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Development Of A Smart Contract Participation Matrix For Renewable Energy-Based Power Networks

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ABSTRACT

Advancements in power systems have led to the transformation of traditional centralized power grids into decentralized energy trading networks. This digital transition is facilitated by the integration of powerful operating systems, communication technologies, and smart meters, allowing consumers to engage in energy transactions with power-producing entities and the grid. Decentralized networks promote renewable energy adoption and enhance energy reliability through consumer-prosumer collaboration. A smart contract between prosumer and consumer is essential for successful integration of renewable energy, as it addresses intermittency and variability challenges. This study focuses on developing a smart contract participation matrix (SCPM) for a power system with most renewable sources to address scalability issues and minimize strain on the main grid.

Keywords— Communication technologies, Decentralized networks, Power producing entities Renewable energy integration, Intermittency, Variability and Smart contract participation matrix.

I. INTRODUCTION

The modernization of power systems has led to a shift from centralized electricity networks to decentralized energy trading systems. This transformation is driven by innovations in technology, such as smart meters and advanced communication platforms, which facilitate direct energy transactions between the grid, prosumers, and consumers. This new decentralized structure allows consumers to play an active role in the energy market, reshaping the traditional power distribution model. The adoption of renewable energy sources contributes to reducing greenhouse gas emissions and fostering environmental sustainability. This decentralized network model lowers energy costs, enhances energy distribution during peak demand, and reduces the need for large-scale infrastructure investments. Localized energy management through increased renewable energy with battery storage systems increases grid reliability and allows users to directly influence energy security and supply. This decentralized framework promotes consumer autonomy, increases market transparency, and operational efficiency. To support effective energy trading in a power system with larger renewable energy sources, this study extends the development of a Smart Contract Participation Matrix with increased energy allocations. This matrix captures contractual relationships and energy trade participation levels between prosumers and consumers, reducing reliance on centralized power systems and easing the burden on grid infrastructure.

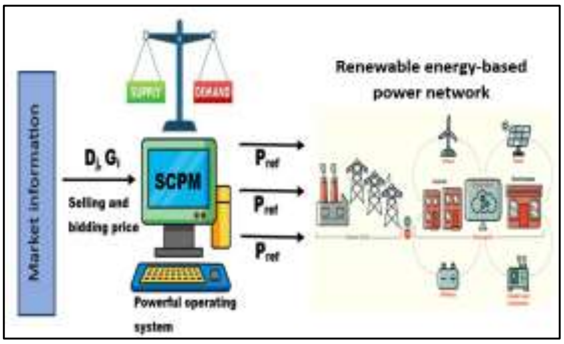

Figure 1 Framework for LFC in Renewable Energy-based Network

The adoption of Smart Contract Participation Matrix (SCPM) aligns with global initiatives to advance decentralized energy models, promoting a sustainable and consumer-focused energy ecosystem. Integrating renewable energy trading in power systems through SCPM modernizes power infrastructure, supports renewable energy penetration, minimizes environmental impacts, and enhances grid reliability. This framework contributes to a more adaptable, efficient, and resilient energy system capable of meeting future energy demands. The project aims to design a smart contract participation matrix for a decentralized power system network to maintain power balance during renewable energy trading. The work is divided into five sections, including introduction, literature review, mathematical construction, SCPM results, and conclusion.

II. LITERATURE SURVEY

The global shift towards decentralized and sustainable energy systems is gaining momentum, with microgrids emerging as a disruptive solution for enhancing energy efficiency, reducing costs, and promoting renewable energy adoption. Microgrids, which incorporate renewable energy sources like solar, wind, and storage, enable direct energy trading amongst prosumers, circumventing traditional utility networks.Technological innovations like blockchain, smart contracts, and decentralized platforms facilitate transparent, secure, and automated transactions, reducing transaction costs and providing real-time data for efficient energy management **Buterin, V. (2013)[1].** P2P trading promotes renewable energy use in local communities by matching energy production and consumption, encouraging households to produce excess energy and trading it with neighbors **Le, H. T., & Nguyen, T. D. (2020) [2].** Decentralized systems like renewable energy hybrid microgrids enhance energy security by diversifying power sources and reducing grid vulnerability, while also offering economic benefits for prosumers **Papageorgiou, A., & Schandl, H. (2021) [3].** China is integrating prosumer-based trading into microgrids to improve energy exchanges and optimize electricity flow, collaborating with leading energy technology companies to bridge energy access gaps in developing countries **Zeng, L., & Wang, J. (2022) [4].** China is utilizing its technological ecosystem to test scalable energy trading solutions in urban and rural micro grids, promoting renewable energy integration and empowering consumers to participate in energy markets, enhancing sustainability and promoting renewable energy **T. Morstyn, A. Teytelboym and M. D. Mcculloch [5].**

III.PROPOSED SYSTEM

This project uses MATLAB to visualize the Smart Contract Participation Matrix, which shows optimized power allocations between all entities and consumers. The study considers power systems with 12 entities, 9 of which are renewable sources, 3 of which are conventional sources, and 9 consumers participating in energy marketing. The study tabulates the generation and demand of individual entities and consumers in Tables 1 and 2. The utility grid's bfit price is 0.1$ per kWh, while the aUG price is 1$ per kWh, as recommended by the grid. The selling price of individual entities varies between 0.1$ to 0.6$ per kWh, while the buying price of individual consumers varies between 0.4$ to 1$ per kWh. The MATLAB script is used to validate enhanced energy trading for power systems with conventional and renewable energy sources.

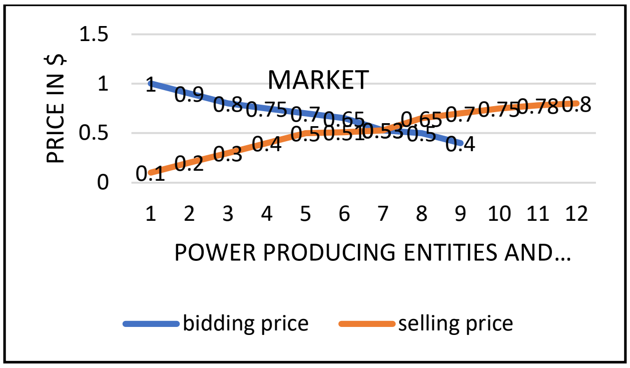

Figure 2 The selling and buying price bids

In this instance, energy trading is prioritized to utilize the cheapest available generation to satisfy the highest-paying demands, ensuring an efficient and cost-effective distribution of resources. So, for this case the market clearing price is obtained as 0.53$ per kW.

Table 1 System's Entities Generation Capacity

POWER PRODUCING ENTITIES	GENERATION CAPACITY(MW)
entity_1	167
entity_2	113
entity_3	63
entity_4	90
entity_5	73
entity_6	92
entity_7	116
entity_8	129
entity_9	119
entity_10	182
entity_11	128
entity_12	192

Table 2 System's consumer demand

CONSUMERS	DEMANDS(MW)
Consumer_1	107
Consumer_2	145
Consumer_3	59
Consumer_4	111
Consumer_5	64
Consumer_6	111
Consumer_7	114
Consumer_8	38
Consumer_9	60

The entity_1 and consumer_1 are matched based on the priority criteria using the double auction technique. Similarly, each entity is matched with a customer. For example, imagine the entity_1 and consumer_1 relationship, where generation exceeds demand. So, the SCPM element is represented as 1, and the contract moves on to the next pair of contracts, entity_2 and consumer_2. Because demand exceeds generation in this case, demand is partially supplied, with the remaining unsatisfied demand being updated as new demand. With the new demand, consumer_2 creates a contract with entity_3, and the cycle is repeated for all pairings to keep the system power balance steady by providing optimal power allocation, as shown in TABLE 3.

Table 3 Cost Reduction in Energy Trading via Smart Contract Power Markets

CONSUMERS (demand in MW)	ALLOTED ENTITIES		POWER ALLOCATION FRACTION (S_{ij})	TOTAL BUYING PRICE PER DAY (with SCPM in $)	TOTAL BUYING PRICE PER DAY (without SCPM in $)	CONSUMERS SAVINGS PER DAY	
	ENTITY (generation / balance capacity in MW)	ALLOTED POWER (in MW)				(in $)	(in %)
Consumer_1 (107)	Entity_1 (167)	107	1	107000kW*0.1$*24hr Total Cost =256800	1797600	1540800	85.71
Consumer_2 (145)	Entity_1 (60) Entity_2 (113)	60 85	0.29268 0.70732	60000kW*0.1$*24hr=144000 85000kW*0.2$*24hr=408000 Total Cost=552000	2436000	1884000	77.33
Consumer_3 (59)	Entity_2 (28) Entity_3 (63)	28 31	0.32184 0.67816	28000kW*0.2$*24hr=134400 31000kW*0.3$*24hr=223200 Total Cost=357600	991200	633600	63.92
Consumer_4 (111)	Entity_3 (32) Entity_4 (90)	32 79	0.22378 0.77622	32000kW*0.3$*24hr=230400 79000kW*0.4$*24hr=758400 Total Cost=988800	1864800	876000	46.97
Consumer_5 (64)	Entity_4 (11) Entity_5 (73)	11 53	0.14667 0.85333	11000kW*0.4$*24hr=105600 53000kW*0.5$*24hr=636000 Total Cost=741600	1075200	333600	31.02
Consumer_6 (111)	Entity_5 (20) Entity_6 (92)	20 91	0.15267 0.84733	20000kW*0.5$*24hr=240000 91000kW*0.51$*24hr=1113840 Total Cost=1353840	1864800	510960	27.40
Consumer_7 (114)	Entity_6 (1) Entity_7 (116)	1 113	0.0086957 0.9913	1000kW*0.51$*24hr=12240 113000kW*0.53$*24hr=1437360 Total Cost=1449600	1915200	465600	24.33
Consumer_8 (38)	Entity_7 (3) Entity_8 (129)	3 35	0.073171 0.92683	3000kW*0.53$*24hr=38160 35000kW*0.65$*24hr=546000 Total Cost=584160	638400	54240	8.49
Consumer_9 (60)	Entity_8 (94 MW)	60	1	60000kW*0.65$*24hr Total Cost=936000	1008000	72000	7.14

Thus, the entire approach creates the SCPM matrix that optimizes the allocation of renewable energy trade, as shown in Figure 3. Also, Table 3 illustrates cost savings in energy trading by comparing total buying price per day without and with SCPM. Here without SCPM trading costs are considered as trading carried out by using utility set pricing for all consumers, which is 0.7$ per kWh.

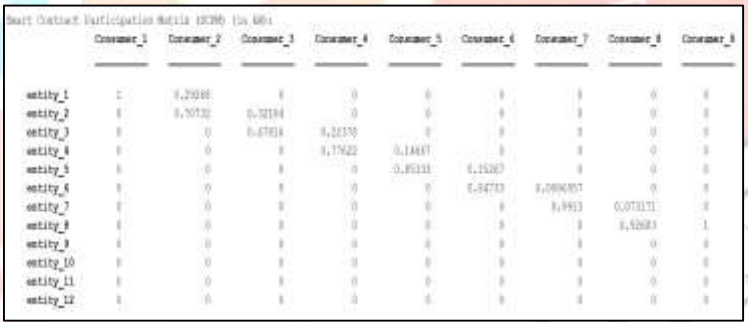

Figure 3. Smart Contract Participation Matrix

The Smart Contract Participation Matrix (SCPM) framework offers significant cost savings for consumers by enabling energy purchases directly from prosumers at competitive rates compared to standard grid pricing. Cost savings per day range from 7.14% to 85.71%, depending on the allocation strategy and available generation entities. Consumer 1 achieved the highest savings (85.71%), while consumers with diversified allocations also saw significant savings. SCPM's optimized allocation resulted in savings of 7.14% for consumers relying on higher-tariff entities. On average, SCPM reduces the daily cost of energy procurement and ensures demand is met through efficient matching with generation capacity. The power allocation fraction (Sij) is used to determine the power reference value for each prosumer, which is subsequently returned to the plant to help with frequency management of the power system as a result of renewable energy integration. This dynamically changes power output to maintain system stability by balancing energy generation and consumption while providing additional economic benefits.

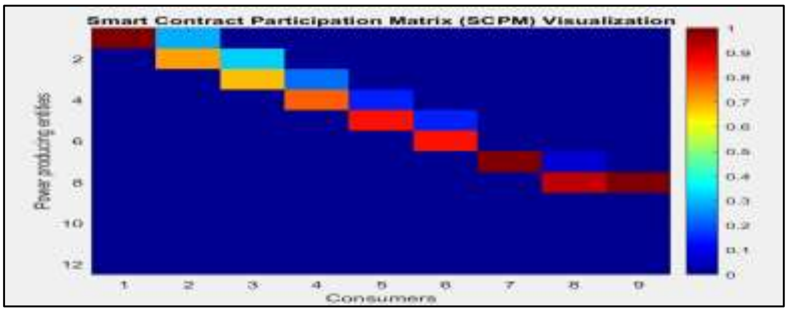

Figure 4. Graphical Representation of SCPM.

Real-time updates to each entity's generation capacities are used to create an updated SCPM, optimizing power references and maintaining the overall frequency of renewable energy-based systems, thereby making trading economically beneficial for all market participants.

IV. CONCLUSION

Renewable energy integration into power system energy trading is becoming increasingly important due to environmental concerns, energy security, and sustainability. As renewable energy sources such as solar and wind become increasingly popular, their intermittent nature poses problems to grid stability. Frameworks like Smart Contract Participation Matrix (SCPM) are crucial for decentralized, real-time energy management, enabling entities to actively participate in the market. This study investigates the impact of renewable energy integration in power system energy trading by developing an extended SCPM. This decentralized approach boosts the resilience and adaptability of the power system, especially in the face of increasing variability due to renewable sources, and opens doors to a resilient, democratized, and future-ready energy infrastructure.

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