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Optimizing the Energy Consumption of an Electric Motor System Incorporates Hybrid Electric Energy Generators Using a Genetic Algorithm

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Abstract— *This study investigates a hybrid electric system that utilizes novel energy sources and is subject to variable production and uncertainty. The study proposes a multi-objective optimization methodology using Genetic Algorithm (GA) to optimize energy source consumption and utilization, accounting for variations in production/load levels across different time intervals. The proposed approach enables the end-user to achieve desired operational outcomes while adhering to specified constraints, taking into account both economic constraints and environmental considerations. The study explores the implementation of intelligent electric energy management in a model electric motor system that incorporates various electric energy generators, including solar cells, fuel cells, micro-turbines, and batteries. The optimization problem was formulated with multi-objectives of minimizing operating cost and environmental pollution. The presented approach demonstrated that the energy management system or electrical system operator is a proficient mechanism. Ultimately, the investigation has resulted in the development of an intelligent energy management system aimed at enhancing the efficiency of the energy production and storage sampling and planning system. The findings of the optimization clearly demonstrate an inverse link between the operating costs and pollution emissions in the system under study.*

Keywords—Multi-objective optimization, Electric motor system, Genetic algorithm, Smart energy management, Cost-emission curve.

1. INTRODUCTION

Currently, in accordance with environmental objectives, researches have placed greater emphasis on the efficacy of hybrid propulsion systems [1–4]. The production of hybrid power involves the utilization of various components, including batteries, fuel cells, and supercapacitors [5–7]. Efficient management of energy for these devices is crucial for enhancing productivity and ensuring an appropriate reaction to variations in propulsion power consumption [8, 9]. Smart energy management has become an increasingly vital tool for countries in the Persian Gulf region, particularly in light of the international sanctions imposed by the West [10]. The implementation of smart energy management strategies can help these countries to effectively manage their energy consumption while simultaneously reducing their dependence on imported energy sources [11]. This, in turn, can help to mitigate the economic impact of sanctions, by enabling countries to maintain a stable energy supply and reduce energy costs. Moreover, smart energy management can contribute to sustainable development by reducing the region's carbon footprint and promoting the use of renewable energy sources. In short, smart energy management has the potential to play a critical role in helping the Persian Gulf countries to navigate the challenges posed by international sanctions, while also contributing to their long-term economic and environmental sustainability [12].

The management of production power in hybrid systems with varying objectives has been a subject of discussion in numerous articles. The study cited in reference [13] presents a hybrid energy production system that incorporates both fuel cell and battery technologies. The authors propose an energy management strategy that seeks to minimize energy consumption and enhance the overall efficiency of the ship. As stated in [14], the location of a battery and fuel cell has been identified as a means to decrease fuel cell consumption and enhance the dynamic response of the propulsion system. A presented energy management strategy aims to enhance power distribution between the fuel cell and battery, thereby demonstrating the benefits of utilizing this combination. As discussed in reference [15], the thrust load experienced by an electric boat is subject to various alterations resulting from wave interactions and propeller rotation, ultimately impacting the vessel's dependability. A predictive control model has been introduced to effectively address the abrupt power fluctuations. As noted in [16], the implementation of

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hybrid technologies has demonstrated efficacy in mitigating fuel consumption and environmental pollution across various vessel categories. Continuing on, the energy management approach has been employed to determine the optimal power output of each resource within the hybrid system. The study in reference [17] conducted a comparative analysis of electric, mechanical, and hybrid propulsion systems, taking into account cost, environmental impact, and risk factors. The findings of the study indicate that the hybrid propulsion method is the most cost-effective option when compared to the other two methods.

In reference [18] outlines a straightforward yet suitable approach to energy management that involves the allocation of power between hybrid resources, comprising a generator and a storage unit (either a battery or a capacitor). This approach involves setting objectives that aim to reduce the consumption of particular fuel types, taking into account the load and dynamics of the various components of the hybrid system being tracked. The utilization of a hybrid system and energy management strategy has been implemented in reference [19] in response to the abrupt alterations in the ship's load and torque resulting from its rotational motion and the presence of waves. The present approach involves the utilization of batteries and capacitors to mitigate abrupt fluctuations in power. The article cited as reference [19] proposes a hybrid system that utilizes a variable speed diesel generator as the primary power source, along with a battery and capacitor, to effectively manage sudden fluctuations in load. The loading of ships results in alterations in voltage, thereby causing an increase. According to reference [20], the utilization of fuel results in elevated levels of pollution.

However, an alternative approach involves the use of a battery for high energy density storage and a superconducting magnet storage 1 for high power density. The implementation of a DC distribution system utilizing batteries has been suggested for a ship, as described in reference [21]. Hatefi einaddin et al. [22] presented a grid-connected hybrid microgrid with wind and photovoltaic resources as the primary power sources and a hydrogen storage system (comprised of a fuel cell and an electrolyzer) as a reserve. A new power management strategy is proposed to facilitate the equitable distribution of demand among microgrid units. For the achievement of control objectives such as DC bus voltage regulation, power factor control, synchronous grid connection, and power fluctuation suppression, a hybrid (distributed/central) control method is utilized. Khademi Astaneh et al. [23] introduced a new topology for multi input converters in hybrid photovoltaic, fuel cell, and battery power supply systems designed for medium power applications. Due to the presence of the coupled inductor in this converter, current disturbance is abolished. Using two transformers with their terminals connected in series will increase the probability of achieving a high voltage efficacy and developing a high-voltage DC link. As a result of the combination of the magnetizing and leakage inductors of these two transformers, there will be zero-voltage switching for the switches and gentle switching for the output diodes due to the presence of the leakage inductor on the secondary side of the transformers. For the proposed converter, the steady state model and control system are explained.

According to the literature, the primary topic of all sources is the technical and economic review of hybrid systems, whereas few studies concentrate on the environmental aspects of these systems. While the discussion of all the technical, economic, and environmental aspects of this system broadens the experts' perspective, this system's technical, economic, and environmental facets are particularly important.

This study examines the hybrid electric system that utilizes novel energy sources and is subject to variable production and uncertainty. The system is analyzed in the context of storage devices. Furthermore, the optimization of energy source consumption and utilization has been achieved through the implementation of multi-objective optimization using a Genetic Algorithm (GA), accounting for variations in production/load levels across different time intervals. This study proposes a multi-faceted perspective on energy supply concerns, taking into account both economic constraints and environmental considerations. The proposed methodology enables the end-user to obtain optimal emphasis on critical factors and achieve desired operational outcomes while adhering to specified constraints. Moreover, addressing a problem with multiple concurrent constraints, also known as a multi-objective function, and deriving a range of solutions at various operating points offers the opportunity to select the optimal operating point from the perspective of the consumer.

2. HYBRID POWER GENERATION SYSTEM

The hybrid system comprises several components, namely an energy production system that utilizes a combination of fuel cell, battery, and super capacitor, a converter system, a control system, and various loads such as ballast pump, steam tunnel thruster motor, bow tunnel thruster motor, and motor. The tour package comprises of four thrusters and a hotel bar. The hybrid system necessitates a control mechanism to regulate the production power levels in response to abrupt power fluctuations and the unique attributes of each constituent component.

During periods of rapid transformation, energy generation is facilitated through utilization of a supercapacitor. The fuel cell and battery necessitate regulation to ensure their capacity to furnish consistent energy.

2.1. Polymer Electrolyte Membrane Fuel Cell

All The polymeric fuel cell is a prevalent fuel cell variant, primarily due to its low operating temperature and rapid power output escalation. The voltage (V) produced by the fuel cell is represented through an analytical model that takes into account the kinetic reactions (V_{act}) resulting from activation losses, as well as the charge transfer (V_r) that arises from resistance and diffusion losses, as expressed in (1):

$$\begin{aligned} &V = E_{oc} - V_{act} - V_r \\ &V_{act} = A\ln\left(\frac{i_{fc}}{i_o}\right)\cdot\frac{1}{sT_d/3+1} \\ &V_r = r_{ohm}.i_{fc} \end{aligned} \tag{1}$$

The aforementioned equation pertains to the determination of the output current (i_{fc}) of a battery. The variables involved include the constant voltage of the battery (E_{OC}), which is measured in volts, the Tafel slope (A), the converted current (i_0), the combination of battery resistance and diffusion (r_{ohm}), and the settling time of the battery to one current step (Td) [24].

2.2. Lead acid battery

The type of battery utilized in this article is a lead-acid battery. Equation (2) can be utilized to determine the battery voltage:

$$\begin{aligned} &V_{batt} = E_0 - k\frac{Q}{Q-it}.it - R_b.I \\ &+A_b\exp\left(-B.it\right) - K\frac{Q}{Q-it} \end{aligned} \tag{2}$$

The aforementioned variables are denoted as follows: E represents the constant voltage of the battery, K represents the constant polarity, Q represents the battery capacity, i^* represents the filtered current of the battery, which is equivalent to the actual charging current of the battery. Additionally, A_b represents the amplitude of the display area, B represents the inverse of the display time zone constant, and R_b represents the internal resistance of the battery. I am interested in the current output process. This object can be identified as a battery. According to reference [24], the polarization voltage can be obtained by evaluating $K(Q/(Q\text{-}it))it$, while the polarization resistance is given by $K(Q/(Q\text{-}it))$.

2.3. Supercapacitor

The Supercapacitor bears resemblance to both conventional electrostatic and electrolytic capacitors, but possesses the added benefit of being capable of storing or discharging high amounts of energy. The calculation of the capacity (C) of the supercapacitor is derived through the utilization of (3):

$$\begin{aligned} & C=\left[\frac{1}{C_H}+\frac{1}{C_{GC}}\right]^{-1} \\ & C_H=\frac{N_e \varepsilon \varepsilon_0 A_i}{d} \\ & C_{GC}=\frac{F Q_c}{2 N_e R T} \sinh \left(\frac{Q_c}{N_e^2 A_i \sqrt{8 R T \varepsilon \varepsilon_0} c}\right) \end{aligned} \tag{3}$$

where C_H and C_{GC} are the Helmholtz and Guy-Chapman capacitors, respectively. N_e is the number of electrode layers. and 0 are the relative permeability coefficient in the electrolyte and vacuum environment, respectively. A_i is the cross-sectional area between the electrode and the electrolyte, d is the length of the Helmholtz layer or molecular beam, F is the Faraday constant, R is the general gas constant, T is the working temperature, Q_c is the electric charge of the cell, and c is the molar concentration. The output voltage of the supercapacitor is calculated using (4):

$$\begin{aligned} & V_{SG}=\frac{Q_T}{C_T}-R_{SC}.i_{SG} \\ & Q_T=N_p Q_C=\int i_{SG} dt \end{aligned} \tag{4}$$

where Q_T and C_T are the total electric charge and total capacity respectively, R_{SC} is the supercapacitor resistance, N_P is the number of parallel cells and $i_S C$ is the supercapacitor current [24].

2.4. DC-DC converter

The $DC-DC$ converter is capable of altering the output DC voltage of both the fuel cell and battery, as they are interconnected. There exist two distinct approaches for modeling $DC-DC$ converters, namely switching and average value. The pulse width modulation technique involves a transition from modeling to design and application, with a ratio of 1. However, this method does not take into account the effects of harmonics and switching losses. The simulation time is extended due to the necessity of a minimal sampling time for the execution of switching operations in this model. In comparison to the average value technique, the utilization of controlled voltage and current sources in switch modeling results in reduced simulation time. The model in question does not make reference to harmonic switching. However, by taking into account the dynamic states of the switches, it is possible to extend the sampling time. The present article employs the average value method.

2.5. DC-AC converter

Similar to the $DC-DC$ converter, the inverter is also represented using the average value technique. The present study models the output of the inverter, which exhibits a line voltage of $400V$ and a frequency of $50Hz$, as reported in reference [24].

2.6. Control method

The present study employs a proportional integral (PI) controller [14]. The PI controller takes the charge rate of battery 3 as input and produces the battery power as output. This battery power is then subtracted from the load value to determine the reference power value of the fuel cell. When the battery charge rate exceeds the reference value and the fuel cell power value is low in the control area, the battery will supply the entire load. On the contrary, in situations where the battery's charge rate falls below the reference value, the fuel cell offers an approximate amount of power to the load. The present article establishes the equivalence of the KP and Ki coefficients for the integral proportional controller at 5000 and 500, respectively.

3. OPTIMIZATION ALGORITHM

GA simultaneously handles a significant quantity of designs. An additional noteworthy aspect pertains to the fact that the tenets of GA are founded upon stochastic processing, or more accurately, directed stochastic processing. Thus, the utilization of random operators involves the evaluation of the search space in a comparative fashion. In order to utilize GA effectively, it is essential to establish clear definitions for the following three fundamental concepts: This text pertains to the elucidation of the objective function or cost function, the genetic space, and the GA operators, including their respective definitions and implementations.

3.1. Objective function

The first objective's purpose is to reduce overall operating expenses. The cost of fueling production resources and the cost of turning them on or off are included in the overall cost of operating the aforementioned system. This function introduces a collection of production capabilities connected to units and in a particular time period that have been estimated under ideal economic circumstances. The first objective function is denoted by (5):

$$\begin{aligned} & \operatorname{Min} f_1(P)=\sum_{t=1}^{T} \operatorname{Cost}^t \\ & =\sum_{t=1}^{T}\left\{\sum_{i=1}^{N_g}\left[\begin{array}{c} ui(t) C\left(P_{Gi}(t)\right) \\ +S_{Gi}\left|u_i(t)-u_i(t-1)\right| \end{array}\right]\right. \\ & \left.+\sum_{j=1}^{N_s}\left[u_i(t) C\left(P_{sj}(t)\right)+S_{sj}\left|u_j(t)-u_j(t-1)\right|\right]\right\} \end{aligned} \tag{5}$$

The variable T denotes the aggregate duration of the study, while N_g and N_s signify the complete count of production units and energy storage components, correspondingly. capacity of the j-th storage unit at time t, respectively. At time t, there is a sign present at location j-th. The functions $C(P_{Gi}(t))$ and $C(P_{sj}(t))$ represent the costs of production units and storage elements, respectively. The associated start-up costs are modeled using S_{Gi} and S_{sj}.

The secondary objective function aims to minimize the aggregate pollution resulting from pollutants, with the intention of considering the detrimental ecological impacts associated with the presence of said pollutants. The optimization problem involves the consideration of the degree of pollution as the secondary objective. The prevalent contaminants utilized in this context are sulfur dioxide, nitrogen oxides, and carbon dioxide. The second mathematical model shares the objective function of (6), whereby the proposed price of the units or energy storage units is determined by the level of pollution they generate:

$$\begin{aligned} & \operatorname{Min} f_2(p)=\sum_{t=1}^{T} \operatorname{Emission}^t \\ & \sum_{t=1}^{T}\left\{\begin{array}{c} \sum_{i=1}^{Ng}\left[u_i(t) P_{Gi}(t) E_{Gj}(t)\right] \\ +\sum_{i=1}^{Ns}\left[u_j(t) P_{si}(t) E_{sj}(t)\right] \end{array}\right\} \end{aligned} \tag{6}$$

The present study considers the relationship between $E_{Gi}(t)$ and $E_{sj}(t)$, where $E_{Gi}(t)$ and $E_{sj}(t)$ represent the pollution levels generated by the i-th unit and the j-th storage, respectively, at time t. These pollution levels are measured in (7) and (8):

$$E_{Gi}(t)=SO_{2_{DG}}(t)+NO_{x_{DG}}(t)+CO_{2_{DG}}(t) \tag{7}$$

$$E_{Gi}(t)=SO_{2_{DG}}(t)+NO_{x_{DG}}(t)+CO_{2_{DG}}(t) \tag{8}$$

The aforementioned relationships denote the rate of escalation of carbon dioxide, nitrogen oxides, and sulfur dioxide emissions from the source, as represented by the variables $NO_x(t)$, $SO_2(t)$, and $CO_2(t)$, respectively.

3.2. Function limitation

The fundamental requirement for utilizing a system is the equilibrium between the load magnitude and the overall production capacity of the units at all times, as denoted by (9):

$$\sum_{i=1}^{Ng} P_{Gi}(t) + \sum_{j=1}^{Ns} P_{sj}(t) = \sum_{k=1}^{Nk} P_{Lk}(t) \tag{9}$$

where, the load k that enters the system at time t, denoted as $P_{Lk}(t)$, and the total count of load levels, which is referred to as N_k.

As per the technical and functional attributes of energy sources, they are required to operate within a designated power range, in accordance with (10):

$$\begin{gathered} P_{Gi,\min}(t) \leq P_{Gi}(t) \leq P_{Gi,\max}(t) \\ P_{sj,\min}(t) \leq P_{sj}(t) \leq P_{sj,\max}(t) \end{gathered} \tag{10}$$

where, $P_{G,min}(t)$ and $P_{s,min}(t)$ represent the minimum active production power of the energy dispersing and storage units, and $P_{G,max}(t)$ and $P_{s,max}(t)$ represent their maximum production power in Time is t.

The research is constrained by the charge and discharge limitations of other energy storage devices. Energy storage systems have the capability to facilitate a specific quantity of charge or discharge within a designated time interval. As per (11) and (12), there exist constraints on the charge or discharge rate and hourly delivery capacity of the aforementioned entities:

$$\begin{gathered} W_{exs,t} = W_{ess,t-1} + \eta_{ch\arg e} P_{ch\arg e} \Delta t \\ -\frac{1}{\eta_{disch\arg e}} P_{disch\arg e} \Delta t \end{gathered} \tag{11}$$

$$\left\{ \begin{gathered} W_{\text{eess}-\min} \leq W_{\text{ess,t}} \leq W_{\text{ess}-\max} \\ P_{\text{charge,t}} \leq P_{\text{charge}-\max} \\ P_{\text{discharge,t}} \leq P_{\text{discharge}-\max} \end{gathered} \right. \tag{12}$$

$W_{ess,t}$ and $W_{ess,t-1}$ represent the quantity of energy stored in the jth battery during the current and previous hours, respectively. $P_{charge,t}$ and $P_{discharge,t}$ represent the current power consumption (charge) and power production (discharge) of the storage device.

Likewise, the quantities charg and discharg convey the overall efficiency of the operation, each of which represents the efficiency of charging or discharging the storage. In this study, in order to investigate the behavior of the system's constituents, both one-hour and $24 - hour$ time periods have been used.

4. RESULTS AND DISCUSSION

Fig. 1 depicts the entire electrical load on the propulsion system of a propulsion system on a given day, including propulsion, propulsion, interior lighting, etc. In addition, Table 1 detail the technical specifications and operational limitations of distributed production units.

Table 1. Capacity limits of production units.

Unit	Min Power(KW)	Max Power (KW)
Micro turbine	1	120
Fuel Cell	1	100
Supercapacitor	-30	30
Battery	-30	30

This paper examines the proposed algorithm for addressing the challenge of managing the utilization of the sample network and optimizing its performance in the allocation of production or power storage, while taking into account both economic and environmental objectives. All proposed models consider the comprehensive costs associated with network operation, as well as the environmental impact of all extant pollutants.

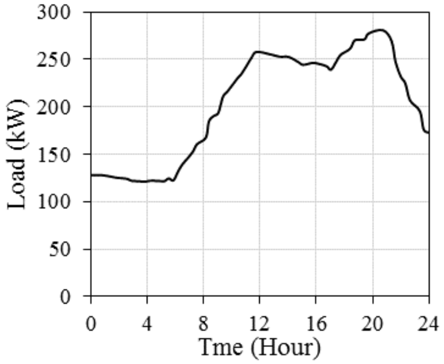

Fig. 1. Load curve during a day.

Conversely, it is imperative to address the optimization quandary on a per-objective function basis, subsequently resolving the overarching issue by amalgamating diverse objective function values in a predetermined format. The present article posits that the resolution of the optimization problem at hand falls under the category of integer linear programming problems. To enhance the identification of costs and pollution within the network and assess their magnitude across varying operational conditions, it is imperative to devise multiple scenarios that deviate from the micro network's working state. Subsequently, informed decisions can be made regarding the construction of the ultimate model, informed by the calculations and results obtained.

4.1. Scenario 1

The first scenario that is proposed in the proposal makes the assumption that the electric system of the engine that is being studied, along with its driving components, are effectively managed and strategically planned in order to maximize the amount of money saved through operational efficiencies. In this particular case, the optimal distribution of work points to production units can be seen depicted in Fig. 2, which is determined by a single economic goal. In point of fact, the numerical values were obtained after the existing equations were solved with a focus on the economic concern. This was done in order to obtain the values. Fig. 2 presents an illustration of the available resources.

The equations that govern the power available to use dictate that the possible range of values for each parameter is dependent on the necessary conditions for the problem to be solved. The operational state of the primary propulsion system, which incorporates both its functionality and performance, may be one of these conditions. The rate at which velocity is continually decreased, as it would be during the act of braking, is referred to as the acceleration rate. It is important to note that the generators that are responsible for charging the batteries are also involved in this reduction in speed. Batteries, which are abbreviated as Batt., go through the charging process in two different ways. The first time is when the system is operating at a low load, which normally takes place in the wee hours of the morning.

The second possible outcome takes place when the percentage of charge in the battery drops below 30 percent. After 9 o'clock in the evening, which is the time of day with the highest demand for power, the batteries are connected to the electrical circuit so that they can supply it. In addition, if one looks at the column labeled "fuel cell (FC)," one can see that the generator maintains its maximum output throughout the entire 24 hour period. This phenomenon can be attributed to two factors: first, the consistent and cost-effective nature of the system's production, and second, the significant expenses associated with its initiation and termination. Both of these factors play a role in the phenomenon. Because the costs associated with starting up and shutting down the microturbine (MTE) are significant, it is in everyone's best interest to avoid doing either of those things as much as possible.

The MT operates continuously throughout the day and night. The power plant generates the most amount of electricity possible when it is operating at its maximum capacity between the hours of 8 am and 11 pm, which corresponds to the time period between load and peak load. In the end, the optimal power values for each source are determined by finding a solution to the conditions that are currently in place. From a financial point of view, during the first few hours that the system was operational, as was previously stated. During times of peak demand, alternative units that have lower prices increase their output, but the fuel cell continues to be the primary source of load due to the fact that its cost is significantly lower. The objective of resource allocation is to ensure that workloads are distributed fairly, which, in turn, should lead to a reduction in overall production costs. The energy management component of the system makes an effort to carry out the procedure of charging the battery during times of low load and at a reduced cost, while postponing the operation of discharging the battery until times of high demand hours.

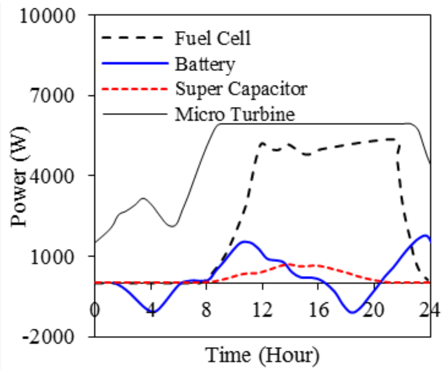

Fig. 2. Optimum performance of existing production resources with the condition of minimum operating cost.

4.2. Scenario 2

The second scenario posits that the control component of the engine will be programmed and managed in a manner that prioritizes minimal environmental pollution during operation, without regard for economic considerations. A penalty will be imposed on the system as a consequence. The present study reveals that the allocation of optimal work points to the production units, solely based on the bio-environmental objective of minimizing pollution, is depicted in Fig. 3.

Changing the focus of exploitation from an economic perspective to a bio-environmental perspective brings about significant changes in the simulation's output, which shows these changes. In contrast to the information that was provided in the initial scenario, there is currently an increase in the number of units that are being used that have a lower amount of pollution output.

The use of solar panels and fuel cells to reduce pollution has become increasingly widespread, which has led to a significant reduction in the dependence on alternative sources of energy. According to the findings of the investigation into the outcomes of both the first scenario and the subsequent ones, fuel cells maintain their maximum level of efficiency throughout the day and serve as the primary focus of energy generation.

4.3. Scenario 3

It has been established, using the sources that were cited, that the development of an intelligent programming scheme that is capable of making appropriate decisions based on various circumstances is essential. This has been determined to be the case. It is essential that a number of factors are present, one of which is the mandate that the plan that is being proposed must be both all-encompassing and adaptable. This requires the ability to readjust in response to any changes in the environment or in the actions taken. The model is characterized by having multiple objectives, in which it establishes a specific set of goals based on user feedback and issue-specific conditions in order to achieve the optimal solution or solutions.

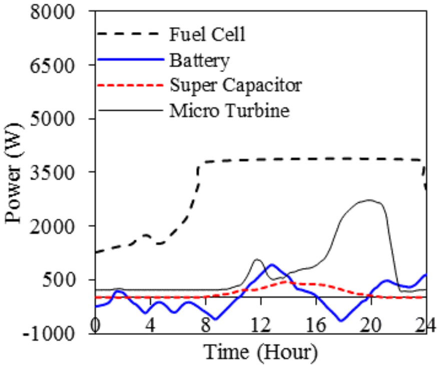

Fig. 3. Optimum performance of existing production resources with the condition of minimum pollution.

This is one of the distinguishing characteristics of the model. When attempting to solve a problem, the third step is to use conditions that are as accurate a representation as possible of the model's actual environment. In addition to this, it is of the utmost importance to provide an appropriate response for the model that has been proposed within a reasonable amount of time. The aforementioned considerations are carefully monitored and incorporated into the model in order to produce the best possible example of a multi-objective optimizer that possesses these qualities. It is hypothesized that the sample system contains a number of units, each of which has the potential to either be operational or dormant depending on the circumstances at hand.

The implication of this is that the generators are responsible for bearing the cost of activation and deactivation in addition to the costs associated with the production of energy and the impact that it has on the environment. When developing the model for the cost function, it is therefore absolutely necessary to take into account any changes in the status of the units. Because there are many different objective functions, it is essential to understand that there is no one solution that can simultaneously reach the highest or best possible point for all of those objective functions at the same time. As a result of this, the assortment of best possible solutions needs to be taken into consideration. The users are given instructions on how to use the system in such a way that each answer within the set of acquired responses signifies a distinct usage pattern and a form of alteration in system usage predicated on the harmonization of a variety of objectives, one of which is cost. The problem of pollution is a significant one for the environment.

Fig. 3 illustrates the cost-emission response curve that was obtained from the data. A demonstration of an approach to multi-objective optimization that was presented with the goal of intelligently managing energy within the context of an electrical system for a motor. The capability of the suggested optimization method to carry out a variety of responsibilities is illustrated by the figure that was just presented. The optimal work points are determined by taking into consideration the relative significance of these tasks. The highest level of performance can be attained once these optimal work points have been reached. When it comes to exploitation, it is important to note that there are both economic and bio-environmental goals that need to be taken into consideration. As they move from the beginning points to the ending points of the respective graphs, the mentions move in the opposite direction, exhibiting an anticlockwise directionality. The approach that has been proposed involves moving toward the optimal path in terms of both costs and emissions.

As part of this process, the usage pattern will be modified to place a higher priority on lowering costs rather than reducing pollution, which will cause a movement toward the upper left quadrant of the figure that has been labeled as Fig. 4. This quadrant represents the optimal point of work, which results in the least amount of pollution to the bioenvironment but has the highest cost. On the other hand, the work point that has the lowest costs but the highest levels of bio-environmental pollution can be found in the lower right quadrant.

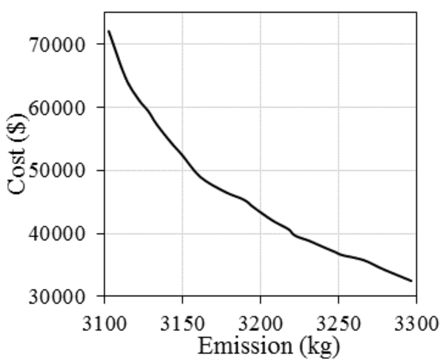

Fig. 4. The cost-emission curve from the optimization of the two-objective smart energy management.

4.4. Comparison with other methods

The method of this study has been compared with two methods of the equivalent fuel consumption minimization strategy [25] and the combination of frequency separation with the fuzzy logic method [26]. Furthermore, the hybrid system model underwent re-evaluation through the utilization of the gray wolf optimization algorithm.

The outcomes of this evaluation are visually depicted in Fig. 5. Fig. 5 shows the battery charge level in the first scenario, according to the control method, as an indicator of measurement error. As it can be seen, in the method given in this study, the battery charging rate works better in reaching the goal which is 64%. The methods presented in references [25] and [26] have errors of about 5% and 8%, respectively, in reaching the battery charge rate of 64%. Meanwhile, the results obtained from the application of the GA demonstrate superior performance compared to the GWO, albeit with a marginal discrepancy in error rate of approximately 0.05%.

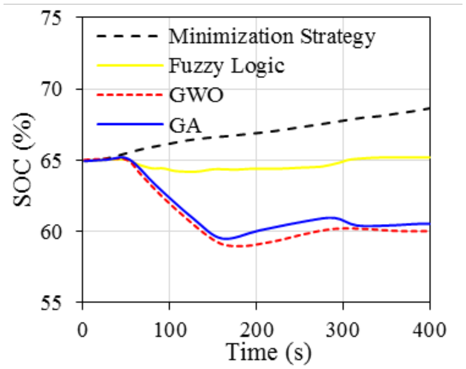

Fig. 5. The comparison between current study and other methods.

5. CONCLUSIONS

The present study explores the implementation of intelligent electric energy management in a model electric motor system that incorporates various electric energy generators, including solar cells, fuel cells, micro-turbines, and batteries. The optimization problem was formulated with multi-objectives of minimizing operating cost and environmental pollution. The appropriate numerical programming technique was employed to derive the set of optimal solutions.

The presented approach demonstrated that the energy management system or electrical system operator is a proficient mechanism. The individual identified the most advantageous work points based on varying work objectives and their respective levels of significance, ultimately attaining optimal outcomes through the attainment of the designated set of optimal solutions. The proposed methodology involves determining the optimal hours of usage and quantities of various energy sources with the aim of minimizing both cost and bio-environmental pollution.

It is noteworthy that the economic and bio-environmental objectives are at odds with each other in the matter of exploitation. The transition from the initial points of the graphs to their end points, as per cost-emission, implies a shift in the usage pattern from a state of less pollution and higher cost to one of greater pollution and reduced cost. Ultimately, the present investigation has resulted in the development of an intelligent energy management system aimed at enhancing the efficiency of the energy production and storage sampling and planning system. Conversely, due to the significant reliance of the optimization function on the load profile of the system, a predictive component is employed to assess the quantity of load or energy generation during the investigation period for the purpose of energy management.The existence of intelligent life has been confirmed. The findings of the optimization clearly demonstrate an inverse link between the operating costs and pollution emissions in the system under study.

As a result, as operating costs rise, the amount of pollution emissions drops; yet, as operating costs fall, the amount of pollution emissions rises. Therefore, when operating costs are around $70,000\$$, $3100\ kg$ of pollutants are released, and if operating costs are around $30,000\$$, $200\ kg$ more pollutants are released..

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