Energy Management System in Smart Microgrid Using Multi Objective Grey Wolf Optimization Algorithm

T. Sowmiya[1], Dr. T. Venkatesan[2]

[1]*M. E. Power Systems Engineering, K. S. Rangasamy College of Technology, Tiruchengode, Tamil Nadu, India.*
[2]*Professor/EEE, K. S. Rangasamy College of Technology, Tiruchengode, Tamil Nadu, India.*

---***---

Abstract - *Nowadays the population is increasing day by day, so that the demand for energy becomes high which in turn increases the demand for coal. This rapid increase in demand of electricity becomes uneconomical, detrimental and high in power losses. Also the conventional grid is unable to adjust to the growing energy demands and locating grid failures. Hence there is the need for other energy resources like renewable sources and this integration may cause unbalanced power flow to the grid which needs an energy management system. This proposed work aims at maximizing the use of local generation, minimizing the consumption price and reducing the emission of greenhouse gases. This efficient energy management system is achieved with the help of two controllers: Energy Market Management Controller (EMMC) and Home Energy Management Controller (HEMC). HEMC shares the information about load and energy storage systems to EMMC which will contain all details about the energy providers, local generation and its price details. The problems in smart grid can be solved using the strategies that were followed in demand response. Among various optimization methods, Multi Objective Grey Wolf Optimization (MOGWO) is preferred due to its fast converging capability compared to other optimization techniques. The simulation result shows the reduction in pollution and consumption price in this work.*

Key Words: **Microgrid, smart grid, energy market management controller, home energy management controller, multi objective grey wolf optimization, energy providers, renewable energy resources.**

1. INTRODUCTION

Energy plays a crucial part in a country's growth of its social and economic position. Because it has a direct impact on the economy and is linked to raising the country's living standards. As the world's population grows, more energy is required to meet the growing demand for energy. As a result of these energy constraints in emerging countries, smart energy management (SEM) can help to alleviate both technical and economic issues.

SEM is concerned with integrating local generation, such as photovoltaic (PV), wind, and fuel cells, as well as effective energy trading between energy providers and customers. By combining both generation and consumption, researchers are attempting to design improved structures for optimal energy and market management.

Consumer-based energy management to increase profit for consumers by employing a stochastic game strategy that combines prosumer decision and the stochastic nature of renewable energy is proposed in [1]. [2] provides task classification-based home energy management, which identifies the best activation task within device restrictions.

The ideal activation time for each type of work is determined using a quadratic utility function. [3] proposes a decision-making controller that optimizes generation, load, and storage. To make decisions more intelligent, intelligent fuzzy logic is offered. In [4,] the integration of a storage system is proposed in order to achieve high energy independence in an SMG that is based on home load control. [5] investigates data-driven home energy management (HEM), which is optimized using a Bayesian algorithm and includes renewable energy resources (RER) and an energy storage system. Within micro-grid (MG) and multi-MG environments, the energy market management system in [6] executes day-ahead optimization of distribution network addressing (MMG).

The goals are to reduce costs by using two operators in a dynamic games function. Researchers in [7] developed a power loss-based energy transaction inside the MG and MMG paradigms to minimize power loss. The Multi Energy Router System is used to achieve this strategy (MERS). [8] proposes a market mechanism for average pricing that is utilized in distribution networks. The goal is to decentralize the formulation of the average price market mechanism in order to spread the cost production of energy resources with a zero margin.

Using Mixed Integral Linear Programming, [10] proposes a multi-objective optimization to handle the energy management-based social and ecological problem for microgrid (MILP). Approach for maximum utilization of renewable distribution is proposed in [11], and the same concept is addressed in [12] to reduce energy loss in order to recognize the economic benefits. [13] presents a quick overview of various control strategies.

In addition, the authors recommended intelligent and IoT-based control solutions for future clustered microgrids. According to a survey of related literature, researchers have solved technological challenges for SMG, such as user comfort, consumption, generation, storage, and trading. However, in order for it to be impactful and useful, more research is required. The majority of the study in this literature focused on energy and market management issues. However, environmental implications such as greenhouse gases (GHGs) and other related problems are not well addressed.

The main goal of this study is to offer end customers a practical answer to their energy management problems specifically, in terms of load control, lowering consumption costs, and promoting users to use domestic generation within their limitations. Objectives of this paper are summarized as follows:

a) This work proposes greenhouse minimization by encouraging the users to use renewable energy resources.
b) It also helps the prosumers to reduce their energy consumption price.
c) These objectives are achieved with the help of multi objective grey wolf optimization technique which gives faster convergence compared to other optimization techniques.

This paper is sectioned as follows: Section 2 deals with the works related to this paper. Modeling of the system and load for the microgrid is discussed in section 3. The proposed work of the EMS is illustrated in section 4. Section 5 shows and discusses the result of this work. Section 6 presents the conclusion of this research and section 7 provides an idea for the future research work.

NOMENCLATURE

P_{pv}	PV system's output power
R_p	Perpendicular Radiation at the surface of PV cell
η_{MPPT}	Efficiency of dc dc converter of PV system
P_w	Mechanical power of wind turbine
P_e	Electrical power of wind turbine
V	Speed of wind at 't'
v_{cutin}	Cut-in speed
v_{co}	Cut-off speed
v_{ref}	Reference speed
P_{Bch}	Charging of battery
P_{Bdis}	Discharging of Battery
P_{RER}	Power of renewable energy resources
P_D	Power demand
ρ(t)	Load demand at time t
P(t)	Electrical price of sources at time t

2. RELATED WORK

Demand response (DR) system that is based on optimal planning is suggested in [14]. RER and intelligent control of domestic heating and cooling systems for smart grid that reduces costs by regulating smart devices were added. [15] proposed a revolutionary market management structure (transaction rules) for industrial consumption, based on block chain and peer-to-peer electricity markets. Load management on the demand side is also investigated in this study. [16] compared trends and associated difficulties in the microgrid. The writers of this publication covered typical MG concerns. In a regulated environment, there are also obstacles for managing and protecting. For controlling energy for smart distribution systems, encompassing implementation, current development, and ongoing research, [17] addresses classification, limitations, and problems.

In [18], the authors developed a ToU gas pricing-based trading model for MG at two levels, in which the goal is realized using Game Theory. The suggested approach is tested on a case study with two scenarios: a single gas pricing scenario and a gas pricing scenario with two scenarios. For multi-home MG, an energy management system is introduced, which reduces market clearing price by 15% and load consumption factor by 30% for a defined time interval [19]. For energy transfer from home to MG or vice versa, as well as load control, net metering and smart devices are explored.

3. SYSTEM MODEL AND LOAD MODEL

Within the smart grid concept, the Micro-grid (MG) has well-defined electrical and communication boundaries for sharing power and communication signals.

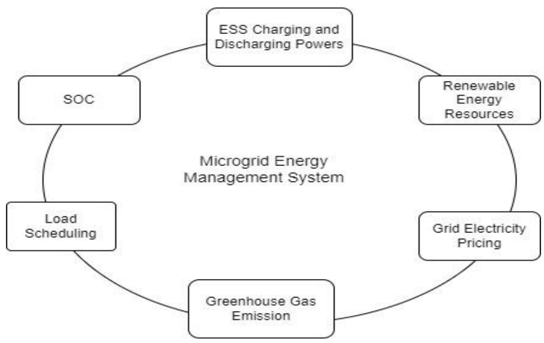


Fig -1: Microgrid energy management system

The proposed work deals with the microgrid that supplies energy to three areas that has its own local generation. EMMC will get the information about power from DGs. This data will be shared with HEMC to schedule the load. The microgrid needs an effective energy management system for which the concepts like battery energy storage system, RER's, greenhouse emission, load scheduling and consumption pricing should be well planned and then designed. Fig -1 represents the microgrid energy management system. The detailed system modeling will be discussed as follows:

3.1. Solar Panel Modeling

Renewable energy resources like solar cell and wind turbine are considered as a local generation for each area. This usage of RER will help the consumer to minimize their consumption price. The output power from each resource is expressed below. The solar power is expressed in equation (1) [20].

$$P_{pv} = (R_p / 1000) \times P_{pv,rated} \times \eta_{MPPT} \quad .... (1)$$

3.2. Wind Turbine Modeling

The mechanical and electrical powers of wind turbine can be expressed in equation (2) and (3) respectively [21]. The details of RER's and thermal power plant are listed in Table -1.

$$P_w = \begin{cases} 0, & if\ v < v_{cut_{in}} \\ P_n(v), & if\ v_{cut_{in}} < v < v_{ref} \\ 1, & if\ v_{ref} < v < v_{co} \\ 0, & if\ v > v_{co} \end{cases} \quad .... (2)$$

$$P_e = \eta \times P_w \quad .... (3)$$

Table -1: Ratings of energy providers

Energy providers	Ratings
Thermal power	1MW
Solar power	500kW
Wind power	500kW

3.3. ESS Modeling

The output power of renewable energy resources always depends upon the weather conditions such as sunlight and wind. Due to the changes in climatic conditions, the power produces will always be fluctuating. To encounter this instability, the usage of battery energy storage system becomes essential [22]. Rating of battery is very important in case of energy storage system. The equation [4] and [5] represents the charging and discharging state of battery [21].

$$P_{Bch}(t) = P_{ch}(t) \quad if \quad P_{RER}(t) > P_D(t) \quad .... (4)$$

$$P_{Bdis}(t) = P_{dis}(t) \quad if \quad P_{RER}(t) < P_D(t) \quad .... (5)$$

3.4. Load Modeling

The proposed system has been implemented on a community having three areas that have different types of loads with different ratings. Each area is setup to have an individual demand of 1MW. The net load of a community will be 3MW.

4. PROPOSED DESIGN OF EMS

EMS can fortify the efficiency of a grid and can supply the demand without any interruption or losses and makes the power supply reliable. For this, there are many factors like consumption price, greenhouse gases, renewable energy resources, etc. should be taken into account and also to be controlled [23]. Fig -2 presents the block diagram of proposed design of EMS.

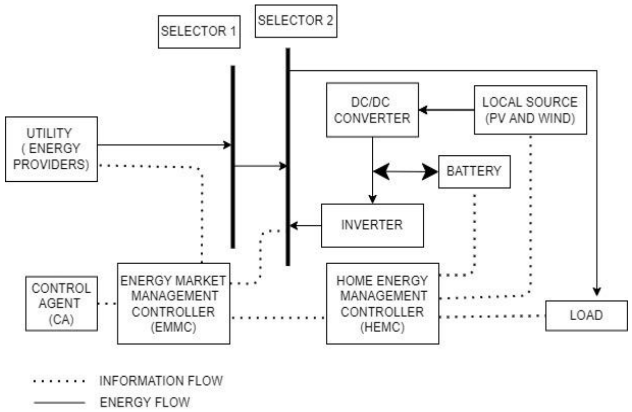


Fig -2: Proposed design of EMS

4.1. Home Energy Management Controller (HEMC)

Home Energy Management Controller (HEMC) is very essential in every residential area which enhances the energy efficiency [24]. Reducing PAR, energy bills and maximizing he user comfort for multi residential homes is proposed in [25]. An optimum home energy management controller is implemented in [26] which minimize the electricity bill upto 21.5%. HEMC will collect the details about load and its need, local generation capacities and battery SOC state. The main objective of HEMC is to schedule the load at minimum consumption price. Thus the cost objective function can be given in (6).

$$\text{Cost} = \text{Minimize} (\quad \textstyle\sum_{t=1}^{24}(\rho(t) \times P(t \quad .... (6)$$

4.2. Energy Market Management Controller (EMMC)

In a traditional grid there is no possibility of two way communication and feedback. This will affect the efficiency of the grid. But in today's era there are lots of methods available that will make the grid smarter. EMS will make the grid and consumer to interact which paves the way for healthy communication.

In our proposed system, the Energy Market Management Controller (EMMC) will collect all the information from energy providers like capacity, cost price and emitting gas details [20]. After receiving all details, the information will be shared to HEMC. Then HEMC will manage and schedule the load. This will be done before t=1. Now optimization will take place with the help of multi objective grey wolf optimization. After that, EMMC will begin to forecast the data from individual HEMC. Then HEMC will send the signal to EMMC about the demand at each area. All these details will be shared to control agent which has the authority to decide which energy provider should supply the demand. This process will be repeated for every 24 hours. A function of EMMC is shown in Fig -3[20].

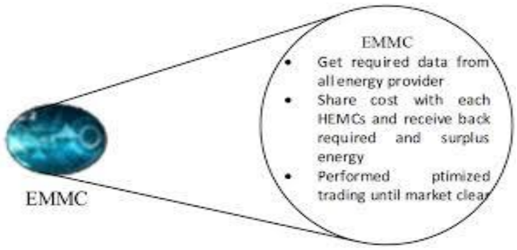


Fig -3: Functions of EMMC [20]

4.3. Multi Objective Grey Wolf Optimization Technique (MOGWO)

Multi Grey Wolf Optimization (MOGWO) technique is one of the effective meta heuristic algorithm proposed in [20]. Because of its excellent precision in solution, low processing cost, and avoidance of premature convergence, this optimization outperforms other algorithm such as Particle Swarm Optimization (PSO), Ant Bee Colony (ABC), Genetic Algorithm (GA), Harmonic Search Algorithm (HSA), etc.

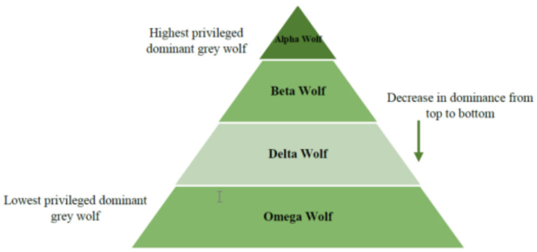


Fig -4: Hierarchy of grey wolves [27]

Grey wolves are the inspiration for this optimization technique. Grey wolves live in packs, with each pack consisting of 5 to 12 wolves. These packs or groups have been divided into many categories based on their hunting behavior. The leader of a grey wolf pack is known as the 'alpha,' and it is responsible for overseeing all of the pack's operations. The 'Beta' level of wolves is responsible for reinforcing alpha's instructions and providing feedback to the leaders. The 'Omega' level is the third and last level, and its role in the pack is similar to that of a scapegoat.

If the wolf in the pack does not fall into the above-mentioned categories, it will be 'Delta,' being the second best option and delta being the third best position. The hierarchy of grey wolves is shown in Fig -4 [27]. The flow chart of the proposed work is shown in Fig -5. The parameters of MOGWO of proposed EMS are listed in Table -2.

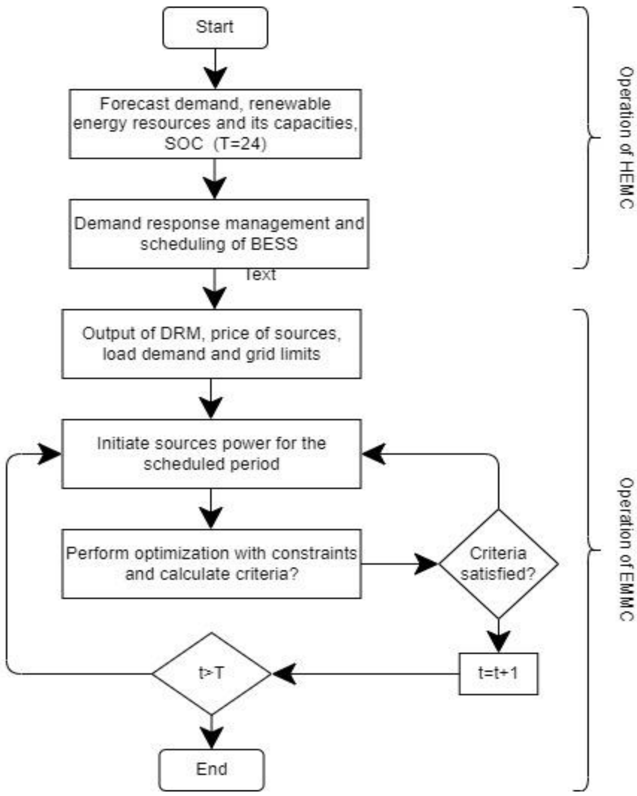


Fig -5: Flowchart of proposed work

Table -2: Parameters of MOGWO

Parameters	Value/Name
Maximum iteration	500
Best position	Alpha position
Best score	Alpha score

5. RESULT AND DISCUSSION

In this section, the output of MATLAB simulation is discussed. The proposed work has been framed to operate in multi residential areas, in a community of many areas, in industry, etc. In this work, solar and wind energy are used as renewable energy resources. The proposed work has met my objectives.

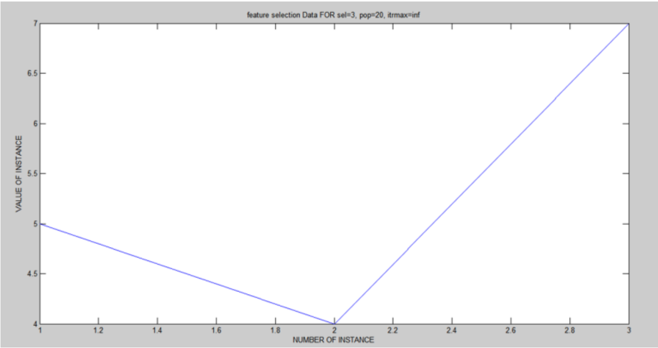


Fig -6: Selection data in MOGWO upto 20th cycle

When the input data were fed in MOGWO, it will not operate for a full cycle. Instead it will take the data set by set and then the best position will be selected. Fig -6 shows the feature selection data in MOGWO upto 20th cycle which has the best value at that instance.

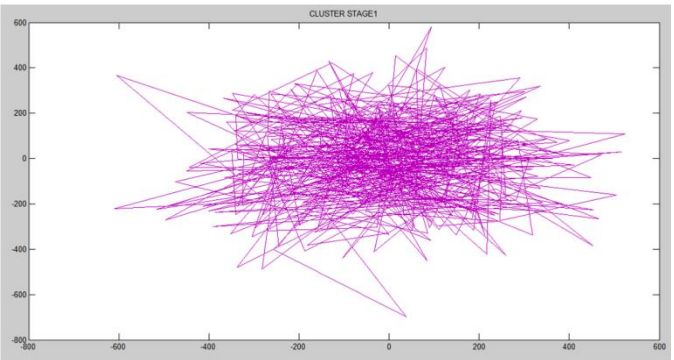


Fig -7: Cluster sampling

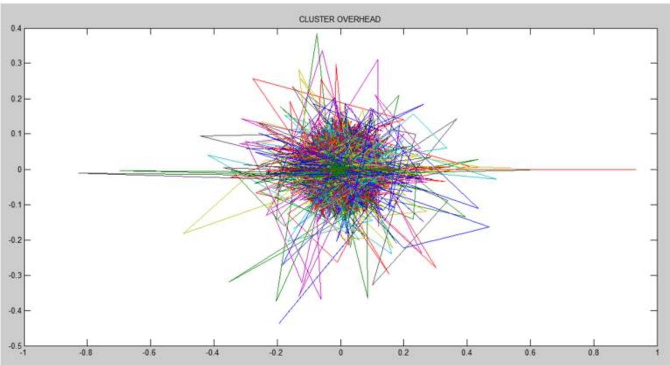
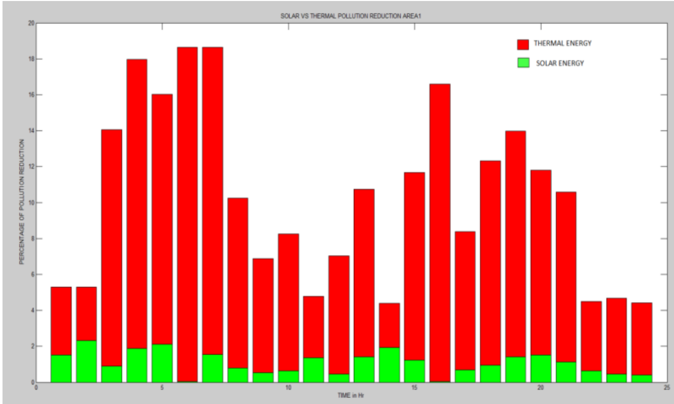


Fig -8: Clustered overhead data

The best position for each cycle is selected and then grey wolf optimization algorithm will create a cluster sampling which is shown in Fig -7. Out of all the best position in every cycle, the average position of all iterations will be sorted out to create a cluster overhead data which is shown in Fig -8. After this, the algorithm will chose the best position as alpha and then the optimization will continue for next cycle.

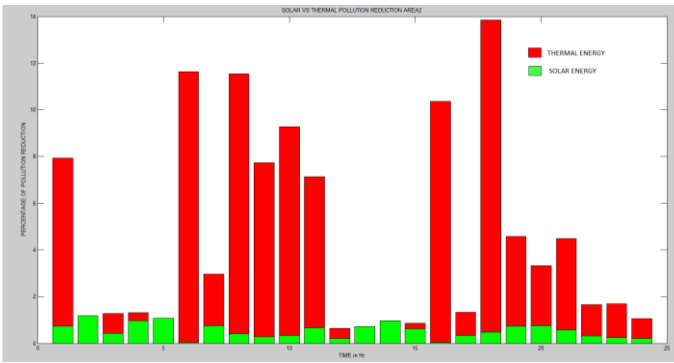


a)

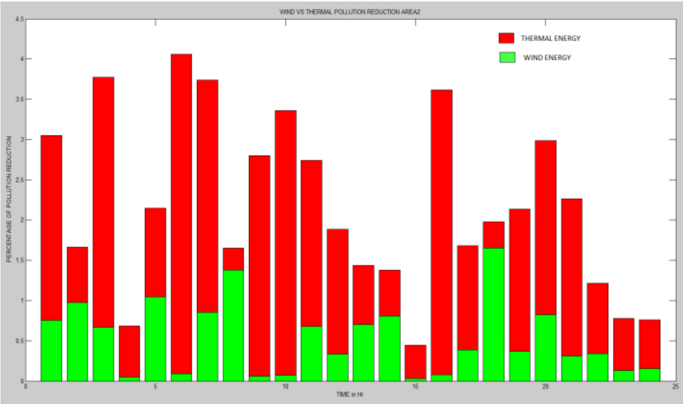
b)

Fig -9: Percentage of pollution reduction in area 1
a) solar and thermal b) wind and thermal

This proposed work helps in finding the solution to reduce the emission of greenhouse gases, increased usage of renewable sources and reduces the consumption price for prosumers. With the help of equation (1), (3), (4) and (5) the information about solar power, wind power and battery capacity were forecasted to EMS. As the next step, load scheduling takes place.



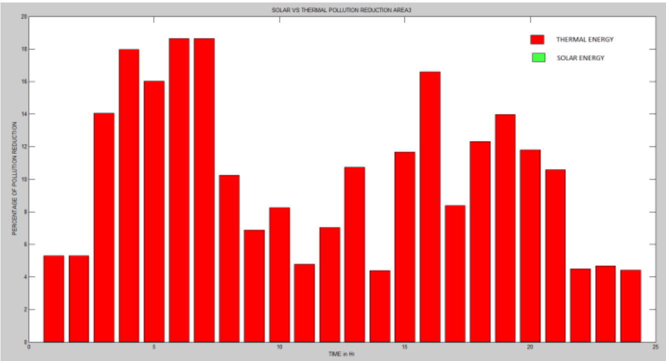
c)



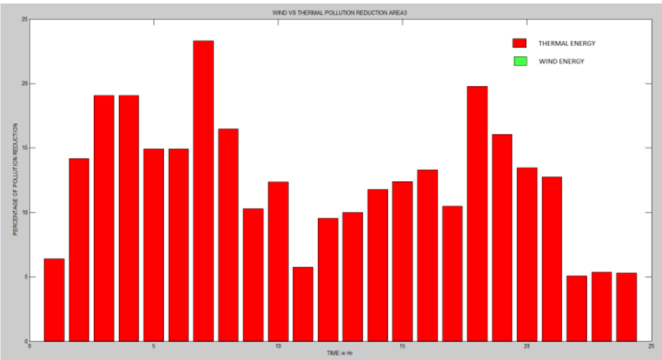
d)

Fig -10: Percentage of pollution reduction in area 2
c) solar and thermal d) wind and thermal

Fig -9 (a), Fig -10 (c) and Fig -11 (e) represents the percentage of pollution reduction in area 1, 2 and 3 respectively in which the demand is supplied by solar and thermal energy. Similarly Fig -9 (b), Fig -10 (d) and Fig -11 (f) represents the percentage of pollution reduction in area 1, 2 and 3 respectively in which the demand is supplied by wind and thermal energy.



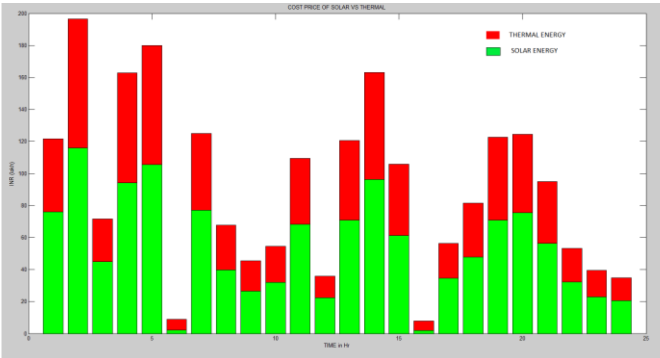
e)



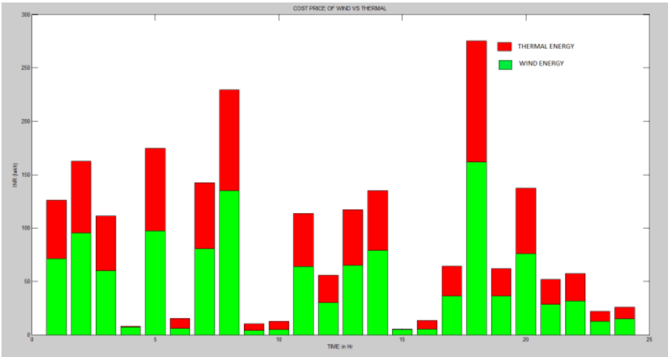
f)

Fig -11: Percentage of pollution reduction in area 3
e) solar and thermal f) wind and thermal

Here in the graph, initially the demand will be forecasted and then CA will make the RER to deliver its energy. If the energy is insufficient for the load, then CA will send signals to receive the energy from grid, so that the usage of RER will be high. Thus with the help of MOGWO with the forecasted information for a time period of 24hrs or for a day, the pollution can be reduced to 39.52% to 45.97%.



g)



h)

Fig -12: Percentage of reduction in consumption price
g) solar and thermal h) wind and thermal

Fig -12: (g) and (h) represents the percentage of price reduction in all the three areas for receiving energy from solar and thermal and wind and thermal respectively. The consumption price for prosumers to buy energy is reduced to a range of 48.51% to 54.69%. Thus the objective of proposed work is achieved with the help of proper EMS.

6. CONCLUSION

This paper proposes an energy management system for an effective operation of the microgrid in smart way. It enables an interaction between the prosumers and energy providers. In this three areas in a community of different ratings were taken into consideration for load which is supported by solar and wind energy as their local generation, and also supported by microgrid. For EMS, there is a need of two controllers viz. Energy Market Management Controller (EMMC) and Home Energy Management Controller (HEMC) with the help of Multi Objective Grey Wolf Optimization (MOGWO) technique. As an initial stage the details of energy providers, its capacities, limits, gas emission rates and cost prices were forecasted to EMMC. Then the information about each area, its demand, local generation details, its cost price and battery SOC were forecasted to HEMC. As a first step, EMMC will share its forecasted details to HEMC, so that it will schedule and manage the load according to the sources. Then the information will be sent to Control Agent (CA) where it decides whether the demand will be supplied by the local generation or form the grid. Then the optimization process takes place with the help of MOGWO which gives faster convergence. As a result of this work, the energy consumption price of prosumers can be reduced upto 48.51% to 54.69%. This technique provides an intellectual solution for economical and technical issues.

7. FUTURE SCOPE

This work has been implemented with two controllers namely Energy Market Management Controller (EMMC) and Home Energy Management Controller (HEMC) with the help of Multi Objective Grey Wolf Optimization (MOGWO) technique. In future the same work can be carried out with different algorithm that converges even faster and also be tested with deep learning algorithm which is becoming the future of automation in big data analysis.

REFRENCES

[1] S. Rasoul Etesami, Walid Saad, Narayan Mandayam and H. Vincent Poor, ''Stochastic games for the smart grid energy management with prospect prosumers,'' IEEE Transactions on Automatic Control, vol. 63, no. 8, pp. 2327–2342, Aug. 2018, doi: 10.1109/TAC.2018.2797217

[2] Samadi, H. Saidi,s M. A. Latify, and M. Mahdavi, ''Home energy management system based on task classification and the resident's requirements,'' Int. J. Electr. Power Energy Syst., vol. 118, Jun. 2020, Art. no. 105815, doi: 10.1016/j.ijepes.2019.105815.

[3] M. Žarkovic and G. Dobric, ''Fuzzy expert system for management of smart hybrid energy microgrid,'' J. Renew. Sustain. Energy, vol. 11, no. 3, May 2019, Art. no. 034101, doi: 10.1063/1.5097564

[4] L. Barelli, G. Bidinia, F. Bonuccib and A. Ottaviano, "Residential microgrid load management through artificial neural networks", Journal of Energy Storage, vol. 17, pp. 287–298, Jun. 2018, doi: 10.1016/j.est.2018.03.011

[5] Guangzhong Dong and Zonghai Chen, "Data Driven Energy Management in a Home Microgrid Based on Bayesian Optimal Algorithm", IEEE Transactions on Industrial Informatics, vol: 15, no. 2, pp. 869-877, Feb. 2019, doi: 10.1109/TII.2018.2820421

[6] X. Tong, C. Hu, C. Zheng, T. Rui, B. Wang, and W. Shen, ''Energy market management for distribution network with a multi-microgrid system: A dynamic game approach,'' Appl. Sci., vol. 9, no. 24, p. 5436, Dec. 2019, doi: 10.3390/app9245436.

[7] X. Shi, Y. Xu, and H. Sun, ''A biased Min-Consensus-Based approach for optimal power transaction in multi-energy-router systems,'' IEEE Trans. Sustain. Energy, vol. 11, no. 1, pp. 217–228, Jan. 2020, doi: 10. 1109/TSTE.2018.2889643.

[8] J. Yang, Z. Y. Dong, F. Wen, G. Chen, and Y. Qiao, ''A decentralized distribution market mechanism considering renewable generation units with zero marginal costs,'' IEEE Trans. Smart Grid, vol. 11, no. 2, pp. 1724–1736, Mar. 2020, doi: 10.1109/TSG.2019.2942616.

[9] S. Zhao, B. Wang, Yachao Li and Yang Li, "Integrated energy transaction mechanisms based on blockchain technology", Energies, vol. 11, no. 9, pp. 2412, Sep. 2018, doi: 10.3390/en11092412

[10] Walter Violante, Claudio A. Canizares, Michele A. Trovato and Giuseppe Forte, "An Energy Management System for Isolated Microgrids with Thermal Energy Resources", IEEE Transactions On Smart Grid, vol. 11, no. 4, pp. 2880-2891, July 2020, doi: 10.1109/TSG.2020.2973321

[11] V. Kalkhambkar, R. Kumar, and R. Bhakar, ''Joint optimal allocation methodology for renewable distributed generation and energy storage for economic benefits,'' IET Renew. Power Gener., vol. 10, no. 9, pp. 1422–1429, Oct. 2016, doi: 10.1049/iet-rpg.2016.0014.

[12] R. Bhakar, V. Kalkhambkar, B. Rawat, and R. Kumar, ''Optimal allocation of renewable energy sources for energy loss minimization,'' J. Elect. Syst., vol. 113, no. 1, pp. 115–130, 2017.

[13] Nikam and V. Kalkhambkar, ''A review on control strategies for microgrids with distributed energy resources, energy storage systems, and electric vehicles,'' International Transactions on Electrical Energy Systems, vol. 6, pp. 1–26, Sep. 2020, doi: 10.1002/2050-7038.12607

[14] S. M. Hakimi and S. M. Moghaddas-Tafreshi, ''Optimal planning of a smart microgrid including demand response and intermittent renewable energy resources,'' IEEE Trans. Smart Grid, vol. 5, no. 6, pp. 2889–2900, Nov. 2014, doi: 10.1109/TSG.2014.2320962.

[15] Dang, J. Zhang, C.-P. Kwong, and L. Li, ''Demand side load management for big industrial energy users under blockchain-based peer-to-peer electricity market,'' IEEE Trans. Smart Grid, vol. 10, no. 6, pp. 6426–6435, Nov. 2019, doi: 10.1109/TSG.2019.2904629.

[16] E. Olivares, A. Mehrizi-Sani, A. H. Etemadi, C. A. Canizares, R. Iravani, M. Kazerani, A. H. Hajimiragha, O. Gomis-Bellmunt, M. Saeedifard, R. Palma-Behnke, G. A. Jimenez-Estevez, and N. D. Hatziargyriou, ''Trends in microgrid control,'' IEEE Trans. Smart Grid, vol. 5, no. 4, pp. 1905–1919, Jul. 2014, doi: 10.1109/TSG.2013. 2295514.

[17] M. S. Alam and S. A. Arefifar, ''Energy management in power distribution systems: Review, classification, limitations and challenges,'' IEEE Access, vol. 7, pp. 92979–93001, 2019, doi: 10.1109/ACCESS.2019.2927303.

[18] K. Lin, J. Wu, and D. Liu, ''Economic efficiency analysis of micro energy grid considering time-of-use gas pricing,'' IEEE Access, vol. 8, pp. 3016–3028, 2020, doi: 10.1109/ACCESS.2019.2961685.

[19] M. Marzband, F. Azarinejadian, M. Savaghebi, E. Pouresmaeil, J. M. Guerrero, and G. Lightbody, ''Smart transactive energy framework in grid-connected multiple home microgrids under independent and coalition operations,'' Renew. Energy, vol. 126, pp. 95–106, Oct. 2018, doi: 10.1016/j.renene.2018.03.021.

[20] Muhammad Haseeb, Syed Ali Abbas Kazmi, M. Mahad Malik, Sajid Ali, Syed Basit Ali Bukhari and Dong Ryeol Shin, "Multi Objective Based Framework for Energy Management of Smart Micro-Grid", IEEE Access, vol. 8, pp. 220302 – 220319, Dec. 2020, doi: 10.1109/ACCESS.2020.3041473

[21] V. V. S. N. Murty and A. Kumar, ''Multi-objective energy management in microgrids with hybrid energy sources and battery energy storage systems", Protection Control of Modern Power System, vol. 5, no. 1, pp. 1–20, Dec. 2020, doi: 10.1186/s41601-019-0147

[22] Ming-Tse Kuo," Scheduling Strategies for Energy-Storage Systems of a Microgrid with Self-Healing Functions," IEEE Transactions on Industry Applications, vol. 57, no. 3, pp. 2156 – 2167, Feb. 2021, doi: 10.1109/TIA.2021.3058233

[23] Younes Zahraoui, Ibrahim Alhamrouni, Saad Mekhilef, M. Reyasudin Basir Khan, Mehdi Seyedmahmoudian, Alex Stojcevski and Ben Horan, "Energy Management System in Microgrids: A Comprehensive Review," Sustainability, vol. 13, pp. 10492, Sept. 2021, doi: 10.3390/su131910492.

[24] William Felipe Ceccon, Roberto Z. Freire , Anderson Luis Szejka and Osiris Canciglieri Junior, "Intelligent Electric Power Management System for Economic Maximization in a Residential Prosumer Unit", IEEE Power and Energy Society Section, vol. 9, pp. 48713 – 48731, Mar. 2021, doi: 10.1109/ACCESS.2021.3068751

[25] H. M. Hussain, N. Javaid, Sohail Iqbal, Qadeer Ul Hasan, Khursheed Aurangzeb and Musaed Alhussein, ''An efficient demand side management system with a new optimized home energy management controller in smart grid", Energies, vol. 11, no. 1, pp. 1–28, Jan. 2018, doi: 10.3390/en11010190

[26] Kutaiba Sabah Nimma , Monaaf D. A. Al-Falahi, Hung Duc Nguyen, S. D. G. Jayasinghe, Thair S. Mahmoud and Michael Negnevitsky, "Grey Wolf Optimization-Based Optimum Energy-Management and Battery-Sizing Method for Grid-Connected Microgrids", Energies, vol. 11, no. 4, April 2018, doi: 10.3390/en11040847