng. Market Issues South Eastern Europe, Nicosia, Cyprus, 2018.

[190] B. Bhandari, S.-H. Ahn, and T.-B. Ahn, "Optimization of hybrid renewable energy power system for remote installations: Case studies for mountain and island," *Int. J. Precis. Eng. Manuf.*, vol. 17, no. 6, pp. 815–822, 2016.

[191] B. Bhandari, K.-T. Lee, G.-Y. Lee, Y.-M. Cho, and S.-H. Ahn, "Optimization of hybrid renewable energy power systems: A review," *Int. J. Precis. Eng. Manuf.-Green Technol.*, vol. 2, no. 1, pp. 99–112, 2015.

[192] B. Bhandari, K.-T. Lee, C. S. Lee, C.-K. Song, R. K. Maskey, and S.-H. Ahn, "A novel off-grid hybrid power system comprised of solar photovoltaic, wind, and hydro energy sources," *Appl. Energy*, vol. 133, pp. 236–242, Nov. 2014.

[193] S. C. Bhattacharyya and D. Palit, *Mini-Grids for Rural Electrification of Developing Countries: Analysis and Case Studies From South Asia*. Springer, 2014.

[194] N. P. Chaudhary and R. Dhital, "Micro & mini hydro based mini-grid for rural energy access in Taplejung, Nepal," in *Proc. IOE Graduate Conf.*, 2016, pp. 71–83.

[195] Ministry of Energy, Water Resources and Irrigation, Government of Nepal, Kathmandu, Nepal. (2013). *Techno-Socio-Economic Study of Baglung Mini Grid*. [Online]. Available: https://www.aepc.gov.np/uploads/docs/2018-07-09_report_on_techno_Socio_economic_Study_on_Baglung_Mini_Grid.pdf

[196] B. Shakya, A. Bruce, and I. MacGill, "Micro hydro interconnected mini grids in Nepal: Potential and pitfalls," in *Proc. Asia–Pacific Solar Res. Conf.*, Brisbane, QLD, Australia, 2015.

[197] *Himal Power Hands Over Mini Hydro Plant to Khimti Rural Electric Cooperative*. [Online]. Available: https://www.waterpowermagazine.com/news/newshimal-power-hands-over-mini-hydro-plant-to-khimti-rural-electric-cooperative/

[198] B. Bhandari, K.-T. Lee, W.-S. Chu, C. S. Lee, C.-K. Son, P. Bhandari, and S.-H. Ahn, "Socio-economic impact of renewable energy-based power system in mountainous villages of Nepal," *Int. J. Precis. Eng. Manuf.-Green Technol.*, vol. 4, no. 1, pp. 37–44, 2017.

[199] AEPC. *Mini/Micro Hydro Technology*. [Online]. Available: http://www.aepc.gov.np/?option=renewable&page=subrenewable&mid=2&sub_id=14&id=4

[200] *Impact Study of Community Electrification*, Alternative Energy Promotion Center, Lalitpur, Nepal, AEPC/NRREP/CESC, 2017.

[201] T. S. Rappaport, *Wireless Communications: Principles and Practice*. Upper Saddle River, NJ, USA: Prentice-Hall, 1996.

[202] F. H. Fitzek and M. D. Katz, *Cooperation in Wireless Networks: Principles and Applications*. Springer, 2006.

[203] D. Sze, "A metropolitan area network," *IEEE J. Sel. Areas Commun.*, vol. JSAC-3, no. 6, pp. 815–824, Nov. 1985.

[204] M. Kuzlu, M. Pipattanasomporn, and M. Rahman, "Communication network requirements for major smart grid applications in HAN, NAN and WAN," *Comput. Netw.*, vol. 67, pp. 74–88, Jul. 2014.

[205] C. Eklund, R. B. Marks, K. L. Stanwood, and S. Wang, "IEEE standard 802.16: A technical overview of the wireless MAN air interface for broadband wireless access," *IEEE Commun. Mag.*, vol. 40, no. 6, pp. 98–107, Jun. 2002.

[206] G. Clapp, M. Singh, and S. Karr, "Metropolitan area network architecture and services," in *Proc. IEEE Global Telecommun. Conf. Exhib. Commun. Inf. Age*, Dec. 1988, pp. 1246–1254.

[207] W. K. Chen, *The Electrical Engineering Handbook*. Amsterdam, The Netherlands: Elsevier, 2004.

[208] T. Sousa, T. Soares, P. Pinson, F. Moret, T. Baroche, and E. Sorin, "Peer-to-peer and community-based markets: A comprehensive review," *Renew. Sustain. Energy Rev.*, vol. 104, pp. 367–378, Apr. 2019.



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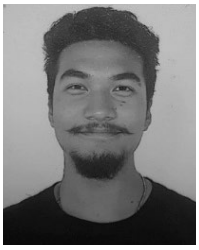
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