IJEW

International Journal of Engineering Works
https://www.ijew.io/
ISSN-p: 2521-2419
ISSN-e: 2409-2770
Vol. 11, Issue 09, PP. 165-170 September 2024
https://doi.org/10.34259/ijew.24.1109165170
Check for updates

Enhancing Energy Security in Pakistan through Smart Grid Technology and Dynamic Scheduling

Umar Khayam[1], Muhammad Umair[2], Farhan Ullah[3]
[1,2,3]Department of US-Pakistan Center for Advanced Studies in Energy (USPCAS-E), UET Peshawar
uk_94@outlook.com[1], umairafridy@gmail.com[2], farhan.ullah58@gmail.com[3]
Received: 03 August, Revised: 04 September, Accepted: 08 September

Abstract— The increasing global demand for electricity, coupled with the imperative to reduce greenhouse gas emissions, has propelled the transformation of traditional power grids into intelligent and adaptive systems known as Smart Grids. At the heart of this transformation lies Dynamic Load Scheduling (DLS), an innovative approach that seeks to enhance grid efficiency, optimize energy utilization, and foster grid resiliency. This study undertakes a comprehensive exploration of DLS within the context of a Smart Grid scenario, employing a mixed-methods research approach encompassing literature reviews, case studies, quantitative analysis. The study's outcomes contribute to the growing body of knowledge on Smart Grid technologies, specifically highlighting the pivotal role that DLS plays in transforming the future of electrical power systems. With the potential to revolutionize energy management strategies, DLS within Smart Grids emerges as a cornerstone for sustainable, reliable, and resilient energy systems. This research offers a roadmap for policymakers, utilities, and researchers to navigate the complex landscape of Smart Grids and harness the transformative power of Dynamic Load Scheduling. This abstract provides a concise overview of the detailed exploration of Dynamic Load Scheduling in Smart Grids and its role in offering different dynamics.

Keywords— World energy council; Distributed energy resources; information and communication technologies, Energy security, Smart Grid.

I. Introduction

The World Energy Council's definition of energy security is “Management of primary energy supply from domestic and external sources, structural reliability to meet current and future needs”. Pakistan is ranked #71, in terms of energy security by WEC for the year 2019, among a list of 128 countries [1]. Pakistan’s peak load demand stands at 27,128 MW (FY 19-20) while it is expected to reach 103,065 MW, in the long run, till 2047 as predicted by IGCEP 2047 under normal economic growth i.e., 4-5.5% GDP [2].

Now, keeping in view the economic life of power projects about 12000 MW of energy will be retired by then. Currently, Pakistan imports thirty percent (30%) of energy requirements in the form of raw materials such as oil, gas and RLNG. Forty-one percent (41%) of the current installed capacity utilizes fuel that is imported. Hence, it remains an energy timid country in the situation of the ongoing financial slump [3].

The conventional electrical grid was conceived a long time ago when needs were simple and satiable. It was designed to provide consumers with load demands, such as light bulbs and a TV at most, and bill them once a month. This unidirectional nature of the grid made it difficult to react to the perpetual energy needs of the century. A solution to this problem is a Smart Grid or a micro grid as it incorporates a bi-directional dialogue where electricity as well as sufficient-information is exchanged between relevant stakeholders. The smart grid is said to be able to reshape the aging infrastructure of Conventional power grids to help manage electricity needs through better communications [4].

Generation of electrical energy is distributed throughout the day. The energy that we use in our homes is generated miles away. That being said, Generation at each instant must equal demand across the entire grid or else the system may be subject to uncertainties and contingencies. Smart grid technologies give grid operators extensive data so they can monitor and control energy use in real time [5]. Engineers will be able to more accurately and consistently regulate the generation of electricity in grid control rooms, obviating the need to start up expensive backup power plants.

Through dynamic scheduling, the distribution aptitude of the smart grid combats variations and interruption by intelligently recognizing the issues, rerouting and reinstating power transfer. Because it offers real-time information and manages uncertainties in stochastic variables, dynamic scheduling is more beneficial in smart grid scenarios [6]. Dynamic scheduling stimulates race and provides multiple choices by allowing energy customers to avail definite facilities from bodies beyond its physical-host control area.

The same is the case for prosumers and generators that can sell beyond their control area in an open market scenario and even in a local energy market. Thus, aggregating the actual number of sellers and buyers leads to increased competition and eventually lower costs and prices [7].

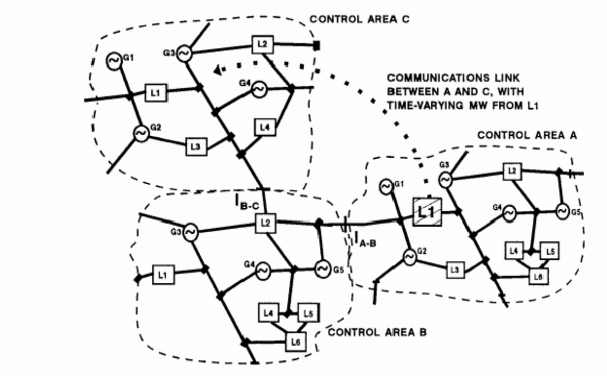

Figure 1. Schematic of multiple control areas and dynamic scheduling of Load L1 from its physical area A to its electronic host control area C.

II. LITERATURE REVIEW

Dynamic load scheduling in microgrids has emerged as a critical area of research due to its potential to optimize energy usage, enhance grid stability, and facilitate the integration of renewable energy sources. Traditional centralized approaches to load scheduling often encounter scalability and efficiency challenges in the context of rapidly evolving energy systems. In response, researchers have increasingly turned to decentralized technologies such as blockchain to enable more flexible and efficient load-scheduling mechanisms.

Blockchain technology, originally designed as the underlying framework for cryptocurrencies, offers a decentralized and tamper-resistant ledger system that can securely record and validate transactions among multiple parties without the need for intermediaries. When applied to microgrid management, blockchain holds promise for enabling peer-to-peer energy transactions, facilitating real-time data exchange, and automating load scheduling processes.

Several studies have investigated the potential benefits of integrating blockchain technology into microgrid operations. For instance, Zhang et al. [8] proposed a blockchain-based energy trading platform for microgrids, demonstrating its ability to improve energy efficiency and reduce operational costs by optimizing load scheduling decisions. Similarly, Liang et al. [9] developed a blockchain-enabled demand response mechanism that allows consumers to adjust their energy consumption patterns dynamically, thereby contributing to grid stability and reliability.

Moreover, the combination of blockchain technology with Internet of Things (IoT) devices and smart meters offers enhanced capabilities for real-time monitoring and control of energy flows within microgrids. By leveraging data from IoT sensors, blockchain-based load scheduling algorithms can adapt to changing grid conditions and consumer preferences more effectively, thereby improving overall system efficiency and resilience [10].

However, while blockchain technology holds promise for enhancing dynamic load scheduling in microgrids, several challenges remain to be addressed. Scalability, interoperability, and privacy concerns are among the key obstacles that need to be overcome to realize the full potential of blockchain-based solutions in this context [11]. Additionally, the integration of blockchain with existing ICT infrastructure poses technical and regulatory challenges that require careful consideration.

In summary, the literature suggests that incorporating blockchain technology as an ICT solution for dynamic load scheduling in microgrids holds significant promise for improving grid efficiency, promoting renewable energy integration, and enabling more flexible energy management strategies. However, further research is needed to address technical challenges and validate the scalability and reliability of blockchain-based microgrid management systems in real-world settings.

III. RESEARCH METHODOLOGY

A proposed architecture that identifies and categorizes key components and tools in P2P exchange, centred respectively on the part they are supposed to perform, is shown in Fig 2.

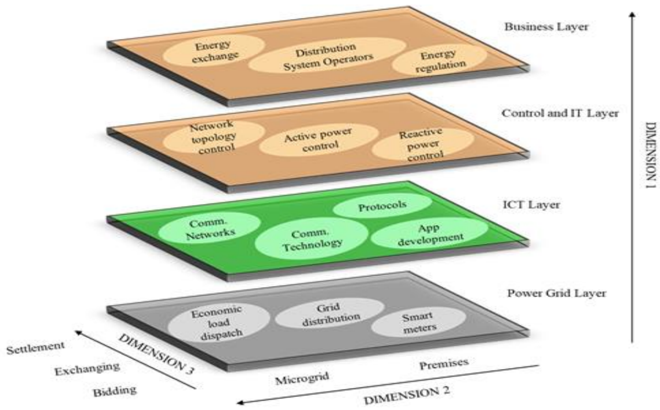

Figure 2: Four layered architecture (P2P energy trading)

The system architecture has three dimensions. The first dimension encompasses three functions involved in P2P trading. These functions have been categorized into four layers. Static Loads are considered for developing the presented scenario, in order to infer about using Blockchain technology as the main ICT in Microgrid and asses the part played by Dynamic load scheduling. Assumptions about the allocation of mandatory energy from Conventional grid is made based on average energy requirements of the MG. Which can be subject to variation on the day-ahead Schedule. And, on an hourly basis in case of peak load demand.

In short, the focus of planning must shift according to energy consumption data collected from MG, the balance of energy within the MG and the state of the whole connected electrical network being considered too.

Daily Load vs. generation curve is shown in figure 3 after incorporating 20% terminal and distribution losses. The graph obtained is shown.

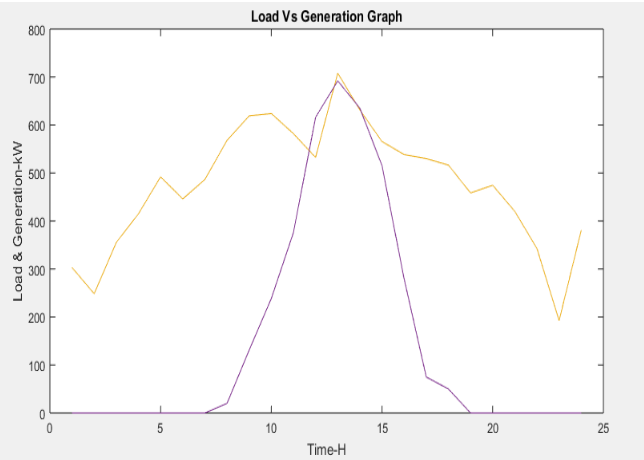

Figure 3: Daily Load verses Generation Curve (yellow curve shows load, purple curve shows generation)

Solar irradiance

A usual hotter day of 10 June Location Peshawar (34 Latitude, 71 Longitude) is selected. Agreeing to the [12] PVGIS software the normal generation of PV in typical summer day of June is 7.68kw/meter square/day. The sunshine on the selected day is 8hours starting from 8:00AM-4:00PM. The hourly PV irradiance for the considered location is shown in figure 4 and from this graph per hour generation of 1kw PV system will be obtained with help of PVGIS software:

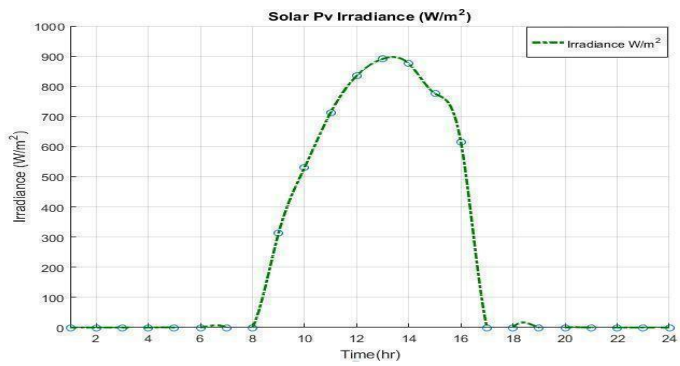

Figure 4: Daily Solar Irradiance by PVGIS Software

The simulation is set up for an intraday energy trading in order to reduce the granularity and get close to a more real time approach, furthermore, indicating the discrete nature of the market. A 60-min time slot is considered as 't ∈ T' for a duration of a month and eventually of one year. The LEM consists of i=14 agents;

The conventional utility grid acts as a producer and helps in balancing generation G^it and demandD^it. Therefore, I= {1, 2,..., n-1, n} are the total market agents. The agents' need is aggregated from Agents' profiles e.g. A [1]. agents' generation is taken from Energy management systems provided at the agents' premises, also the smart meters can communicate data both ways.

Using game theory, Simulation of a single time period is carried out. P2P bidding is considered as a non-cooperative game because all the players make independent decisions. All the energy agents are the players of the game having demands that can or cannot be transferred in time in order to adjust for various conditions such as Demand response and demand side management. All the agents are characterized as being noble citizens contributing to energy balance. However, for the Microgrid to act and operate independently, it needs to have adequate resources to manage demand at its premises.

I is equal to 1,2,3,...,n, where n is the total number of players in the game and I is the set of all of them.In a strategy combination S_ji^i, j^i=1,2,...,m_i, where m_i stands for the number of strategies a player can choose, a player's strategy is the decided status of flexible demand, which directly affects the amount of electricity injected or absorbed.. S^iis the set of strategies of player i. m_i is equal to 2, as flexible demand is either off or on during the energy exchange time period.

'S' is the set of all combinations in the game.

$$M=\prod_{i=1}^{n} \quad m_i \qquad (1)$$

(1) is the number of total strategies.

$$P_k^i = \frac{E_{o-i-k} * C_k^i}{|E_{mgo-k}|} \qquad (2)$$

(2) describes the award as a result of the participants' action, inspires him to implement a design and is, therefore, a key to implement his behavior.

A strategy combination in 'S' is given as k, where k ∈[1,M], $PO_k^i$is the payoff function of player i in (E_{o-i-k}) is the amount of energy injected or absorbed by player i in strategy combination k; $|(E_{mgo-k})|$, is the absolute amount of electrical energy exchange in strategy combination k between the conventional grid and the microgrid;

C_k^i: Represents the comfort index of player i in strategy combination in k. it is introduced in the payoff function in order to ensure that the scheduling of flexible demand, in response to demand response or demand side management, does not worsen customer comfort. Particularly in cases where the use of energy is intended for air conditioning or water conditioning loads. If a strategy chosen by player i does not lead to initiate comfort violation,C_k^i takes 1 as a value and hence the strategy is approved. Otherwise, 0 and rejected.

Air conditioning Load and Water conditioning load is represented as a percentage of Maximum Demand. Considering that all the buildings are well insulated that can keep comfort levels in limit for one time period.

TABLE I. CONFORT INDEX

Strategy Corresponding to Temp update	T_k^i<T_{min}^i	$T_{min}^i \leq T_k^i \leq T_{max}^i$	T_k^i>T_{max}^i
Strategy One (flexible demand Off)	C_k^i=1	C_k^i=1	C_k^i= 1
Strategy Two (flexible demand On)	C_k^i=1	C_k^i=1	C_k^i=0

The associated payoff value of player i can be calculated, given a strategy combination 's', denoted by $U^i(s)$. It can be noted that C_k^i is used to implement Demand response or to an intended degree of demand side management.

Nash equilibrium is equal to solving the following equation,

$$\text{Min}\sum_{i\in I} \quad [\beta^i - U^i(\sigma)]$$
$$\text{s.t,} \quad U_j^i(\sigma_j^{*-i}, \sigma_j^i) - \beta^i \leq 0$$
$$\forall J^i = 1,2,..,m^i \qquad \forall i \in I$$
$$\sum_{ji=1}^{m^i} \quad \sigma_{ji}^i = 1 \qquad \forall i \in I$$
$$\sigma_{ji}^i \geq 0 \qquad \forall J^i = 1,2,..,m^i \qquad \forall i \in I \quad (3)$$

'β^i' is an auxiliary variable, calculated by solving the optimization problem expressed in eq.3, represents the highest possible payoff value of player 'i'. As we know $U_j^i(\sigma_j^i)$ stands for the payoff value of player i in strategy combination σ_j^i, the objective function is to minimize the sum of differences between the highest possible payoff value and actual payoff value of player i ,$U_j^i(\sigma_j^i)$ so that each player has a payoff value close to the highest possible after optimization.

IV. RESULTS AND DISCUSSION

The intake of energy is prioritized as follows:

- First priority is to allocate any excess generation from solar within the microgrid.
- Second priority is the conventional grid, if local generation is unable to meet demand Microgrid takes energy from a state distribution company and fulfils load demand.
- The third priority is based around Diesel/Gas powered power plants, its operating times will determine peak-hours in case of peak demand.

Scenario:(interval of interest)

According to the Load-generation graph, as shown in figure 3, energy requirement during interval 08-09 am is 568 kWh. Similarly, the generation graph suggests total generated energy within the microgrid during interval '8' to be 20 kWh from 8-9 am. The surplus-deficit graph, shown in Fig 3.1, indicates that the microgrid along with the conventional grid can satisfy demands beyond interval '8' without the operation of D/G generator till interval.

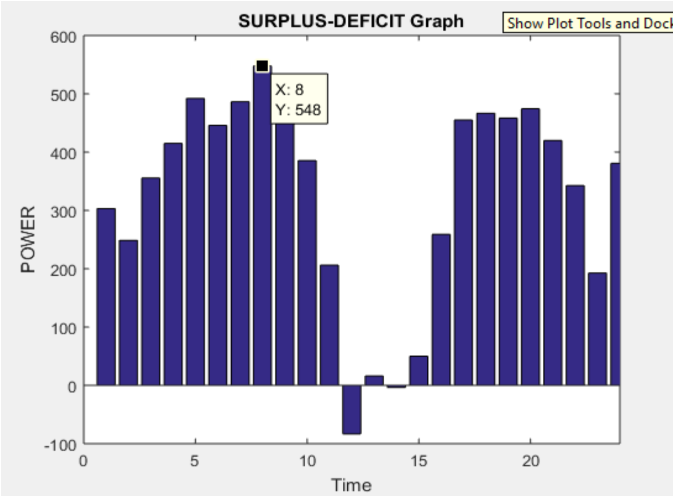

Figure 5: Surplus - Deficit graph

However, as we already said that the conventional grid in its forecast is liable for providing only the average demand of 500 kW, the existing deficit of 48 kWh must be provided by the D/G generator (if an import from a neighbouring grid cannot be availed as considered in our approach). The D/G generator having the capacity of delivering 250 kW at full load is operating for an energy demand of 48 kWh does not seem to be an optimized option.

That being said, A more modern solution to this situation is demand scheduling in such a way that it does not compromise human comfort. Provided the exact amount of flexible demand and considering all factors that could vile up system parameters, this shortage of 48 kWh can be shifted to a healthy interval i.e., from 08-09 am to any other interval provided that all parameters are within limits. Due to a higher generation factor, the scheduled energy will cost less than its cost during interval 8 which being a scarce interval would have led to a higher price of energy than during an interval of high generation factor. Also, by doing so, the microgrid can avoid periods of energy abundance that could saturate the market.

On the other hand, the energy provided by prosumers committing themselves to the utility's scheduling strategy resulted in increased revenue. because if it wasn't for the scheduling signal, prosumers would have been transacting this much amount of energy with the grid at market clearing price (which is the lowest of all price limits).

One of the most potential and cost-efficient flexibility resources to provide the needed balancing services is customer demand response. However, customers should have enough motivation to incur discomfort cost by reacting to the price signals. Demand response programs aim to incentivize customers to reshape their demand in response to the market prices. Calculations suggest that interval '8' needs to be scheduled, as shown in figure 3.

Since the operation of D/G generators is not feasible for interval '8', the micro grid will opt for demand response strategies. In our case we have assumed all customers to be good citizens in regard to their compliance. Additionally, considerations include that all buildings considered are well insulated and can keep temperature within comfort levels for about an hour, so to say the heat loss is about 0.9K/min. calculations were carried out using the hospital as an example. strategy combinations are devised statically through an agents' status of flexible demand. if an agent has Flexible demand switched in the preceding interval, it can receive a demand response signal for the interval in consideration.

That being said, interval '8' has a deficiency of 48 kWh, after analysing the objective functions and having the payoffs and statuses of agents it occurred that only three agents are liable to respond to the utility's decision of opting for demand response. The agents/peers that can be responsive are shown in Table II.

TABLE II. PAYOFF OF RESPONSIVE PEERS IN EACH STRATEGY COMBINATION

Strategy combinations	Peer-3	Peer-5	Peer-10	Peer-13	Payoff	Possible load After DLS
SC-1	1	1	1	0	0.080561	498
SC-2	0	1	1	0	0.085995	495
SC-3	1	0	1	0	0.08598	495
SC-4	0	0	1	0	0.09142	492
SC-5	1	1	0	0	0.08985	493
SC-6	0	1	0	0	0.094954	490
SC-7	1	0	0	0	0.094944	490
SC-8	0	0	0	0	0.10038	487

One of the agents has a flexible demand of 50 kWh, the second agent 5 kWh and the third agent can shed 6 kWh in response to the utility's DR signal. Three agents responsive can have six possible combinations i.e., we, now, have different choices to select from, but a healthy and fruitful selection is the one that clears the deficit. If maximum load reduction is intended, flexible demand of all three agents is switched offline resulting in an instantaneous load of 487 kWh. surplus-deficit graph provided in fig. 3 takes the form as shown in figure. 4.

On the other hand, if it is intended by the system operator to only clear the deficit, the agent with 50kWh of Flexible consumption is taken offline, resulting in a minimum scheduled interval as shown in fig. 3.5. load is under grid limits now.

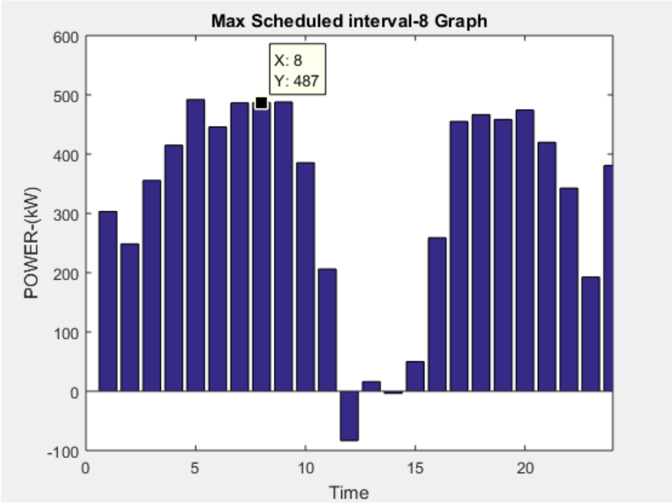

Figure 6. Max scheduled interval-8 Graph

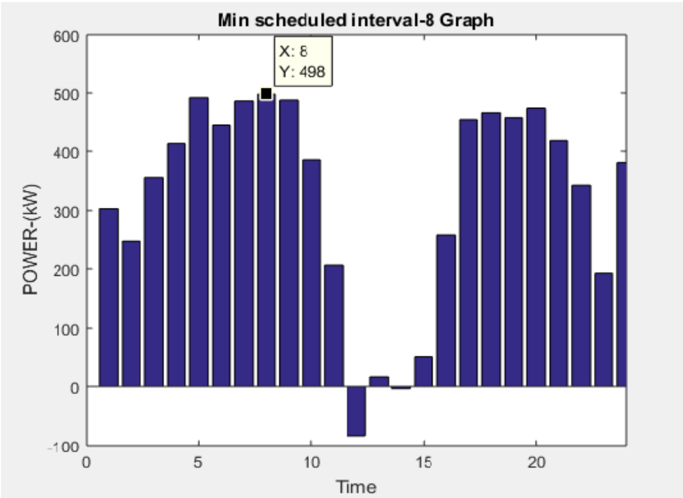

Figure 7. Minimum scheduled interval-8 Graph

CONCLUSION

If the prevailing Net-Metering system and block chain enabled local energy markets are compared, Blockchain based markets offer better prices depending on its use and time of availability. During scarce intervals prices are relatively higher due to low generation indicators. On the other hand, the net metering system has a constant crediting price of 18.85 PKR throughout the year. Furthermore, if we take interval '8' in to consideration it is observed that blockchain enabled micro grid offers 17.9 percent increase in revenue as compared to net metering system.

BEFORE SCHEDULING
Total Load= 568 kW
Total Generation= 20 kW
Conventional Grid offers 500 kW
Deficit= 48 kW

	ENERGY TRADED	COST OF ENERGY
CONVENTIONAL GRID	500	500*22=11000
MICROGRID	20	20*22=440

AFTER SCHEDULING
Total Load= 498 kW
Total Generation= 20 kW
Conventional Grid offers 478 kW

	ENERGY TRADED	COST OF ENERGY
CONVENTIONAL GRID	478	478*22 = 10,516
MICROGRID	20	20*22 = 440
Net-Metering	20	20*18.85 = 373
Percent increase in revenue as compared to Net Metering $\Rightarrow \frac{440-373}{373} =$ **17.9%**		

REFERENCE

[1] World Energy Council (WEC), "World Energy Council definition of energy security," [Online]. Available: https://www.worldenergy.org/. [Accessed: May 12, 2024].

[2] Pakistan Integrated Energy Plan (IGCEP) 2047, Government of Pakistan.

[3] "Pakistan Energy Statistics 2019," Pakistan Energy Information Administration (PEIA).

[4] International Energy Agency (IEA), "Smart Grids: Core Elements," [Online]. Available: https://www.iea.org/reports/smart-grids-core-elements. [Accessed: May 12, 2024]

[5] Smart Electric Power Alliance (SEPA), "Smart Grid Benefits," [Online]. Available: https://sepapower.org/our-work/smart-grid/. [Accessed: May 12, 2024].

[6] Electric Power Research Institute (EPRI), "Smart Grid Research," [Online]. Available: https://www.epri.com/research/areas-of-focus/smart-grid. [Accessed: May 12, 2024]

[7] Institute of Electrical and Electronics Engineers (IEEE), "Dynamic Scheduling in Smart Grids," [Online]. Available: https://ieeexplore.ieee.org/. [Accessed: May 12, 2024].

[8] Zhang, Y., Chen, Y., Fu, Y., & Zhang, Y. (2019). Blockchain Based Energy Trading Platform for Microgrid. In 2019 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm) (pp. 1-6). IEEE.

[9] Liang, Y., Shi, L., Hu, X., & Huang, Y. (2020). A Blockchain-enabled Demand Response Mechanism for Microgrids. In 2020 IEEE International Conference on Smart Grid Communications (SmartGridComm) (pp. 1-6). IEEE.

[10] Wang, J., Xiong, W., Yang, Y., & Han, Z. (2021). Blockchain-Enabled Dynamic Load Scheduling for Microgrids with IoT Integration. IEEE Internet of Things Journal, 8(1), 398-407

[11] Zeng, Y., Zhang, H., Gjessing, S., & Zhou, J. (2021). Challenges and Opportunities of Blockchain for Energy Management in Microgrids: A Review. IEEE Access, 9, 53603-53620.

[12] Jamil et al., 2017, Jamil Irfan, Zhao Jinquan, Zhang Li, et al. Evaluation of energy production and energy yield assessment based on feasibility, design, and execution of 350 MW grid-connected solar PV pilot project in Nooriabad".

How to cite this article:

Umar Khayam, Muhammad Umair, Farhan Ullah "Enhancing Energy Security in Pakistan through Smart Grid Technology and Dynamic Scheduling" International Journal of Engineering Works, Vol. 11, Issue 09, PP. 165-170, September 2024. https://doi.org/10.34259/ijew.24.1109165170.