DOI: 10.24906/isc/2023/v37/i4/ 43717

Feature Article

Multi Objective Slime Mould Algorithm Based Energy Management in Hybrid Micro Grid System

Suravi Singha[1], Parthasarathi Bera[2]

Abstract
The effective operation of Micro-grid systems involves reconciling multiple conflicting objectives, including cost minimization, renewable energy utilization maximization and emissions reduction. This study proposes the application of recently developed Multi-objective slime mould algorithm (MOSMA) to address the challenges for minimizing cost and emission of a hybrid micro-grid system connected with utility grid. Further, the results are compared with another optimization algorithm to show its efficiency, economic viability, and environmental impact for green micro-grids.

Keywords: Micro grid, Renewable Energy Sources, Multi-objective slime Mould Algorithm (MOSMA).

Introduction
Stochastic penetration of solar panel in residential smart micro-grid is the challenge for energy management and research focus on cost and emission optimization. Simulation-based optimization of a Photovoltaic and wind-based hybrid energy conversion systems are performed in [1,2] and the study focuses on optimizing system components under different load and auxiliary energy conditions to increase the efficiency of the system. As reported by Elsied et al. [3], an AC micro grid system based on green energy sources are analysed, modelled and controlled and in this work, the integration of renewable energy into micro-grid systems are explored and the importance of effective control strategies are emphasized. As reported by Kumar et al. [4], a comprehensive overview of the current state of wind energy technology, challenges, and potential solutions are presented with the objective of consolidating knowledge on wind energy for researchers and practitioners. A generic model of a community-based micro-grid that integrates wind turbines, photovoltaic (PV) systems, and Combined Heat and Power generations are presented by Ullah et al. [5] and in this work, the technical and operational aspects of integrating multiple distributed energy resources in a community micro-grid are explored. Integrated renewable energy based micro grid is optimized by Zheng

[1,2] Department of Electrical Engineering, Kalyani Government Engineering College, Kalyani-741235, India
Email: [1]suravi.ee.kgec@gmail.com, [2]parthabera1977@gmail.com
ORCID: Suravi Singha: http://orcid.org/0009-0000-6071-2219
ORCID: Parthasarathi Bera: http://orcid.org/0000-0002-5946-7452

et al. [6] and probabilistic energy management approach for a renewable energy based micro-grid is proposed by Niknam et al. [7]. Different algorithms are proposed for energy management in hybrid micro grid system in [8-11]. A fuzzy approach for Micro Grid Energy Management Strategy (MGEMS) is proposed for combined heat and power systems [12-13]. In this work, the challenges of managing energy in micro grids that integrate both electricity and heat generation is addressed. Robust energy management for micro-grids with high-penetration of renewables is addressed by Zhang et al. [14]. The integration of distributed energy resources (DERs) from the perspectives of control, protection, and stability in micro grids is conducted by Basak et al. [15]. An AC micro-grids and DC micro-grids with DERs is compared by Justo et al. [16] and in this work, the advantages, challenges, and applications of both AC and DC micro-grid architectures are also analysed. A comprehensive review of various aspects of DERs, including renewable energy sources, energy storage, and their integration into micro-grids is provided by Shi et al. [17]. A performance analysis of an integrated Combined Heat and Power system with both thermal and electric energy storage for residential applications is conducted in [18-20]. An optimization of Fuel Cell based power system is focused by Arsalis et al. [21] and an extensive review of green energy system based optimization methods are provided by Montoya et al. [22]. The multi-objective optimization using developmental algorithms are focused for hybrid green energy systems [23]. Multi-objective optimal operation of micro-grids is proposed using stochastic programming framework in [24]. In this work, the challenges of operating micro-grids under uncertainty and aims to optimize their performance considering multiple objectives were addressed. An optimal micro-grid operation management approach for micro-grids using the Point Estimate Method and the Firefly Algorithm is presented by Mohammadi et al. [25].

Multi objective slime mould algorithm (MOSMA), a recently developed algorithm, is incorporated by Premkumar et al. [26] with Elitist Non-Dominated Sorting approach for solving complex optimization problems. MOSMA is applied for different optimization problems successfully like optimal power flow etc in [27-30] but it is not applied in the micro-grid systems. In this work, MOSMA is applied for optimizing the cost and emission in the microgrid energy management system. In view of the above, in the present work, following contributions are made.

- Various hybrid energy sources such as photovoltaic (PV) generator, wind generator, fuel cell (FC) and coal handling plant (CHP) are integrated into a micro-grid.
- This hybrid micro-grid system is assumed to be connected to the main utility grid so that it can draw power from the utility grid when its power generation is inadequate.
- MOSMA, a recently developed algorithm, is proposed to minimize cost and emission while calculating the schedule power for 24 hours for both summer and winter seasons.
- The results are compared with the other multi-objective optimization algorithms like Multi-objective Grey Wolf Algorithm (MOGWA) to show the effectiveness and superiority of MOSMA.

Description of Micro grid Energy Management System

In this work, a modern micro grid system is considered which is the part of a distribution system. This micro grid system is located at the substation of a distribution system. The system includes wind, PV, CHP and FC are connected to the DC bus and the DC bus is connected via DC/AC converter with the main grid via grid transformer as shown in Fig. 1. The wind and CHP are connected to DC bus via AC/DC converter, PV and FC are connected to DC bus via DC/DC converter. The load is connected via load transformer at the junction point of main grid and DC bus. This micro grid normally operates at grid connected mode but the management of micro grid system is to supply a portion of load disconnected from main grid so as to provide optimum emission and economic dispatch and even run in islanded mode.

Methods of Micro grid Energy Management System

This section introduces the micro-grid energy management system (MGEMS) optimization

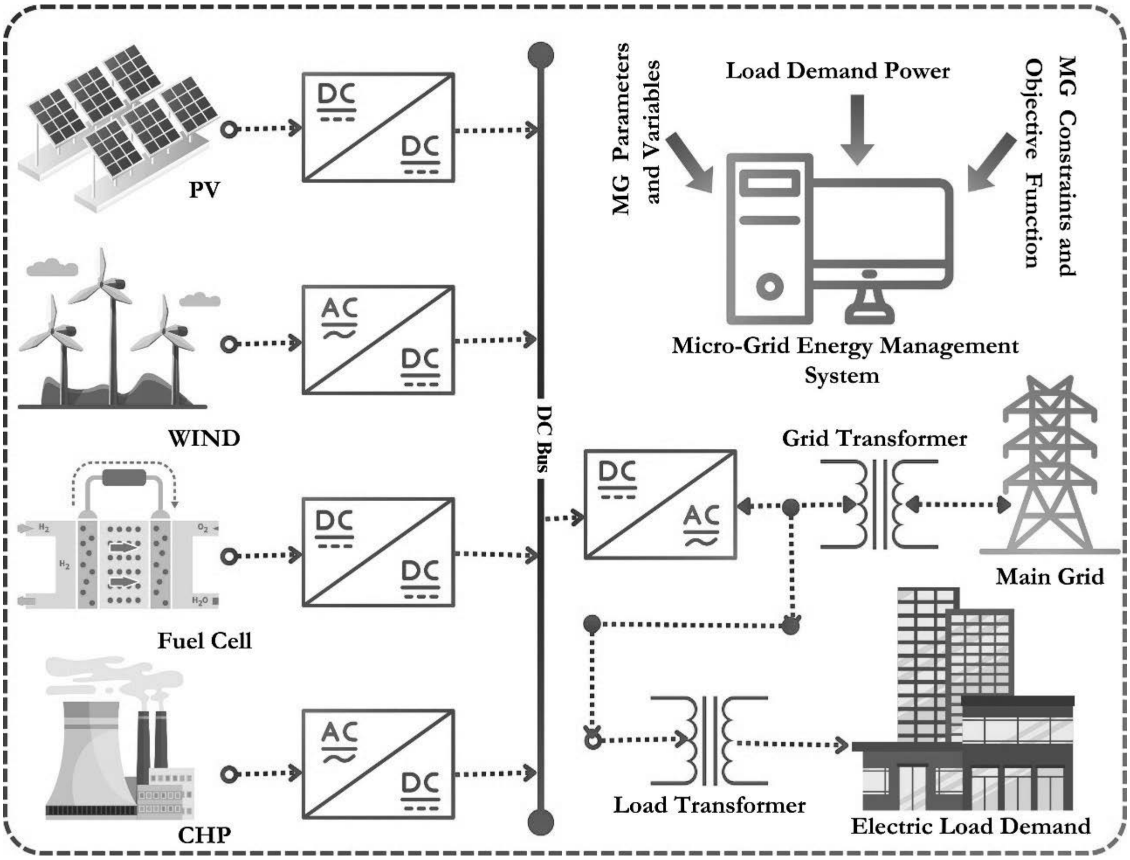

Figure 1: MG network structure

model and the objective of proposed MGEMS is to meet load demands while taking economic and environmental considerations into account. In order to set optimal power for each source, the decision variables include the generation of the utility grid, Wind, FC, CHP and PV.

Hourly Cost of Main grid and other Distributed Energy Resources

In this work, the hybrid micro-grid system is assumed to be connected to the main utility grid so that it can draw power from the utility grid when its power generation is inadequate. The selling cost and buying cost of main grid for each hour is given in Table-1. The hourly Cost of CHP (C_{CHP}) and FC (C_{FC}) are Euro 0.4 Euro/ KWh and Euro 0.3 Euro/KWh respectively for each hour and the hourly Cost of Wind (C_{Wind}) and PV (C_{PV}) are 0.82 Euro/ KWh and 0.71 Euro /KWh respectively for each hour.

Emission Factor

The current study takes into account CO_2, SO_2, and NO_x as three of the most significant emissions of FC and CHP and Table-2 shows the factor of emission for FC and CHP.

Table 1. Cost of main grid (Euro/kWh)

Time (hr)	Winter		Summer	
	Selling	Buying	Selling	Buying
1	0.32	0.22	0.32	0.21
2	0.33	0.23	0.31	0.22
3	0.31	0.21	0.32	0.22
4	0.32	0.22	0.33	0.23
5	0.32	0.22	0.31	0.22
6	0.32	0.23	0.32	0.21
7	0.61	0.4	0.71	0.61
8	0.92	0.82	0.73	0.62
9	0.92	0.81	0.72	0.62
10	0.92	0.82	0.71	0.62
11	0.91	0.81	0.98	0.93
12	0.65	0.45	0.99	0.92
13	0.45	0.32	0.96	0.92
14	0.45	0.31	0.99	0.93
15	0.45	0.33	0.98	0.92

Time (hr)	Winter		Summer	
	Selling	Buying	Selling	Buying
16	0.45	0.31	0.72	0.62
17	0.45	0.32	0.71	0.63
18	0.85	0.73	0.72	0.63
19	0.98	0.92	0.72	0.63
20	0.99	0.91	0.98	0.93
21	0.97	0.92	0.96	0.92
22	0.98	0.91	0.99	0.91
23	0.81	9.73	0.98	0.92
24	0.52	0.42	0.72	0.63

Table 2. Factor of emission (kg/kWh)

MGEMSs	FC	CHP
CO_2	0.2	0.3
SO_2	2.45e-6	2.97e-6
NO_X	6.3e-6	8.8e-5

Objective Function

In this work, two objectives are considered, one is to reduce energy cost and other is to minimize emission and MOSMA is applied while calculating the schedule power for 24 hours for both summer and winter seasons.

Cost

The cost function is incorporated with various cost of power generation of renewable energy resources along with the cost of main utility grid as given in Eqn.(1):

$$J_C=\mathrm{Min}\left\{\begin{array}{l}\sum_{t=1}^{Th}C^t_{CHP}P^t_{CHP}+\sum_{t=1}^{Th}C^t_{FC}P^t_{FC}+\sum_{t=1}^{Th}C^t_{Wind}P^t_{Wind}+\sum_{t=1}^{Th}C^t_{pv}P^t_{PV}\\ +\sum_{t=1}^{Th}C^t_{gridbuy}P^t_{gridbuy}-\sum_{t=1}^{Th}C^t_{gridsale}P^t_{gridsell}\end{array}\right\} \quad (1)$$

where C^t_{CHP}, C^t_{FC}, C^t_{Wind}, C^t_{PV} represent the cost/kWh, P^t_{CHP}, P^t_{FC}, P^t_{Wind} and P^t_{PV} represent CHP, FC, Wind and PV output active power respectively, $P^t_{Gridbuy}$ and $P^t_{Gridsell}$ are the grid buying and selling power respectively of the t-th hour. The buying price and selling price of the main grid at hour t are $C^t_{gridsale}$ and $C^t_{gridbuy}$ respectively. It is noted that selling cost is subtracted from total cost when total power generation of microgrid is greater than load and added when power generation is inadequate. Th = No of time interval which is 24.

Constraints

MGEMS should guarantee the security and margin of reserve capacity while taking into account CHP, FC, Wind and PV characteristics. Accordingly, the MG optimization model is subjected to the constraints as follows.

i) *Equality Constraints*

According to this restriction, the total power of the load demand P_L at t^{th} hour must be equal to the total power of CHP, FC, Wind, PV and power from grid. The following can be written as the mathematical expression for such a constraint:

$$\sum_{t=1}^{T}P^t_{CHP}+\sum_{t=1}^{T}P^t_{FC}+\sum_{t=1}^{T}P^t_{Wind}+\sum_{t=1}^{T}P^t_{PV}+\sum_{t=1}^{T}P^t_{gridbuy}-\sum_{t=1}^{T}P^t_{gridsale}-\sum_{t=1}^{T}P^t_{L}=0 \quad (2)$$

ii) *Inequality Constraints:*

Following are the limits of power supplied by different DER present in the microgrid.

$$\begin{array}{l}P^{min}_{CHP}\le P_{CHP}\le P^{max}_{CHP}\\ P^{min}_{FC}\le P_{FC}\le P^{max}_{CHP}\\ P^{min}_{Wind}\le P_{Wind}\le P^{max}_{Wind}\\ P^{min}_{PV}\le P_{PV}\le P^{max}_{PV}\end{array} \quad (3)$$

P^{max}_{CHP}, P^{max}_{CHP}, P^{max}_{Wind} and P^{max}_{PV} represent the maximum rate of active power and P^{min}_{CHP}, P^{min}_{FC}, P^{min}_{Wind} and P^{min}_{PV} represent the minimum rate of active power.

For this micro-grid system upper and lower limits of CHP, FC, Wind and PV are given in

Table 3. DERs limits in kW

MGEMS	P_{min}	P_{max}
wind	0.1	55
FC	1.2	45
PV	0.1	45
CHP	2.1	50

Emission

The emissions due to different oxides as discussed in **Section 3.2** are to be minimized to reduce environment pollution and following is the objective function incorporated with emission cost.

$$E=\min\left\{\begin{array}{l}\sum_{t=1}^{T}E^{CHP}_{CO_2}P^t_{CHP}+\sum_{t=1}^{T}E^{CHP}_{SO_2}P^t_{CHP}+\sum_{t=1}^{T}E^{CHP}_{NO_x}P^t_{CHP}\\ +\sum_{t=1}^{T}E^{FC}_{CO_2}P^t_{FC}+\sum_{t=1}^{T}E^{FC}_{SO_2}P^t_{FC}+\sum_{t=1}^{T}E^{FC}_{NO_X}P^t_{FC}\end{array}\right\} \quad (4)$$

$E_{CO_2}^{CHP}$, $E_{SO_2}^{CHP}$ and $E_{NO_X}^{CHP}$ are the factor of emission of SO_2, NO_X and CO_2 respectively delivered by CHP for each unit in kg at time t. $E_{CO_2}^{CHP}$, $E_{SO_2}^{CHP}$ and $E_{NO_X}^{CHP}$ are the factor of emission of SO_2, NO_X and CO_2 delivered by FC in kg/kWh and P_{CHP} and P_{FC} represent the active power of CHP and FC.

Load Demand

The hourly load demand of each day for both summer and winter seasons to be fulfilled by microgrid are given in Fig. 2.

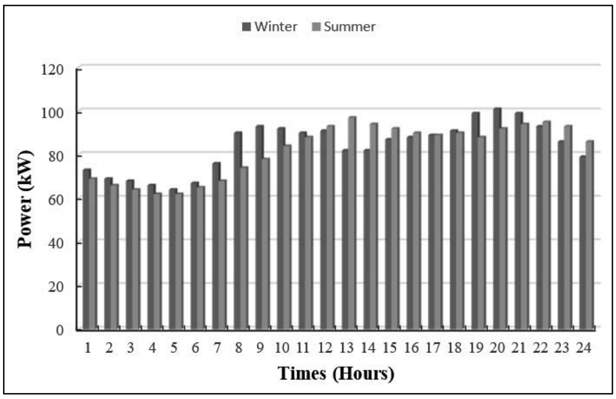

Figure 2: Load profile for 24 hours in winter and summer

Proposed Algorithm

Slime Mould Algorithm (SMA)

Li et al. [31] have proposed SMA, which is an innovative population-based metaheuristic algorithm that draws inspiration from the oscillatory behaviours observed in slime mould found in nature. The feedback mechanism in food route is incorporated to develop the equations for SMA. To avoid collisions among slime mould, grabble phenomenon is followed in this algorithm and approach phenomenon is followed in the learning process as slime moulds move towards the centre of the food source. The advancement of the SMA algorithm is influenced by several parameters, including vibration parameter (Vbr), weight of fitness (Wt) etc. Vbr serves to either facilitate early exploration or enhance the accuracy of later exploitation in individual slime moulds, ensuring a balance between exploring new possibilities and exploiting existing knowledge. The stepwise procedure of the SMA algorithm, involving actions like grabbing food, wrapping food, and approaching food, can be precisely elucidated through mathematical descriptions as follows:

$$Y(C\_itr+1)=\begin{cases} Y_b(C\_itr)+vbr.\left(Wt.Y_A(C\_itr)-Y_B(C\_itr)\right), rd<p \\ vdc.Y(C\_itr), rd \geq p \end{cases} \tag{5}$$

where vbr is a parameter with a range of [−d, d], vdc decreases linearly from one to zero. C_itr is current iteration and 'Wt' denotes the slime mould's weight, Y_b is the individual location of maximum odour, 'Y' is the location of slime mould, Y_A and Y_B represent randomly selected two individuals from slime mould. The formula of p is described as follows:

$$p=\tanh\left|St(i)-DFt\right| \tag{6}$$

where $i \in 1,2,...,n$, St(i) represents the fitness of Y, The variable 'DFt' indicates the best fitness achieved throughout all iterations. The formula of vbr is as follows:

$$vbr = [d, -d] \tag{7}$$

$$d=\operatorname{arctanh}\left(-\left(\frac{C\_itr}{itr_{max}}\right)+1\right) \tag{8}$$

The formula of Wt is listed as follows:

$$Wt\left(SmellIndex(i)\right)=\begin{cases} 1+rdlog\left(\frac{bFt-st(i)}{bFt-wFt}+1\right), condition \\ 1-rdlog\left(\frac{bFt-st(i)}{bFt-wFt}+1\right), Other \end{cases} \tag{9}$$

where, St(i) is responsible for sorting the population' first half, The variable 'rd' is a randomly generated number, bFt and wFt indicate the optimal and worst fitness value respectively, and Smell Index represents the sequence sorted in ascending order (in problems where the goal is to minimize values). Lastly, 'itr_{max}' represents the maximum number of iterations.

MOSMA

Initially MOSMA involves calculation of non-dominated solutions. Then it implements ranking followed by non-dominated sorting and the process is iteratively repeated until the specified final conditions are met. To identify the optimal solution from the obtained set of best solutions using MOSMA, a fuzzy decision function incorporating a membership function is utilized. This function, denoted by μ_k^i evaluates the optimality of the ith objective function among the kth Pareto optimal solutions, as calculated using Equation.

$$\mu_i^k = \begin{cases} 1 & f_i \le f_i^{min} \\ \dfrac{f_i^{max} - f_i}{f_i^{max} - f_i^{min}} & f_i^{max} < f_i < f_i^{min} \\ 0 & f_i \ge f_i^{max} \end{cases} \tag{10}$$

In this proposed approach, these boundaries are computed individually for each objective function based on the optimization outcomes. The value of μ_i^k falls between 0 and 1, where $\mu_i^k = 0$ suggests the solution does not align with the specified objectives, whereas $\mu_i^k = 1$ indicates complete compatibility. For each optimal solution in Pareto set k, the normalized membership function is derived using Equation

$$\mu^k = \frac{\sum_{i=1}^{m} \mu_i^k}{\sum_{k=1}^{n} \sum_{i=1}^{m} \mu_i^k} \tag{11}$$

The solution exhibiting the highest membership function value is chosen as the most compatible solution. Due to its enhanced search capabilities, the algorithm incorporates a randomized search component. The utilization of non-dominant sorting not only confers a Pareto advantage but also enhances solution diversity through the introduction of crowding distance.

The Algorithm steps of MGEMS using MOSMA is given as follows:

- **Step 1:** Read input data like cost of main grid, DER price and emission factor and DER limits. Set the number of population and iteration for potential solutions.
- **Step 2:** Evaluate the objective function as given in equation no. (1) and (4) of each solution in the initial population based on the defined objective function and constraints.
- **Step 3:** Calculate the value of objective function and update the population based on the algorithm's selection criteria.
- **Step 4:** Determine the pareto front from the set of non-dominated solutions and calculate best value from this using Eqn. (11).
- **Step 5:** Periodically re-optimize the system as conditions change or new data becomes available. Ensure the micro-grid remains efficient and effective over time.

Simulation Results

In the present work, optimum power dispatch of DERs (FC, CHP, Wind and PV) and emission are found using MOSMA for a micro grid system connected with main grid for the typical forecasted load for summer and winter seasons. The forecasted load data for both summer and winter season are provided during a period of time from 0.00 to 24.00 hours for each day as given in **Fig. 2**. The available power from wind and PV are shown in **Fig. 3** and **Fig. 4**. The population size and the maximum iteration number are taken as 200 and 100 respectively for the minimization of cost function (Eqn. 1) and emission function (Eqn. 4) and the optimum result are found for 24 hours. The best point from pareto front is found out using eqn. (9). The results for optimum dispatch of power are given in **Table 4** and **Table 5** for summer and winter respectively. From the result, it is seen that microgrid sells power to utility grid during winter seasons for particular duration in a day for optimum operation. Further, the results found using MOSMA are compared with MOGWA for both summer and winter seasons as shown in Table 6. From this table, it is seen that MOSMA gives better results compared to MOGWA.

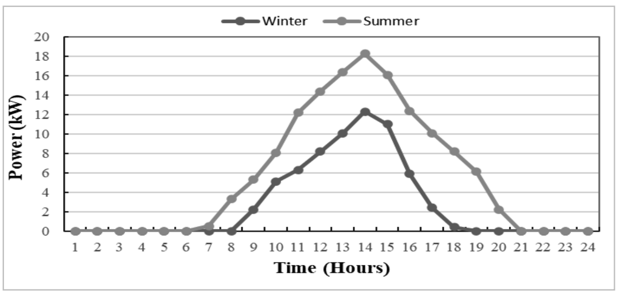

Figure 3: PV Profile of 24 hours for summer and winter

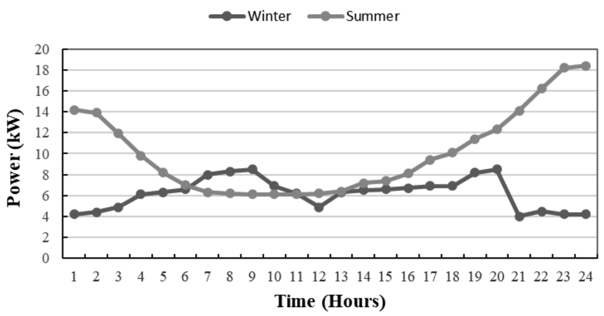

Figure 4: Wind Profile of 24 hours for summer and winter

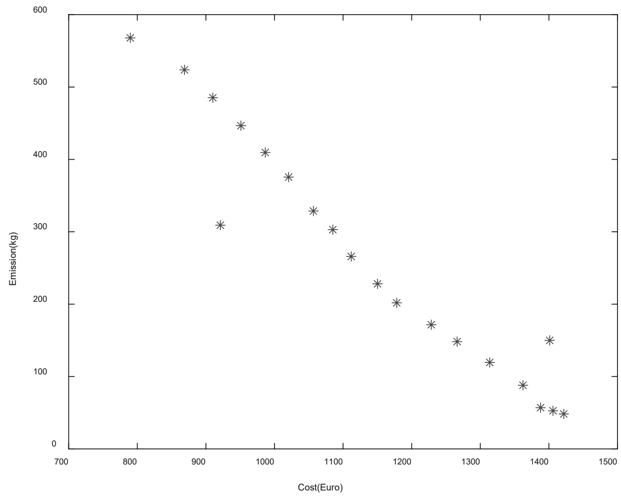

Figure 5: Pareto Optimal Front by using MOSMA during Winter.

Table 4. Allocation of Optimum Power during the winter season

Time (hour)	FC (kWh)	CHP (kWh)	Wind (kWh)	PV (kWh)	Grid (kWh)	Cost (Euro)	Emission (kg)
1	38.05	2	0	0	32.95	26.51	9.49
2	39	2	0	0	28	25.7	9.71
3	39	2	0	0	27	25.23	9.71
4	35.11	2	0	0	28.89	25.4	8.82
5	39	2	0	0	23	25.06	9.71
6	37.77	2	0	0	27.23	26.56	9.43
7	39	35.61	0	0	1.39	33.15	22.15
8	35.96	47.13	0	0	0.91	37.4	25.71
9	36.73	49.12	0	0	-0.86	38.62	26.63
10	38	50.98	0	0	3.02	44.43	27.61
11	37.66	51.82	6.07	5.96	-11.51	32.5	27.84
12	38.2	50.87	0	0	1.93	43.9	27.61
13	39.25	39.56	0	0	3.19	41.35	23.67
14	39	40.1	0	0	2.9	42.72	23.81
15	39.34	44.43	0	0	3.24	43.67	25.49
16	39.74	36.55	0.02	0	11.68	41.67	22.67
17	36.91	42.92	0.01	0	9.15	39.95	24.38
18	37	50.92	6.37	1.03	-4.31	34.77	27.35
19	37.68	51.85	7.36	0	2.11	40.53	27.85
20	37.93	50.52	0	0	12.55	50.96	27.42
21	36.73	50.56	4.79	0	6.92	42.24	27.16
22	38.11	50.52	0	0	4.37	39.6	27.46
23	34.57	47.31	0	0	3.12	35.45	25.46
24	36.96	48.94	0	0	-6.91	31.4	26.61
Total						868.77	523.75

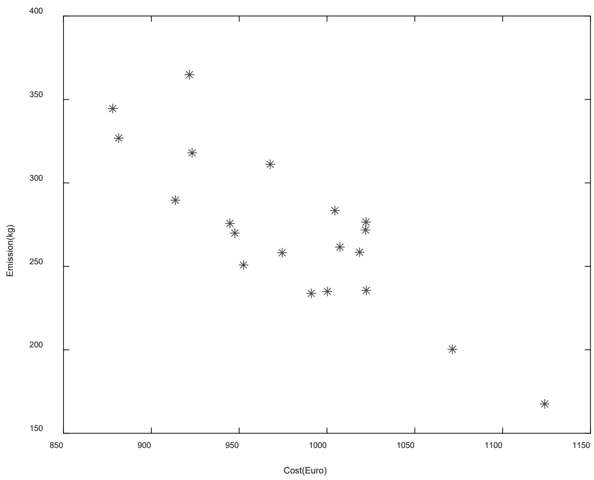

Figure 6: Pareto Optimal Front by using MOSMA during Summer

Table 5. Allocation of Optimum power during the summer season

Time (hour)	FC (kw)	CHP (kw)	Wind (kw)	PV (kw)	Grid (kw)	Cost (Euro)	Emission (kg)
1	4.3	2	4.58	0	58.13	24.44	1.73
2	43.99	2	4.82	0	15.19	22.96	10.86
3	31.63	2	5.31	0	25.06	22.41	8.02
4	38.57	2	5.88	0	15.54	22.17	9.61
5	28.92	2	6.35	0	24.73	22.59	7.39
6	38.49	2	6.97	0	17.54	23.67	9.59
7	45	2	7.76	0	13.24	28.74	11.09
8	43.42	2	8.44	0	20.15	39.28	10.73
9	45	2	8.61	2.23	20.15	41.49	11.09
10	45	2	7.67	5.02	24.31	46.52	11.09
11	45	2	6.46	6.34	28.2	49.76	11.09
12	45	2	5.63	8.03	32.34	45.64	11.09
13	45	2	5.94	10.49	33.57	41.73	11.09
14	45	2	6.38	11.89	28.73	40.9	11.09
15	45	2	6.61	10.16	28.22	39.64	11.09
16	35.53	2	6.68	6.19	39.61	39.15	8.91
17	45	2	6.71	2.94	32.35	36.45	11.09
18	45	2	6.9	1.12	34.98	50.49	11.09
19	45	4.22	7.83	0	30.95	51.94	11.91
20	45	2	8.47	0	36.53	57.41	11.09
21	45	3.25	4.59	0	41.16	59.02	11.55
22	45	2	4.48	0	43.52	60.62	11.09
23	45	2	4.43	0	41.57	51.6	11.09
24	43.06	2	4.43	0	36.51	36.34	10.64
Total						951.66	247.28

Table 6. Comparison of Cost and emission

Season	MOSMA		MOGWA	
	Cost (Euro)	Emission (Kg)	Cost (Euro)	Emission (Kg)
Winter	868.77	523.75	873.45	535.24
Summer	951.66	247.28	962.67	255.37

Conclusion

The adoption of an energy management system in a hybrid micro-grid represents a pivotal step toward a more sustainable and environmentally conscious energy future. Various hybrid energy sources such as PV, wind generator, FC and CHP are integrated into the micro-grid. Further, the micro-grid is assumed to be connected to the main utility grid so that it can draw power from the utility grid when power generation of the microgrid is inadequate. Considering two objectives, (i.e., one is to reduce energy cost and other is to minimize emission) power generation for these sources are determined for 24 hours load demand for winter and summer seasons using MOSMA. From the result it is seen that microgrid sells power to utility grid during winter seasons for particular duration in a day. The value of cost and emission for 24 hours for both summer and winter seasons found using MOSMA are compared with MOGWA to prove its superiority for optimal solution of the MGEMS.

References

1. M Alilou, B Tousi, H Shayeghi, Home energy management in a residential smart micro grid under stochastic penetration of solar panels and electric vehicles, Solar Energy, Vol 212, page 6–18, 2020. https://doi.org/10.1016/j.solener.2020.10.063
2. B Y Ekren, O Ekren, Simulation based size optimization of a PV/wind hybrid energy conversion system with battery storage under various load and auxiliary energy conditions, Applied Energy, Vol 86, No 9, page 1387–1394, 2009. https://doi.org/10.1016/j.apenergy.2008.12.015
3. M Elsied, A Oukaour, H Gualous, S Youssef, R Hassan, A A Amin, Analysis, modeling, and control of an AC microgrid system based on green energy, Renewable Energy and Power Quality Journal, Vol 10, No 12 page 896–901, 2014. https://doi.org/10.24084/repqj12.525
4. A Kumar, M Z U Khan, B Pandey: Wind Energy: A review paper, Gyancity Journal of Engineering and Technology, Vol 4, No 2, page 29–37, 2018. https://doi.org/10.21058/gjet.2018.42004
5. Z Ullah, M Baseer, Operational planning and design of market-based virtual power plant with high penetration of renewable energy sources. International Journal of Renewable Energy Development, Vol 11, No 3, page 620–629, 2022. https://doi.org/10.14710/ijred.2022.44586
6. Y Zheng, B M Jenkins, K Kornbluth, A Kendall, C Traeholt, Optimization of a biomass-integrated renewable energy microgrid with demand side management under uncertainty, Applied Energy, Vol 230, page 836–844, 2018. https://doi.org/10.1016/j.apenergy.2018.09.015
7. T Niknam, F Golestaneh, M Shafiei, Probabilistic energy management of a renewable microgrid with hydrogen storage using self-adaptive charge search algorithm, Energy, Vol 49, page 252–267, 2013. https://doi.org/10.1016/j.energy.2012.09.055
8. M Elsied, A Oukaour, H Gualous, R Hassan, Energy management and optimization in microgrid system based on green energy, Energy, Vol 84, page 139–151, 2015. https://doi.org/10.1016/j.energy.2015.02.108
9. S Behera, N B D Choudhury, S Biswas Maiden application of the Slime mould algorithm for optimal operation of energy management on a microgrid considering demand response Program, SN Computer Science, Vol 4, No 5, 2023. https://doi.org/10.1007/s42979-023-02011-9
10. J L Bernal-Agustín, R Dufo-López, Simulation and optimization of stand-alone hybrid renewable energy systems, Renewable & Sustainable Energy Reviews, Vol 13, No 8, page 2111–2118, 2009. https://doi.org/10.1016/j.rser.2009.01.010
11. W Su, J Wang, Energy management systems in micro-grid operations. The Electricity Journal, Vol 25 No 8, page 45–60, 2012. https://doi.org/10.1016/j.tej.2012.09.010
12. M Motevasel, A R Seifi, T Niknam, Multi-objective energy management of CHP (combined heat and power)-based micro-grid, Energy, Vol 51, page 123–136, 2013. https://doi.org/10.1016/j.energy.2012.11.035
13. M H Moradi, M Hajinazari, S Jamasb, M Paripour, An energy management system (EMS) strategy for combined heat and power (CHP) systems based on a hybrid optimization method employing fuzzy programming, Energy, Vol 49, page 86–101, 2013. https://doi.org/10.1016/j.energy.2012.10.005

14. Y Zhang, N Gatsis, G B Giannakis, Robust energy management for microgrids with High-Penetration renewables. IEEE Transactions on Sustainable Energy, Vol 4, No 4, page 944–953, 2013. https://doi.org/10.1109/tste.2013.2255135
15. P Basak, S Chowdhury, S Dey, S Chowdhury, A literature review on integration of distributed energy resources in the perspective of control, protection and stability of microgrid. Renewable & Sustainable Energy Reviews, Vol 16, No 8, page 5545–5556, 2012. https://doi.org/10.1016/j.rser.2012.05.043
16. J J Justo, F Mwasilu, J Lee, J W Jung: AC-microgrids versus DC-microgrids with distributed energy resources: A review. Renewable & Sustainable Energy Reviews, Vol 24, page 387–405, 2013. https://doi.org/10.1016/j.rser.2013.03.067
17. J Shi, L Ma, C Li, N Liu & J Zhang, A comprehensive review of standards for distributed energy resource grid-integration and microgrid. Renewable & Sustainable Energy Reviews, Vol 170, No 112957, 2022. https://doi.org/10.1016/j.rser.2022.112957
18. P J Mago, A D Smith, Evaluation of the potential emissions reductions from the use of CHP systems in different commercial buildings. Building and Environment, Vol 53, Page 74–82, 2012. https://doi.org/10.1016/j.buildenv.2012.01.006
19. A D Smith, P J Mago, N Fumo, Benefits of thermal energy storage option combined with CHP system for different commercial building types. Sustainable Energy Technologies and Assessments, Vol 1, page 3–12, 2013. https://doi.org/10.1016/j.seta.2012.11.001
20. M Bianchi, A De Pascale, F Melino, Performance analysis of an integrated CHP system with thermal and Electric Energy Storage for residential application, Applied Energy, Vol 112, page 928–938, 2013. https://doi.org/10.1016/j.apenergy.2013.01.088
21. A Arsalis S K Kaer, M P Nielsen, Modeling and optimization of a heat-pump-assisted high temperature proton exchange membrane fuel cell micro-combined-heat-and-power system for residential applications, Applied Energy, Vol 147, page 569–581, 2015. https://doi.org/10.1016/j.apenergy.2015.03.031
22. F G Montoya, C Gil, A Alcayde, J Gómez, Optimization methods applied to renewable and sustainable energy: A review, Renewable & Sustainable Energy Reviews, Vol 15, No 4, page 1753–1766, 2011. https://doi.org/10.1016/j.rser.2010.12.008
23. M Fadaee, M a M Radzi, Multi-objective optimization of a stand-alone hybrid renewable energy system by using evolutionary algorithms: A review, Renewable & Sustainable Energy Reviews, Vol 16, No 5, page 3364–3369, 2012. https://doi.org/10.1016/j.rser.2012.02.071
24. T Niknam, R Azizipanah–Abarghooee, M R Narimani, An efficient scenario-based stochastic programming framework for multi-objective optimal micro-grid operation, Applied Energy, Vol 99, page 455–470, 2012. https://doi.org/10.1016/j.apenergy.2012.04.017
25. S Mohammadi, B Mozafari, S Soleymani, Optimal operation management of microgrids using the point estimate method and firefly algorithm while considering uncertainty, Turkish Journal of Electrical Engineering and Computer Sciences, Vol 22, page 735–753, 2014. https://doi.org/10.3906/elk-1207-131
26. M Premkumar, P Jangir, R Sowmya, H H Alhelou, A A Heidari , H Chen, MOSMA: Multi-Objective Slime Mould algorithm based on Elitist Non-Dominated Sorting, IEEE Access, Vol 9, page 3229–3248, 2021. https://doi.org/10.1109/access.2020.3047936
27. S Khunkitti, A Siritaratiwat, S Premrudeepreechacharn, Multi-Objective optimal power flow problems based on Slime Mould algorithm. Sustainability, Vol 13, No 13, page 7448, 2021. https://doi.org/10.3390/su13137448
28. E H Houssein, M A Mahdy, D Shebl, A Manzoor, R Sarkar, W M Mohamed, An efficient slime mould algorithm for solving multi-objective optimization problems. Expert Systems With Applications, Vol 187, No 115870, 2022. https://doi.org/10.1016/j.eswa.2021.115870
29. M Al-Kaabi, V Dumbrava, M Eremia, A Slime Mould Algorithm Programming for Solving Single and Multi-Objective Optimal Power Flow Problems with Pareto Front Approach: A Case Study of the Iraqi Super Grid High Voltage, Energies, Vol 15, No 20, 7473, 2022. https://doi.org/10.3390/en15207473
30. T Zhu, H Wan, Z Ouyang, T Wu, L Ji, W Li, B Li, S Han, Multi-objective slime mold Algorithm: A slime mold approach using multi-objective optimization for parallel hybrid power system, Sensors and Materials, Vol 34, No 10, page 3837, 2022. https://doi.org/10.18494/sam4020
31. S Li, H Chen, M Wang, A A Heidari, S Mirjalili, Slime mould algorithm: A new method for stochastic optimization, Future Generation Computer Systems, Vol 111, Page 300–323, 2020. https://doi.org/10.1016/j.future.2020.03.055