Efficient Energy Managemet System Based on Demand Shifts in Domestic Grid Considering Emission and Tax on Carbon

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***Abstract*—Nowadays, there is a global need for energy management to reduce cost, planet damage and dependence on fossil fuels to save energy. In this paper, we suggest an efficient Energy Management System (EMS) with an emphasis on Demand Response (DR), the planning of generation units in the grid and exchanges between the grid and the upstream network, with the aim of reducing the Market Clearing Price (MCP), Emission Reduction (ER) and consequently reductions of Tax on Carbon (ToC). In the proposed problem, technical and economic constraints include any producer/consumer equipment, as well as the DR, ER, ToC, MCP and grid connection requirements to the main upstream network. To find the best possible solution, Particle Swarm Optimization (PSO) methodology is applied. The obtained results showed a noticeable decrease in MCP and ER by 37% and 55%, respectively.**

Keywords—Energy Management System, Demand Respond, Emission Reduction, Tax on Carbon, Particle Swarm Optimization

NOMENCLUTURE

e/ω	Electrical/ Thermal
E	Emission
EN	Energy
π	Offered Price
n	Electric Total Load
Δt	Time Step (1 hour in this paper)
ϕ	A coefficient of total microgrid capacity
μ / μ'	Index/ Obtained Emission
λ / λ'	Predicted/ Obtained MCP
f_{ε}	Ratio between maximum shift able power and load demand at time t
E_x	Home-Microgrids consumption capacity
g_{ε}	Upper and lower bounds of the variations of the shiftable power amount at time t
P^*	Limit Coefficient of Buy from Grid
$\alpha, \beta, \gamma, \varphi$	Constant Coefficient
$S\dot{O}C$, $S\ddot{O}C$	Minimum and Maximum of SOC
$\dot{EN}$, $\ddot{EN}$	Minimum and Maximum of Energy
REF	Refrigerator
DW	Dishwasher
TD	Thermal Dump
HHW	Heat and Hot Water
CHP	Combine Heat and Power
PV	Photovoltaic
ES	Electrical Energy Storage
Grid	National Grid
TES	Thermal Energy Storage
GB	Gas Boiler
EV	Electrical Vehicle
SSP	Selling Price of the System
SBP	Purchase Price of the System
RLD	Responsive Load Demand
NDU	Non-dispatchable Unit
DU	Dispatchable Unit

I. INTRODUCTION

It is a well-known fact that the expansion of electrical production to cater for a rising demand for electric power has led to a substantial increase in CO_2 emissions and which, in turn, has a direct impact on global warming threatening the earth's natural environment. With the expansion of distributed generating devices, especially renewable resources, Home Micro-grids (H-MG) have been increasingly considered as a potential clean and green solution for the environment. In order to achieve micro-grid capabilities such as lowering demand costs, increasing reliability, improving the quality of power, and more importantly, reducing greenhouse gas emissions, providing an Energy Management System (EMS) is of paramount importance [1]–[3]. EMSs are designed to cope with the optimal management of each H-MG's production sources, exchange between H-MG and main network, and optimal use of backup systems (such as Energy Storage (ES) and Combined Heat and Power (CHP)) resources; besides balancing the supply and demand. The use of ES, in addition to being able to play an effective role in increasing reliability, can be used to minimize peak energy consumption in H-MGs by being in place of final consumption and provides ES at low load hours [4]. In addition to handling peak load response, the ES can replace fossil power generation as alternative [5]. On the other hand, the H-MGs, by utilizing the Demand Response (DR), can reduce the expensive cost of purchasing ES [6] as well as reducing the volatility of the random demand of the power. The power shift from the current period to the upcoming intervals in which the power production exceeds the consumption will not only balance the supply and demand but also can play an important role in reducing emissions [7], [8]. In recent years, tax on Carbon (ToC) has been employed as a common energy policy in advanced countries to address the greenhouse gas emissions and global warming issue. ToC means the cost of emissions from fossil fuel consumption is calculated at the electrical bill [9]. ToCs can be considered as incentives for a maximum payment to renewables investment, because of their non-pollution properties, and they will not actually be taxed [10]. In this way, previous research has defected which are covered, such as:

- Lack of a robust EMS to focus on emission and ToC [11]–[14]
- Using DR without considering emission section [15]–[17]

In this paper, an environmental-economic approach to EMS related to a H-MG is presented. In this regard, EMS will take full advantage of the availability of renewable equipment and then, by considering the conditions of the ESS, it will attempt to supply power from the main network or CHP. The considered DR strategy allows fossil fuel generators or global network to produce/ purchase electricity only if the Emission Index (EI) will not violate a predetermined limitation. Consequently, by limiting production/purchasing power from polluting generators and shifting the demand of H-MG into future periods, the ToC also decreases accordingly. On the other hand, EMS along with optimized power management should minimize the Market Clearing Price (MCP) through dynamic pricing (DP) with the help of the optimization algorithm. The main novelties of this paper can be paraphrased as follows:

1) Implementation of EMS based on DP with the consideration of uncertainty in an H-MG structure and with the goal of reducing MCP and increasing profit
2) Integrating ESS and DR to reduce ToC by the participation of more consumers in the local market

The paper is established as follows. Section II is an overview of the suggested approach. Implementation of proposed algorithm is presented in section III. Problem formulation is presented in section IV, which covers all constrains of each H-MGs, MCP, ER and ToC. Section V presents simulation and yielded results and discusses them. Finally, the paper is deduced in section VI.

II. An Overview of the Proposed Approach

In this article, we assume that the H-MG is connected to the global network and is capable of distributing its power to the network when its generation is in excess mode. Similarly, it can purchase power whenever the production is less than the demand. The schematic of H-MG is depicted in Fig.1. PV and Thermal Solar Panel (TSP) are the main source of H-MGs. It should be noted that, there are several types of electrical and thermal loads in the H-MG such as Dish washer (DW), Electrical Vehicle (EV), Refrigerator (REF), Heat and Hot Water (HHW) and Gas Boiler (GB).

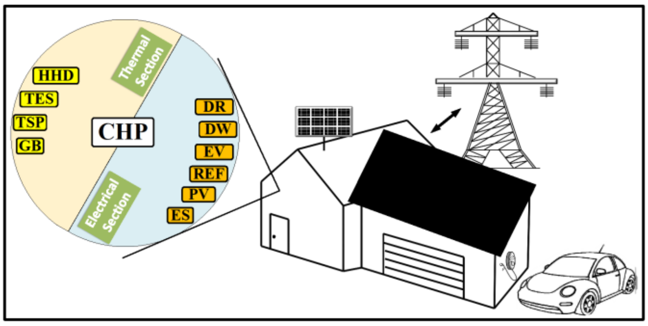


Figure 1. The schematic of H-MG

III. Implementation of Proposed Algorithm

According to Fig.2, the implemented structure is presented in four steps. The first step is to collect the initial data and deliver it to the second step called uncertainty unit, which is based on the Taguchi Orthogonal Array Test (TOAT) method.

In second step some data like atmospheric conditions, H-MG power demand, estimated MCP value, and the System Buy/ Sell price from/ to the global network (SBP, SSP) using normal distribution and radiation equation are under probability calculations. Further explanations are about how TOAT works can be found in [4]. Moreover, the third step which is how to implement EMS-DR is shown in Fig. 3. The composition of EMS-DR is multi-level, and, in turn, it is feasible to obtain the optimal points for meeting the objective function of the problem using particle swarm optimization (PSO). Beside [18], Authors described the pros and cons of the PSO algorithm in [4] in details.

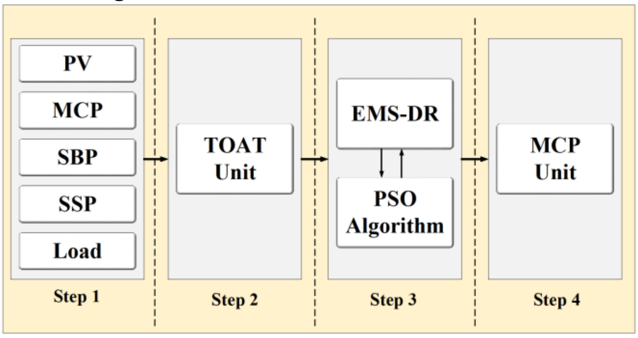


Figure 2. The structure of proposed algorithm

As it can be seen from Fig. 3, after sun raising, the priority for EMS is the use of PV. Also, during this period, avoiding using CHP, and buying power from Grid and emphasizing more on ES and DR are considered to reduce the emission dramatically. Besides, when the weather is cloudy, if there is a shortage of power and if the need for CHP is to be met, the emission limit should first be satisfied. After the CHP comes to the circuit, if surplus production occurs, the power is devoted to ES and shift loads from previous times. However, if there is still a shortage of power after adding CHP to the circuit, the DR should be checked first, and then, if the power is required from the global network, the EMS should partially supply power from the network such that the EI satisfied. Note that, if the CHP constraints cannot be satisfied, and it is not possible to add CHP to the network, ES is discharged if it has this ability. If there is still a lack of power, in the case of power shortage less than the power shift constraint, the power can be shifted to other periods, but if the power shortage is greater than that, by considering the EI, power is purchased from the network. Also, based on Fig. 3, in the thermal section, GB will also be allowed to be used if its own constraints and EI would be satisfied. Otherwise, the GB cannot be used, and then the thermal energy shortage should be supplied by the Thermal Energy Storage (TES).

Finally, in the last step, the MCP is calculated. In MCP unit, each market participant will share their production/ consumption potential along with their offer on the local market. Given the fact that the producers have ascending step chart unlike the consumers which have descending step chart, the value of MCP is calculated as the intersection of these two charts.

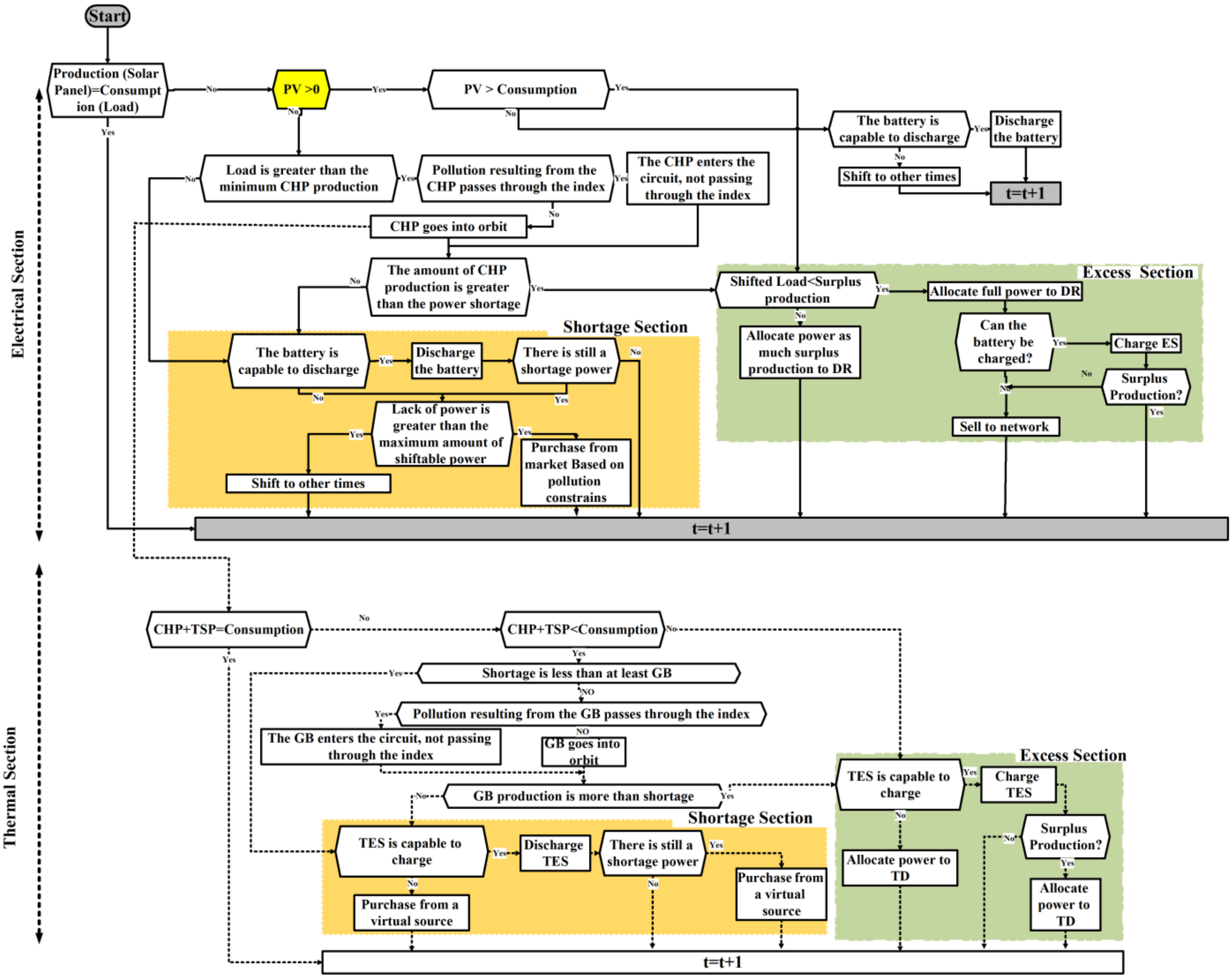


Figure 3. EMS-DR flowchart

IV. PROBLEM FORMULATION

For the sake of implementing H-MG mathematically, the objective function is defined as the profit to be maximized in a daily performance. In (1), $\mathbb{R}$ is the production revenue and $\mathbb{C}$ denotes the costs of electricity consumption. Equation (2) and (3) describe the revenue and costs related to H-MG existing components respectively.

$$Max \sum_{t=1}^{24} (\mathbb{R}-\mathbb{C})\times \Delta t \tag{1}$$

$$\begin{gathered} \mathbb{R}=\mathbb{R}_e^Q+\mathbb{R}_\omega^J \\ Q\in\{PV, ES-, CHP_e, Grid-\},\ J\in\{CHP_\omega, TES-, GB\} \end{gathered} \tag{2}$$

$$\begin{gathered} \mathbb{C}=\mathbb{C}_e^M+\mathbb{C}_\omega^N \\ M\in\{DW, REF, EV+, ES+, Grid+\} \\ N\in\{TES+, HHW, TD\} \end{gathered} \tag{3}$$

Also, (4) shows the minimization of ToC.

$$\min \sum_{t=1}^{24}\left(\left(E_t^{CHP}+E_t^{GB}+E_t^{Grid-}\right)\right)\times\theta\times\Delta t \tag{4}$$

According to existing different types of ESS, the ESS energy capacity is defined in (5).

$$\dot{EN}_t^Z \le EN_t^Z \le \ddot{EN}_t^Z \\ Z \in \{ES, TES, EV\} \tag{5}$$

The maximum and minimum limitation of ESS is determined by (6). In addition, (7) expresses that in each t period, the new charge condition of ESS is checked.

$$S\dot{O}C_t^Z \le SOC_t^Z \le S\ddot{O}C_t^Z \tag{6}$$

$$SOC_{t+1} = \left| SOC_t + \frac{(P_t^{Z+} - P_t^{Z-}) \times \Delta t}{EN_{Tot}^Z} \right|, P_t^{EV-} = 0 \tag{7}$$

The amount of transferable demand power in each time interval is shown in (8). Equation (9) indicates that during two consecutive intervals the power cannot be transmitted beyond a certain limit.

$$P_t^{DR+} \le f_\varepsilon \times P_t^n \tag{8}$$

$$-g_\varepsilon \le P_t^{DR+} - P_{t-1}^{DR+} \le g_\varepsilon \tag{9}$$

H-MG and global network can exchange power if and only if (10) is satisfied.

$$P_t^{Grid+/Grid-} \le P_t^{EX} \tag{10}$$

$$P_t^{EX} \le \phi \times \left(P_{t,e}^{CHP} + P_t^{PV} + P_t^{ES-} \right)$$

On the other hand, according to the goal of reducing emission, (11) shows that the algorithm can buy power from the network if the requested power is greater than a certain amount.

$$P_t^{Grid+} \ge P_t^* \tag{11}$$

Furthermore, (12) and (13) indicates the amount of emission produced by each producer.

$$E_t^{Grid-} = \varphi \times P_t^{Grid-} \tag{12}$$

$$E_t^v = \alpha \left(P_t^v \right)^2 + \beta \left(P_t^v \right) + \gamma \\ v \in \{CHP, GB\},\ (\alpha, \beta, \gamma) \in [0,1] \tag{13}$$

Also, (14) to (21) are describing the bidding constrains.

$$0 \le \pi_{t,e}^A \le MCP \\ A\{ES+, ES-, EV+, PV, REF, DW, DR+, DR-\} \tag{14}$$

$$0 \le \pi_{t,e}^{Grid+} \le SSP \tag{15}$$

$$0 \le \pi_{t,e}^{Grid-} \le SBP \tag{16}$$

$$P_{t,\omega}^B \le \pi_{t,\omega}^B \le 2P_{t,\omega}^B \\ B \in \{CHP, GB\} \tag{17}$$

$$0 \le \pi_{t,\omega}^D \le \min\left(\pi_{t,\omega}^{TES-}, \pi_{t,\omega}^{CHP}, \pi_{t,\omega}^{GB}, \pi_{t,\omega}^{PV} \right) \\ D \in \{TD, HHW\} \tag{18}$$

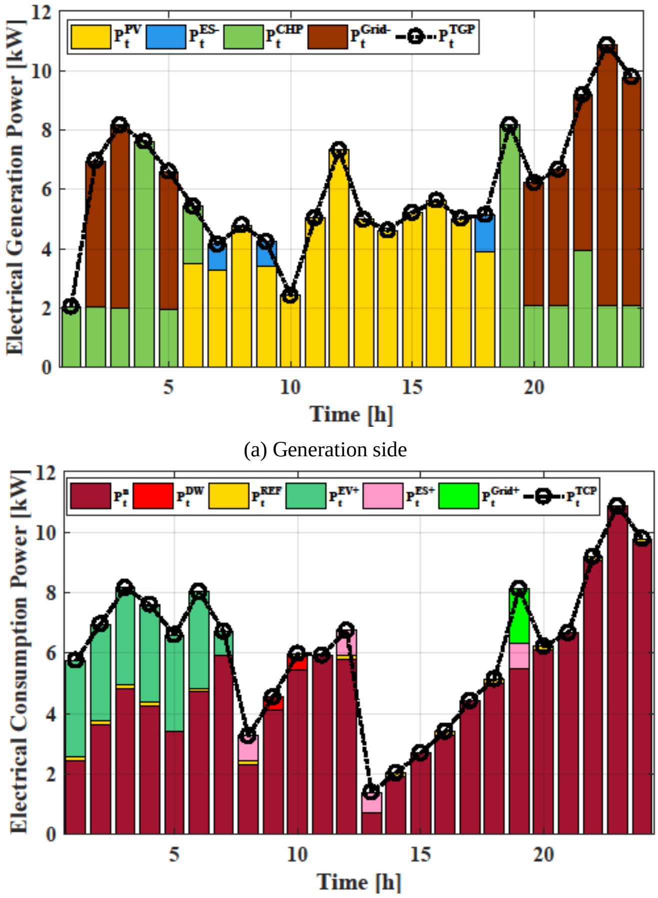
$$0 \le \pi_{t,\omega}^{TES+} \le Max\left(\pi_{t,\omega}^{HHW}, \pi_{t,\omega}^{TD} \right) \tag{19}$$

$$0 \le \pi_{t,\omega}^{TES-} \le \min\left(Max\left(\pi_{t,\omega}^{GB}, \pi_{t,\omega}^{CHP} \right), \pi_{t,\omega}^{PV} \right) \tag{20}$$

$$0 \le \pi_{t,\omega}^{PV} \le Max\left(\pi_{t,\omega}^{TES-}, \pi_{t,\omega}^{GB}, \pi_{t,\omega}^{CHP} \right) \tag{21}$$

V. SIMULATION RESULTS

In this section, the results of the EMS-DR algorithm performance are presented over a 24-hour period. Simulations were conducted through MATLAB software, operating a personal computer with a 4.0 Gigabytes of memory and 2.5 GHz CPU. Figure 4-a shows the electric power generation bar graph. As can be seen, at intervals where PV is not present, power is provided through CHP and the global network. Although there was a shortage of power at t=1, and due to the absence of PV, the CHP was in the circuit, but this presence was limited by DR.



(a) Generation side

(b) Consumption side

Figure 4. Generation and consumption bar graph in the 24-hour

According to Fig. 7, if the amount of CHP production be resulted in EI violation, CHP will be limited. In other words, the maximum amount of CHP production is when it does not cause EI violation. Therefore, according to Fig. 5, the algorithm has transferred the remaining power shortage to the future periods. At t=6, PV has been generating power with sunlight, but since, in accordance with Fig. 4-b, the request is higher than PV production, and the CHP is added to the network while the EI is considered and the amount of power shortage has been shifted to future periods. At t=7, the algorithm between ES and CHP, selects ES and compensating the power shortage is shifted to the next intervals.

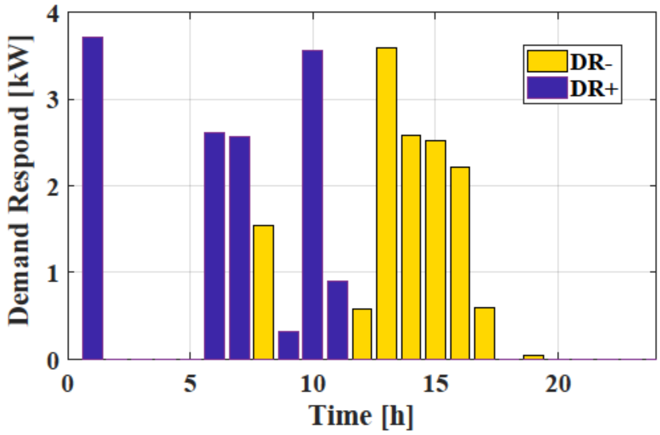


Figure 5. DR Performance

At t=8, the PV generation value is greater than the amount of consumption, and therefore the excess power generation is initially allocated to the ES charge and then, according to Fig. 5, it is assigned to respond to the shifts loaded from the previous steps. In the time interval $9 \le t \le 11$ with respect to the increase in load consumption, the algorithm relied on PV and ES as much as possible to respond, but the remaining amount of power has been shifted. Because if the CHP is not being used and purchasing energy from global network, and also focusing on PV, as shown in Fig. 8, the MCP has significantly decreased. In the time interval of $12 \le t \le 17$, due to the reduction of electric power consumption and being in peak hours of PV production, the ES is fully charged and the rest of the shifted power from the previous steps is also answered.

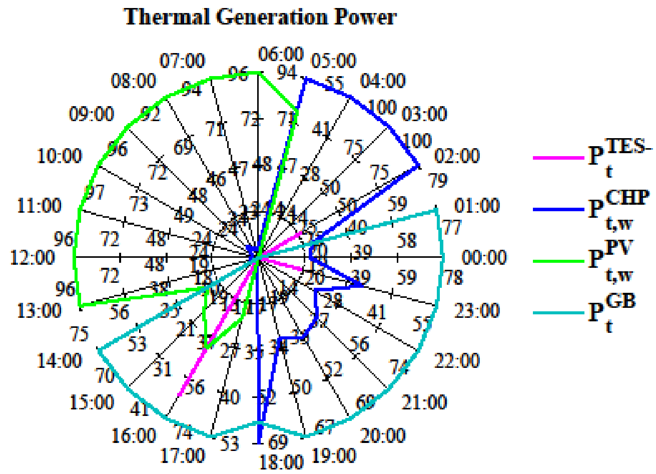


Figure 6. Heat generation during 24-hour system operation

At t=19, at the same time as the sun sets and the PV does not produce, the power consumption increases and thus the algorithm enters the circuit to meet the CHP load. Note that because the CHP output power is greater than the power consumption, the ES is first charged and then the remained power is shifted. On the other hand, given that there is still a surplus of power; excess power is sold to the global network. In the interval of $20 \le t \le 24$ due to the growing trend of loading and being in the night hours and the lack of PV production, the algorithm, which focuses more on CHP and purchasing power from the global network, has been able to respond to demand but on the other hand, emission has increased dramatically.

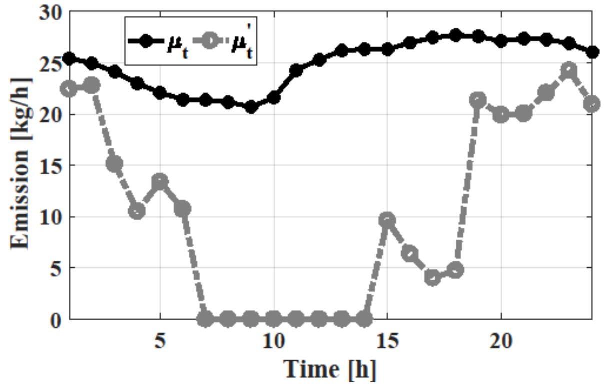


Figure 7. Emission chart

The important thing is that the total load time has been answered during the day, and in this regard, the proposed method has been able to reduce emissions efficiently and has supplied the entire demand

The amount of production of the thermal equipment is shown in Fig. 6. Due to the active presence of CHP in the electrical sector, its heat production was significant in the thermal sector. As the amount of demand has increased with decreasing the PV value, GB has been able to supply while the thermal constraints are considered. Additionally, TES, in accordance to its capacity, responds to the demands as possible as it can.

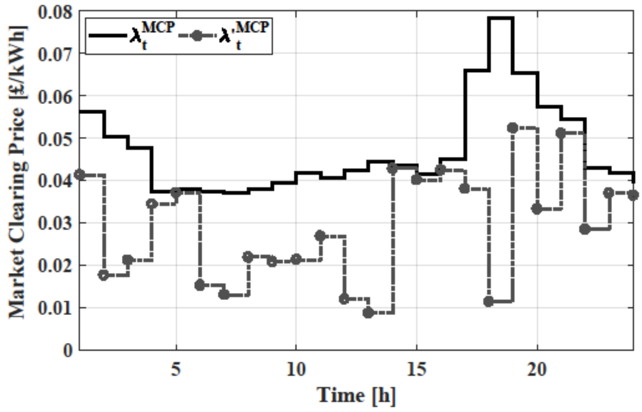


Figure 8. MCP for every time interval of the day when operating

As shown in Fig. 7, the rate of H-MG emission was significantly reduced with regard to DR. At $1 \le t \le 6$, the air emission was reduced by 30% . This is while in the interval of $7 \le t \le 12$ due to the focus on PV and ES, the amount of emission was zero. In the $13 \le t \le 18$ period, due to reduced consumption and the presence of PV, the amount of emissions decreased by 85%, but unlike the two earlier periods, in the interval of $19 \le t \le 24$ due to increased focus on the supply of power from CHP and the power purchase from the network, the amount of emission has decreased by only 20% . Due to the direct relationship between ToC and emission, ToC also decreased significantly. Table I shows the average ToC for any 6-hour period of 24-hour system operation.

TABLE I. THE AVERAGE ToC FOR ANY SIX HOURS OF 24-HOURS SYSTEM OPERATION

ToC[$/ kg$CO_2$]	$1 \le t \le 6$	$7 \le t \le 12$	$13 \le t \le 18$	$19 \le t \le 24$
μ_t	0.112542	0.107279	0.128398	0.129501
μ_t'	0.075788	0	0.019716	0.102596

As shown in Fig. 8, the proposed algorithm can reduce MCP in 100% of the time intervals. Table II shows the average MCP for any 6-hour period of 24-hour system operation.

TABLE II. THE AVERAGE MCP VALUE FOR ANY SIX HOURS OF 24-HOURS SYSTEM PERFORMANCE

MCP[$/ kWh]	$1 \le t \le 6$	$7 \le t \le 12$	$13 \le t \le 18$	$19 \le t \le 24$
λ_t^{MCP}	0.044	0.039	0.053	0.05
$\lambda_t'^{MCP}$	0.027	0.019	0.030	0.04

VI. CONCLUSION

With the advancement in science and technology and the increase in electricity demand and, consequently, too much fossil fuel consumption, worrying about climate-changing has risen dramatically. In this paper, the EMS-DR method, along with the PSO algorithm, have been proposed. Objective functions are: increasing the benefit of an H-MG, reducing emission, ToC, and achieving the optimal utilization of the use of electrical/thermal resources accessible in an H-MG. Focusing more on renewable resources, energy storage, shifting power from high-demanded periods to future periods and, applying strict constraint for CHP and GB and Buying power from the grid are the main ideas of this article. The outcomes explain that DR, considering both the ES and PV being optimally controlled, decreased the greenhouse gases emission and ToC by about 55% and improved the profit of H-MG by 37%.

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