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ENERGY MANAGEMENT IN SMART INTER-CONNECTED MICRO-GRIDS USING A HYBRID SPERM SWARM OPTIMIZATION AND GRAVITATIONAL SEARCH ALGORITHM

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ABSTRACT

In order to achieve global optimal solutions, this paper proposes a new hybrid sperm swarm optimization and gravitational search algorithm (HSSOGSA), which is based on the idea of balancing the exploration and exploitation capabilities by combining sperm swarm optimization (SSO), which has a fast convergence rate, and a gravitational search algorithm (GSA), which can efficiently explore a search domain. Here, the suggested algorithm is utilized to assess how interconnected micro-grids (IMGs) should operate economically, including optimization energy management for charging the system of electric vehicles (EVs), where the optimal charging system for the EV is applied in one micro-grid of interconnected micro-grids. Each micro-grid (MG) consists of various distributed generation (DG) units, including solar photovoltaic (PV), wind turbine (WT), and micro-turbine (MT). The primary objective function of each micro-grid seeks to minimize the cost of total power generation while taking into account the power exchange between IMGs and utility with a focus particular emphasis on technical constraints. The suggested HSSOGSA algorithm is compared with another optimization technique based on sperm swarm optimization (SSO) and war strategy optimization (WSO) algorithms to demonstrate its effectiveness. Results obtained from the HSSOGSA algorithm demonstrate how to manage energy transfer between each MG and the utility. It has small electricity consumption for a variety of daily loads Including the loads for charging EVs as well as small the price of overall electricity output, small utility costs, raising micro turbine (MT) efficiency and smart regulation of EVs charging throughout the day.

KEYWORDS: Electric vehicles, Energy management, Smart grid, Interconnected micro-grids (IMGs), Hybrid sperm swarm optimization and gravitational search algorithm (HSSOGSA).

إدارة الطاقة في الشبكات الصغيرة المترابطة باستخدام الخوارزمية الهجينة المكونه من سرب الحيوانات المنوية مع خوارزمية بحث الجاذبية

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الملخص

يقترح هذ البحث خوارزمية جديدة للحصـــول علي الحل الامثل وهي (الخوارزمية الهجينة المكونه من ســرب الحيوانات المنوية مع

خوارزمية بحث الجاذبية) ، التي تعتمد على فكرة تحقيق التوازن بين قدرات الاستكشاف والاستغلال من خلال الجمع بين تحسين أسراب الحيوانات المنوية التي لديها معدل تقارب سريع، وخوارزمية بحث الجاذبية التي يمكن أن تستكشف بكفاءة. يتم استخدام الخوارزمية المقترحة لتقييم كيفية عمل الشبكات الدقيقة المترابطة اقتصاديًا، بما في ذلك تحسين إدارة الطاقة لشحن نظام المركبات الكهربية حيث يتم تطبيق نظام الشحن الأمثل للمركبات الكهربية في احد الشبكات الصغيرة المترابطة.وتتكون كل شبكة صغيرة من انواع مختلفة من وحدات التوليد الموزعة، بما في ذلك الطاقة الشمسية ، توربينات الرياح ، والتوربينات الصغيرة حيث ان الغرض الرئيسي لكل شبكة هو الحد من التكلفة الاجمالية لتوليد الطاقة بها مع الأخذ في الاعتبار تبادل الطاقة بين الشبكات الصغيرة المترابطة والشبكة العامة مع التركيز بشكل خاص على القيود التقنية. كما تم عمل مقارنة بين الخوارزمية المقترحة مع خوارزميات اخري مثل (خوارزمية تحسين سرب الحيوانات المنوية وخوارزمية تحسين استراتيجية الحرب) لإظهار فاعليتها. وتبين النتائج التي تم الحصول عليها من تلك الخوارزمية المقترحة ان إدارة نقل الطاقة بين كل من الشبكات الصغيرة المترابطة والشبكة العامة تستطيع أن تقلل من التكلفة الاجمالية لاستهلاك الطاقة الكهربية لمجموعة متنوعة من الأحمال اليومية المتضمنة لاحمال منظومة شحن المركبات الكهربية ، زيادة كفاءة التوربينات الصغيرة المستخدمة في توليد الطاقة الكهربية بما في ذلك التنظيم الامثل لعملية شحن المركبات الكهربية داخل الشبكات .

الكلمات المفتاحية : المركبات الكهربية, ادارة الطاقة, الشبكة الذكية, الشبكات الصغيرة المترابطة, الخوازمية الهجينة المكونه من سرب الحيوانات المنوية مع خوارزمية بحث الجاذبية.

1. INTRODUCTION

The task of moving our energy systems away from fossil fuels and toward renewable energy sources is becoming more challenging as a result of rising energy usage. To meet this increased demand and attempt to eliminate existing fossil fuels, new renewable energy sources with low carbon emissions are required. Traditional power grids (PGs), which are powered by fuels, generate 64.5% of the world's electricity. These PGs emit more carbon, with the generation and transportation sectors emitting nearly 40% and 24% of carbon, respectively [1]. The energy information administration (EIA) predicts that the average household electric bill will rise by 2.3% next year [2]. A smart grid, which satisfies electrical infrastructure and intelligent information networks, is the name of the power grid of the future [3], [4]. In order to efficiently offer sustainable, affordable, and secure power supplies, a smart grid is an electricity network that can intelligently integrate the behaviors of all users connected to it (generators, consumers, and those who do both) [5]. A combination of distributed resources for energy generation along with loads, all of which placed in small-scale areas with low voltage amounts is called micro-grid. Actually, separate operation or cooperative performance of these grids may be possible, considering the type of their connection to the main grid [6], [7], [8], [9], [10].

Micro-grids provide an optimal solution to utilize distributed energy resources in electricity networks. Micro-grids are an electric distribution network involving loads and various sources (controllable loads, renewable energy resources, dispatch able energy resources, and energy sources) that can be operated in a controlled and coordinated manner. Also, MGs can operate in both grid-connected and isolated modes [11]. The MG is operated in two modes: grid-connected and isolated types [12]. In grid-connected mode, the MG remains connected to the main grid either totally or partially, and imports or exports power from or to the main grid. In case of any disturbance in the main grid, the MG switches over to stand-alone mode while still feeding power to the priority loads. The penetration of MGs has increased recently because it is more economical and environment friendly than conventional centralized fossil fuel power plants [13], [14].

There are numerous definitions of energy management in the literature. According to the definitions provided in [15, 16, 17, 18, 19, 20], energy management can be defined as a set of strategies and procedures that can adjust and optimize energy use. These functions improve energy efficiency and manage the available energy sources. It involves monitoring, managing, and reducing the amount of electricity used in a structure, a neighborhood, etc. Energy management should be able to reduce the risk of loss of production excess and optimize costs. Several optimization techniques were addressed in the literature to be used in the energy management problem of micro-grids. Game theory, gradient-based optimization algorithms, nonlinear programming, Monte Carlo, Quadratic Programming, GA, Interior Point Method, Multi-agent Algorithm, Bee Colony, Simulated Annealing, Particle Swarm (PS)…etc. were all analytic and heuristic optimization methods that were reviewed in [21].

In [22], The operational costs of a micro-grid energy management problem were reduced while taking into account the start-up and shut-down durations of the DGs, a hybrid GA and interior point algorithm were employed. Numerous approaches were used in the literature [23, 24] to solve the economic dispatch optimization problem. For instance, [23] employed the particle swarm optimization (PSO) algorithm in the grid-connected mode of the MG, and [24] considered the economic dispatch problem as a multi-objective optimization problem without taking into account sold and bought power. In [25] it is suggested to use a heuristic algorithm for stand-alone MG energy management to prevent wasting the available renewable potential at each time interval.

The effectiveness of the smart energy management system (EMS) was investigated in [26] with the aim of minimizing operation costs and applying small-scale energy resources (SSERs) in the best way possible. In [27] described the load demand management of connected MGs as a power dispatch optimization problem. In [28] outlined an effective particle swarm optimization (PSO) based technique for managing the energy and operations of a micro-grid that included various distributed generation units and energy storage devices. Developed a modified version of global basic Porcellio Scaber algorithm (PSA) was more effective than a variety of other meta-heuristic methods in determining the best economic dispatch for multiple micro-grids that incorporate different types of distributed generators [29].

Electric vehicles were developed in the early days of the industrial revolution. Over the past few decades, interest in electric vehicles has grown significantly. In the USA, the first attempt at an electric vehicle for using on roads was made in 1834 [30]. In an effort to replace the complex and polluting internal combustion engines, more efforts were required to develop improved storage and management systems and more efficient motors. Pure electric vehicles adopt a number of advantages, including [31]: Simpler and reliable infrastructure, less and cheaper maintenance, up to 10 times lower transportation cost, full power available at the entire RPM range and taxes reduction through subsidies.

Finally, the main contribution of this paper can be summarized as follows: A new optimization algorithm called “hybrid sperm swarm optimization and gravitational search algorithm (HSSOGSA)” is presented for the management of energy exchanged between the utility and each MG ,the effectiveness of the proposed HSSOGSA optimization algorithm is confirmed by comparing it with two other powerful algorithms “SSO, and WSO” ,the optimal daily charging schemes for EV are selected in order to achieve the lowest possible cost and It can lower the electricity consumption for a variety of daily loads including the demands for charging EVs is reduced ,while also lowering as well as the price of overall electricity output, small utility costs, raising micro turbine (MT) efficiency.

2. MICROGRID ARCHITECTURE

A micro-grid is a portion of the electrical system that views generating and related loads as a subsystem and can function both in connection with and independently from the utility. It can be connected to the utility or another MG, and it has the ability to both provide and absorb power. The first micro-grid in this study consists of WT, MT, and storage batteries (SB). The second micro-grid consists of PV, MT, and SB. Each MG may purchase from and sell to another, as well as the utility. The structure of the system is indicated in figure 1.

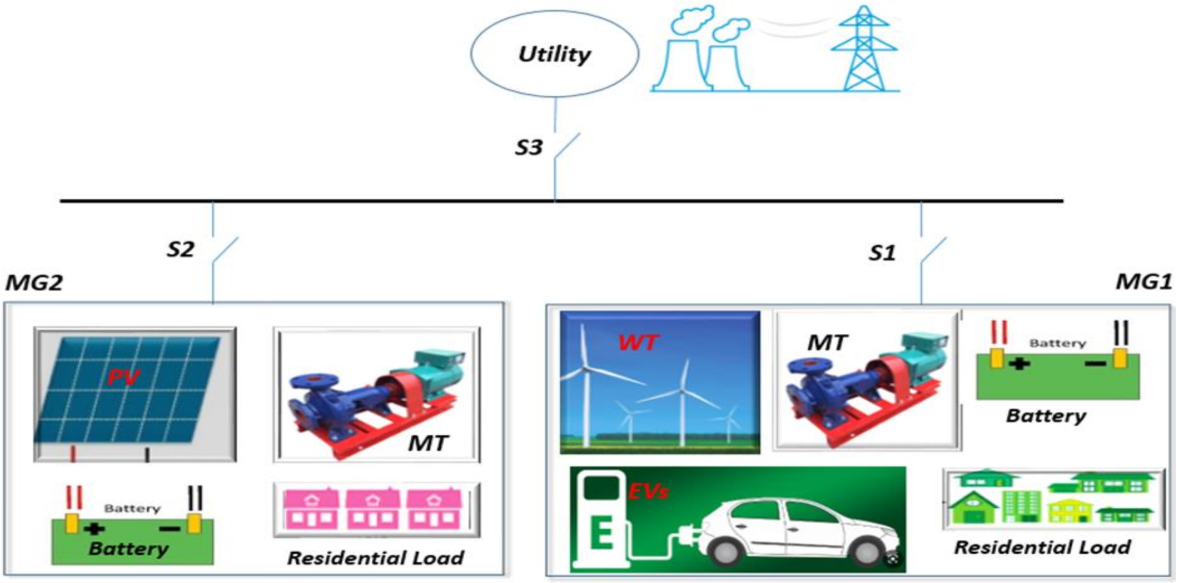

Figure 1. System components of the network with two MGs.

2.1. Demand Load Model

The load model for each MG is constant and illustrated in Figure 2, these load curves are almost the same for different countries. The MG1 reaches a peak value at 7H and varies slowly between 7 and 18 H and MG2 load reaches peak values between 17 and 20 H. [32].

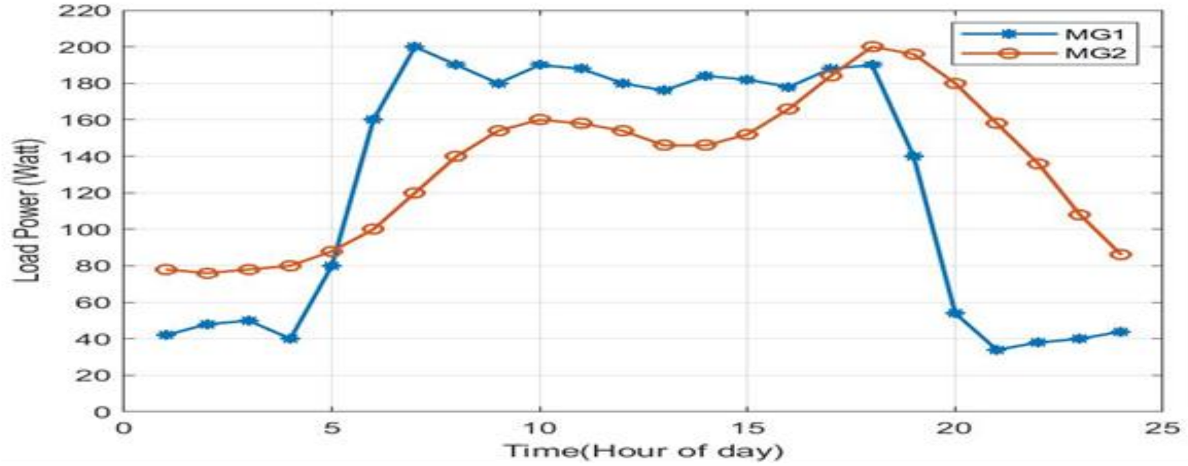

Figure 2. Daily load curve for two MGs.

2.2. Power Generation Model

In Figure.3 and Figure.4, respectively, show the amount of electricity produced by WT in MG1 and PV in MG2 throughout the day is depicted. Both WT and PV have a maximum generation capacity of 100 kW.

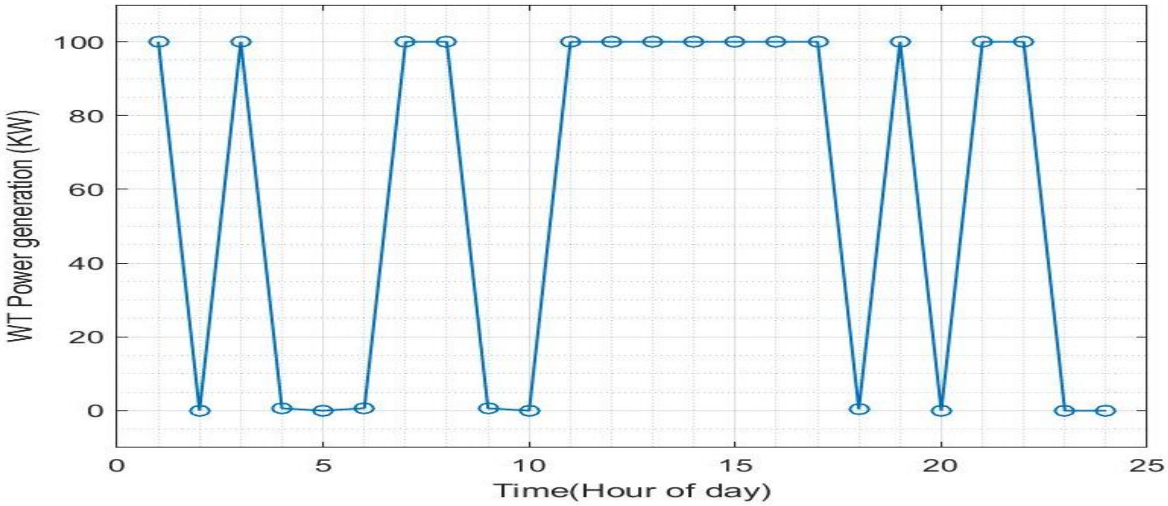

Figure 3. WT Power Generation.

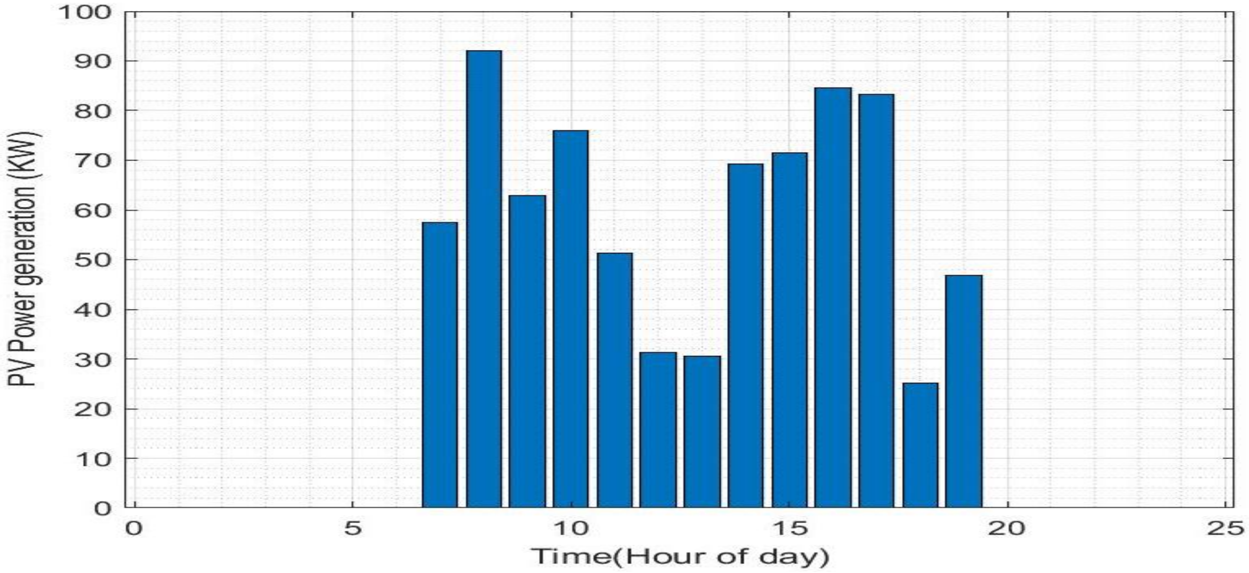

Figure 4. PV Power Generation

Three algorithm strategies are employed to optimize the power output of, MT, SB, and optimize demand power of EV which are selected as the decision variables for the energy management problem. However, Table 1 makes these restrictions clearer. If, $P_{SB} \geq 0$,SB is in discharging mod, $P_{SB} \leq 0$,SB is in charging mode. Then, equality (1) can be applied in calculating the value of the power output from the utility.

Table 1. The max and min power produced by each of SB , MT and EV in both MGs

Item	SB (kW)		MT (kW)		EV Demand (kW)	
	Min	Max	Min	Max	Min	Max
MG1 & MG2	-80	100	0	100	0	300

$$P_{utility} = (P_{total.load} + P_{EV}) - (P_{PV} + P_{WT} + P_{MT} + P_{SB}) \tag{1}$$

2.3. Cost Model

a. MT Cost Function [33]

$$\sum_{t=1}^{t=24} F_{t,MT} = C_{MT}.F_{MT}.\sum_{t=1}^{t=24} P_{t,MT}.\Delta T + \sum_{t=1}^{t=24} OM_{t,MT} + \sum_{t=1}^{t=24} SC_{t,MT} \tag{2}$$

where:

$F_{t,MT}$	Total operation cost of MT
C_{MT}	Cost of natural gas (fuel cost of MT)= 0.36 \$/m^3
F_{MT}	Fuel Consumption rate = 0.0009 m^3/Wh
$P_{t,MT}$	Real power output from the MT (W)
ΔT	Energy management time step = 1 hour
$OM_{t,MT}$	Operation and maintenance cost of MT (\$) = $K_{oc}.\sum_{t=1}^{t=24} P_{t,MT}.\Delta T$
	Where K_{oc} is taken as 0.000006 \$/Wh
$SC_{t,MT}$	The start-up cost of MT (\$)

b. Utility Cost Function

$$\sum_{t=1}^{t=24} F_{t,utility} = C_{utility} \cdot \sum_{t=1}^{t=24} P_{t,utility} \tag{3}$$

where:

$F_{t,MT}$	Total utility cost function
$C_{utility}$	cost of the energy utility unit (*\$/Wh)*
$P_{t,utility}$	utility unit's actual power output

2.4. Objective Function

The major objective of the system is to reduce the cost of overall power generation from each MG while accounting for power exchange across IMGs and utilities. Consequently, the primary goal of the optimization problem (Min(OF)) in each MG is equal to:

$$Min(OF) = \sum_{t=1}^{t=24} \left(F_{t,utility} + F_{t,MT} \right) \tag{4}$$

3. REVIEW OF THE HSSOGSA AlGORITHM

The proposed algorithm HSSOGSA)'' is the combination of ''gravitational search algorithm (GSA)'' and ''sperm swarm optimization ". In this section, we give a brief description of both standard SSO and GSA algorithms in which we discuss their metaphor, structure, and mathematical modeling.

3.1 Standard sperm swarm optimization (SSO)

SSO is a swarm-based approach which is proposed by [34, 35, 36, 37]. The SSO was inspired by the attitude of swarm of sperm while fertilizing the Ovum (egg). It utilizes a set of candidate solutions (sperms), which swim in a multidimensional search space domain to discover an optimal solution. Simultaneously, the swarms look at the best solution (best sperm) in their tracks. In another sense, sperms consider the best value which has obtained so far (global best solution) as well as, their own best solution (sperm best solution). Each sperm in SSO should modify its location by taking into account its current velocity, current location, distance to x_{sbest}, and distance to x_{sgbest}. Eq. (5) can be used to represent the mathematical representation of SSO:

$$\begin{aligned} V_i(t) = {} & D.\log_{10}(pH\_rand_1).Vi + \log_{10}(pH\_rand_2).\log_{10}(Temp\_rand_1).(X_{sbesti}(t) - X_i(t)) + \\ & \log_{10}(pH\_rand_3).\log_{10}(Temp\_rand_2).(X_{sgbesti}(t) - X_i(t)) \end{aligned} \tag{5}$$

where:

V_i	The velocity of sperm i at iteration t
D	The factor of velocity damping, which will be varied between 0 and 1
Temp_Rand1, Temp_Rand2	The temperature metrics of the visited location, which will be varied between 35.1 and 38.5
pH_Rand1, pH_Rand2, and pH_Rand3	The pH metrics of the visited location, which will be varied between 7 and 14
x_i	current location of sperm i at iteration t

x_{sbest}	personal best location of sperm i at iteration t
x_{sgbest}	global best location of the swarm

The solution of current best can be calculated by Eq. (6):

$$X_i(t) = X_i(t) + V_i(t) \tag{6}$$

4. Standard gravitational search algorithm (GSA)

Newton's theory served as the foundation for the GSA [38]. The theory of GSA is “every object in the cosmos attracts every other object with a force that is directly proportional to the product of their masses and inversely proportional to the square of their distance, according to this hypothesis” [39]. There are a number of agents in the search space of GSA whose masses are proportional to the value of their fitness functions. All masses use gravity to attract one another during the creation process, with a heavier mass having a stronger force of attraction. The mathematical equation of GSA can be represented as follows: The algorithm starts the process by allocating N agents at random to the search path's domain. The gravitational forces from agent’s j and i at time t can be calculated as follows for all iterations.

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t) * M_{aj}(t)}{R_{ij}^d(t) + \varepsilon}\left(X_j^d(t) - X_i^d(t)\right) \tag{7}$$

where:

M_{aj}	The agent j active gravitational mass
M_{pi}	The agent i passive gravitational mass
G(t)	The gravitational constant at time
ε	a small constant
R_{ij}	The Euclidean distance between two agent i and agent j

G(t) can be calculated as follows:

$$G(t) = G_0 * e(-a * iter / \max\_iter) \tag{8}$$

where:

G_0	The initial value
a	The descending coefficient
iter	The current iteration
max_iter	The maximum number of iterations

Eq. (9) can be used to get the total force acting on agent I in dimension d of the problem space.

$$F_i^d(t) = \sum_{\substack{j=1 \\ j \neq i}}^{N} rand_j F_{ij}^d(t) \tag{9}$$

where $rand_j$ is a random number in the range of (0, 1).
The acceleration of all agents should be determined as in Eq. (6), based on the low of motion, each agent's acceleration is proportional to the inverse of its mass and the result force.

$$ac_i^d(t) = \frac{F_i^d(t)}{M_i(t)} \tag{10}$$

where M_i is the inertia mass of agent i; t is a specific time.
The position and velocity of agents can be calculated as follows:

$$Vel_i^d(t+1) = rand_i * Vel_i^d(t) + ac_i^d(t) \tag{11}$$

$$X_i^d(t+1) = X_i^d(t) + Vel_i^d(t+1) \tag{12}$$

Where, $rand_i$ is a random number in the range of (0,1).

The initialization of all masses with a random value is the first phase in the GSA operation. Each mass is taken into account as a candidate solution. Following the initialization phase, Eq. (11) is used to determine the velocities for each mass. Eqs. (8) through (10) are used to compute the gravitational constant, total forces, and accelerations, respectively. After then, Eq. (12) can be used to determine the positions of masses (8).

5. The hybrid sperm swarm optimization and gravitational search algorithm (HSSOGSA)

HSSOGSA, a new hybrid optimization technique that combines the "gravitational search algorithm" with "sperm swarm optimization". Several hybridization methods for meta-heuristic approaches have been proposed in [40]. Due to the functionality of both systems being combined, the suggested hybrid algorithm is low-level. Additionally, it is co-evolving since we utilize both methodologies concurrently rather than sequentially are utilized. Given that two different methodologies are used to produce the end outcome; it is seen as heterogeneous. The fundamental goal of HSSOGSA is to combine social thinking (x_{sgbest}) in SSO with the local search capabilities ($ac_i(t)$) of GSA. To combine these strategies, Eq. (13) is suggested as follows.

$$V_i(t+1) = D * rand_1(pH) * V_i(t) + rand() * ac_i(t) + rand_2(pH) * rand_1(temp) * (X_{sgbest} - X_i(t)) \tag{13}$$

where:

D	The factor of velocity damping, which will be varied between 0 and 1
Vi(t)	The velocity of agent i
rand1(pH), and rand2(pH)	The pH metrics of the visited location, which will be varied between 7 and 14
rand ()	Random value between 0 and 1
rand1(temp)	The temperature metric of the visited location, which will be varied between 35.1 and 38.5
ac_i (t)	The acceleration of agent i at iteration t
x_{sgbest}	global best location of the swarm (best solution so far).

The following equation is used to update the sperm positions after each iteration

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{14}$$

HSSOGSA technique starts by randomly initializing each agent, where each agent is viewed as a candidate solution. Then, using Eqs. (7) through (9), the gravitational force, gravitational constant, and consequent forces among agents are determined. Hence, the accelerations of sperms are determined by Eq. (10). In each iteration, the x_{sgbest} should be updated. After calculating the $ac_i(t)$ and updating the x_{sgbest}, the Vi(t) of all agents can be calculated using Eq. (13). At the end, the locations of agents are defined as in Eq. (14). The process of updating locations and velocities will be terminated by meeting an end criterion. Following is a full procedure of hybrid sperm swarm optimization and gravitational search algorithm (HSSOGSA) process [41]:

```
Algorithm    Hybrid sperm swarm optimization and gravitational search algorithm
             (HSSOGSA)

Begin
Step 1       Initialize the candidate objects Xi (i = 1, 2, . . ., N).
Step 2       while (the end criterion is not reached) do
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```
Step 3      For all objects, evaluate the fitness
            Calculate best, worst, $M_i$, $M_j$.
            Calculate forces $F_{ij}$ by Eq. (7).
            Calculate gravitational constant by Eq. (8).
            Calculate resultant forces by Eq. (9).
            Update acceleration by Eq. (10).
Step 4      apply SSO.
            By using Eq. (13), update velocities.
            By using Eq. (14), update positions
Step 5      Return the best search agent.
End
```

6. SIMULATION RESULTS AND DISCUSSION

This section evaluates how well the suggested IMGs can distribute power among MG loads. In figure 1's structure, the utility and two IMGs networks are depicted. Each MG's power generation system is composed of one renewable energy source and a storage battery. The system's primary objective is to minimize the cost of overall power generation while taking into account the power exchange between IMGs and utility. For every optimization task, 30 independent runs are performed, where HSSOGSA, SSO, and GSA parameters setup can be explained as follows in Table 2:

Table 2. The parameters used for SSO, WSO and HSSOGSA.

SSO		WSO		HSSOGSA	
Iteration Number	200	Iteration Number	200	Iteration Number	200
Population-Size	50	Soldier size	50	Population size	50
Inertia	1	R	0.1	Gravitational constant (Go)	1
Correction Factor	1.5				

The purchased and selling price between two MGs equal to the selling price to the utility and is constant throughout the day ($C_{utility.sell}$ = CMG = 0.000075 $/kW), but the purchased price from the utility is variable as shown in Table 3 [42].

Table 3. The buying and selling costs from the utility and MGs

	Item	**Profile Purchasing Cost ($/kW)**
1	Utility purchase price ($C_{utility}$)	$[10 ,8.5, 9 , 12 , 9 , 12.5 , 24.5 , 27 , 28 ,17, 16 , 16 , 16 , 14 , 9 , 8 , 9 , 9.5 ,7.5, 7.5, 7.5, 7.5, 7.5, 7.5]*10^{-5}$
2	Selling price from the utility ($C_{utility.sell}$)	0.000075
3	purchase and sale prices between two MGs (C_{MG})	0.000075

The energy management system will also be applied to the system with power sharing between IMGs and utility, through two different cases, the first of them does not have the EVs charging system as an additional load on the system's actual loads, and the other after adding the EVs charging system to MG1 as an additional load other than its actual loads.

Case Study1 (Management of the IMGs Energy system without adding EVs according to Table3**)**
When power sharing between IMGs, is applied to the system in Fig.1 without an electric vehicle charging system. In addition, power-sharing takes place through the utility. If the energy generated by each MG during the day is either insufficient for or exceeds the demand load., it is traded with IMGs and utility through sales or purchases in accordance with the cost values shown in Table 3. The optimization techniques SSO, WSO, and HSSOGSA employed in this study can be seen as convergent in Fig.5 and 6. The objective function mentioned above gives

the minimum values of 334.0568 $, 327.0196 $, and 292.4735 $, for SSO, WSO, and HSSOGSA in MG1 respectively, while gives 421.2769$, 420.8316 $, and 394.0025 $ for SSO WSO, and HSSOGSA in MG2 respectively. Tables 4,5 and 6 illustrate the precise set of each MG, sharing between IMGs, and utility optimal power outputs.

Table 4. Case study 1. SSO optimized power outputs of each MG, sharing line and utility in kW

HR.	MG1 - SSO				MG2 - SSO			
	MT	*BS*	*Share*	*Utility*	*MT*	*BS*	*Share*	*Utility*
1	2.4	20.6	-43.1	-38.0	20.8	14.0	43.1	0.0
2	11.2	65.2	0.0	-28.4	2.2	74.2	0.0	-0.4
3	60.1	-29.4	-15.2	-65.5	74.5	-11.7	15.2	0.0
4	93.5	18.7	-22.2	-50.7	42.0	15.8	22.2	0.0
5	7.4	5.3	0.0	67.3	9.5	-10.7	0.0	89.2
6	30.0	-30.7	0.0	160.0	4.9	-2.4	0.0	97.5
7	13.5	28.8	33.0	24.8	84.5	11.0	-33.0	0.0
8	64.2	-9.5	0.0	35.3	52.7	-46.9	0.0	42.2
9	96.2	26.3	0.0	56.8	64.5	9.4	0.0	17.2
10	56.9	-48.0	0.0	181.1	32.3	28.4	0.0	23.4
11	35.8	8.6	0.0	43.6	7.7	-21.4	0.0	120.3
12	44.3	27.5	0.0	8.2	4.8	12.7	0.0	105.1
13	16.0	-15.0	0.0	74.9	15.4	17.6	0.0	82.4
14	77.6	19.4	-13.0	0.0	24.6	-52.9	13.0	92.1
15	36.0	-44.1	15.5	74.6	59.8	36.2	-15.5	0.0
16	38.5	19.0	0.0	20.4	3.0	13.9	0.0	64.5
17	28.8	23.7	0.0	35.5	13.7	-32.0	0.0	119.1
18	5.0	-41.5	0.0	226.1	63.2	27.9	0.0	83.7
19	34.8	9.4	-4.2	0.0	72.2	-59.8	4.2	132.6
20	62.6	13.4	-22.0	0.0	52.4	46.4	22.0	59.2
21	24.1	3.5	-58.9	-34.7	79.9	19.3	58.9	0.0
22	31.6	10.7	-104.3	0.0	6.3	-66.0	104.3	91.3
23	2.1	-28.6	9.4	57.2	87.0	30.4	-9.4	0.0
24	15.2	27.3	1.5	0.0	83.2	17.8	-1.5	-13.6

Table 5. Case study 1. WSO optimized power outputs of each MG, sharing line and utility in kW

HR	MG1 - WSO				MG2 - WSO			
.	*MT*	*BS*	*Share*	*Utility*	*MT*	*BS*	*Share*	*Utility*
1	15.5	21.7	-13.1	-82.2	25.9	38.9	13.1	0.0
2	18.7	17.8	0.0	11.4	26.2	42.4	0.0	7.4
3	41.8	43.0	-54.9	-79.9	30.5	-7.4	54.9	0.0
4	51.2	-62.3	0.0	50.4	19.4	3.4	0.0	57.3
5	20.9	11.3	0.0	47.8	18.6	7.0	0.0	62.3
6	49.8	31.0	0.0	78.5	4.8	-6.4	0.0	101.6
7	6.9	6.5	23.4	63.2	80.2	5.7	-23.4	0.0
8	32.0	21.7	0.0	36.3	97.7	-59.0	0.0	9.4
9	30.3	-22.9	29.4	142.6	58.9	61.6	-29.4	0.0
10	29.0	12.4	0.0	148.5	12.2	-58.4	0.0	130.3
11	62.4	-46.2	0.0	71.8	6.5	59.0	0.0	41.1
12	75.2	1.8	0.0	3.0	49.4	-2.8	0.0	76.0
13	61.7	17.6	-3.3	0.0	73.0	-46.0	3.3	85.2
14	48.0	32.6	0.0	3.4	51.4	12.7	0.0	12.6
15	45.6	-37.9	0.0	74.3	35.7	31.4	0.0	13.3
16	31.3	44.8	0.0	1.9	22.4	-38.6	0.0	97.6
17	7.7	-59.2	0.0	139.6	55.1	26.8	0.0	18.8
18	66.4	5.8	0.0	117.4	25.7	21.6	0.0	127.6
19	40.1	31.4	-31.6	0.0	26.6	-55.3	31.6	146.4
20	22.0	1.0	0.0	31.0	77.9	3.1	0.0	99.0
21	16.8	11.7	-81.8	-12.6	38.0	38.1	81.8	0.0
22	11.9	-33.6	-40.4	0.0	70.6	-20.7	40.4	45.7
23	36.4	44.0	-40.4	0.0	28.8	7.1	40.4	31.7
24	45.1	-47.2	0.0	46.1	24.2	30.4	0.0	31.4

Table 6. Case study 1. HSSOGSA optimized power outputs of each MG, sharing line and utility in kW

HR.	MG1 - HSSOGSA				MG2 - HSSOGSA			
	MT	*BS*	*Share*	*Utility*	*MT*	*BS*	*Share*	*Utility*
1	6.0	11.1	-19.3	-55.8	16.1	42.5	19.3	0.0
2	24.5	9.2	0.0	14.3	55.3	15.8	0.0	4.9
3	23.5	3.2	-30.9	-45.8	11.8	35.2	30.9	0.0
4	7.4	7.2	0.0	24.7	83.8	-32.4	0.0	28.6
5	24.2	43.2	0.0	12.7	4.6	28.0	0.0	55.4
6	23.7	1.1	0.0	134.4	24.3	-43.0	0.0	118.6
7	9.8	6.9	55.2	28.1	71.7	46.0	-55.2	0.0
8	14.0	-49.3	23.6	101.7	82.7	-11.1	-23.6	0.0
9	77.5	1.3	0.0	100.6	54.4	5.4	0.0	31.3
10	46.2	33.1	0.0	110.7	14.5	-47.1	0.0	116.6
11	1.5	19.6	0.0	66.9	50.3	54.3	0.0	2.0
12	66.8	-24.8	0.0	38.0	14.2	-64.6	0.0	173.0
13	74.9	28.5	-27.5	0.0	14.8	53.5	27.5	19.7
14	3.9	-63.8	0.0	143.9	51.8	-69.4	0.0	94.3
15	77.6	17.0	-12.6	0.0	16.4	33.3	12.6	18.1
16	1.7	44.5	0.0	31.8	29.0	0.6	0.0	51.7
17	62.3	-54.0	0.0	79.7	4.1	20.2	0.0	76.4
18	45.0	21.8	0.0	122.9	7.8	22.9	0.0	144.2
19	49.0	35.5	-44.5	0.0	35.0	-41.6	44.5	111.4
20	23.1	-47.1	0.0	78.0	55.1	7.9	0.0	117.0
21	25.7	1.3	-93.0	0.0	33.2	5.3	93.0	26.5
22	35.9	13.5	-26.5	-84.8	78.4	31.1	26.5	0.0
23	28.0	12.8	-0.8	0.0	13.3	-33.0	0.8	127.0
24	7.3	17.8	0.0	18.9	35.9	21.6	0.0	28.5

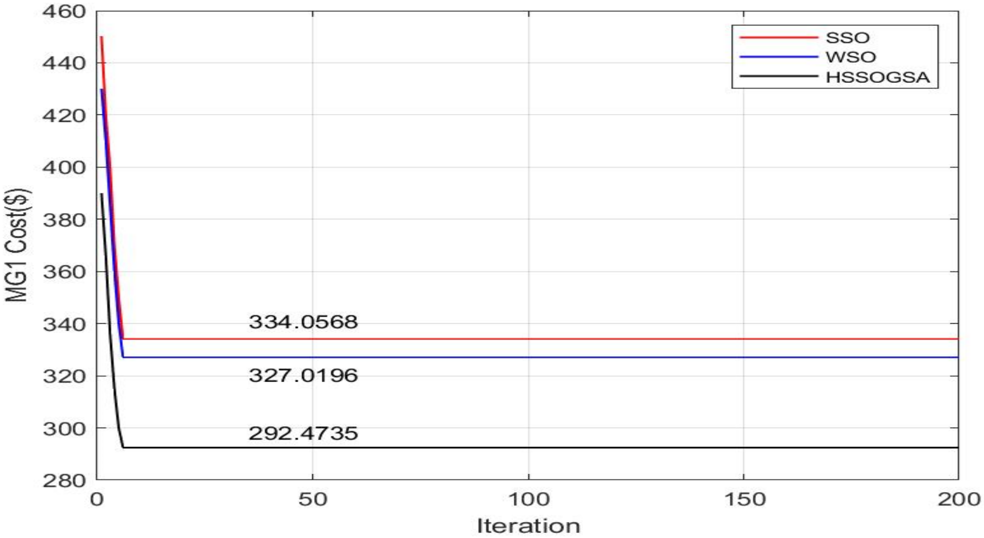

Figure 5. Case study 1. Optimization cost of SSO,WSO and HSSOGSA for MG1

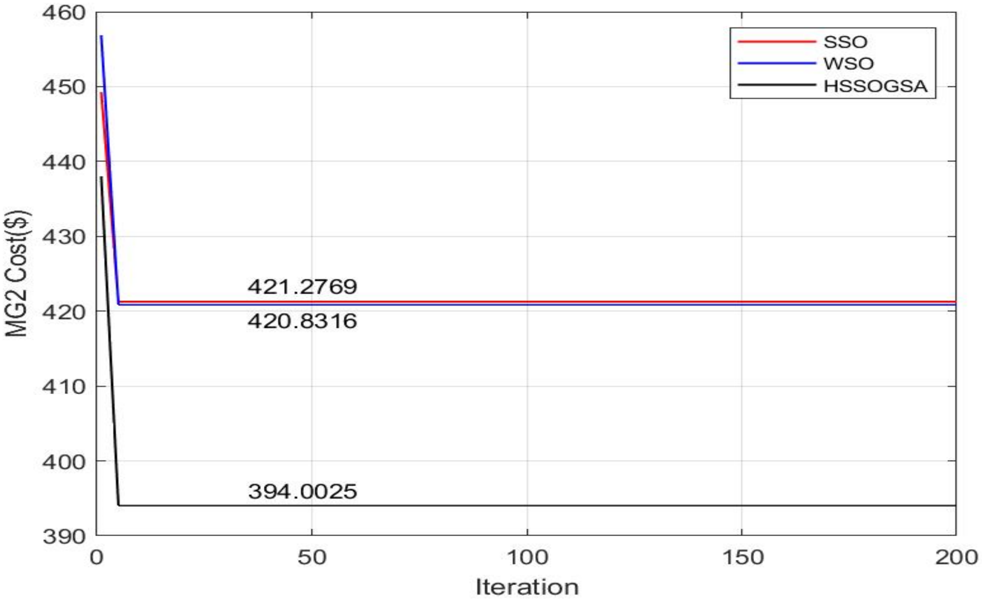

Figure 6. Case study 1. Optimization cost of SSO,WSO and HSSOGSA for MG2

Figures 7 and 8 show the total power generation and demand load for MGs 1 and 2 throughout the day, respectively. It is evident that there are a few hours of the day when more power capacity is produced than there is overall demand. In this instance, the sale is made to the other MG, or to utility and sold electricity will have a negative value. It can also be used in charging the BS system and the capacity designated for charging the battery will have a negative value. On the other side, when the capacity generated power is less than the entire load hence, the power is bought from the other MG or the utility. In the present occasion, the utility power purchase value is positive.

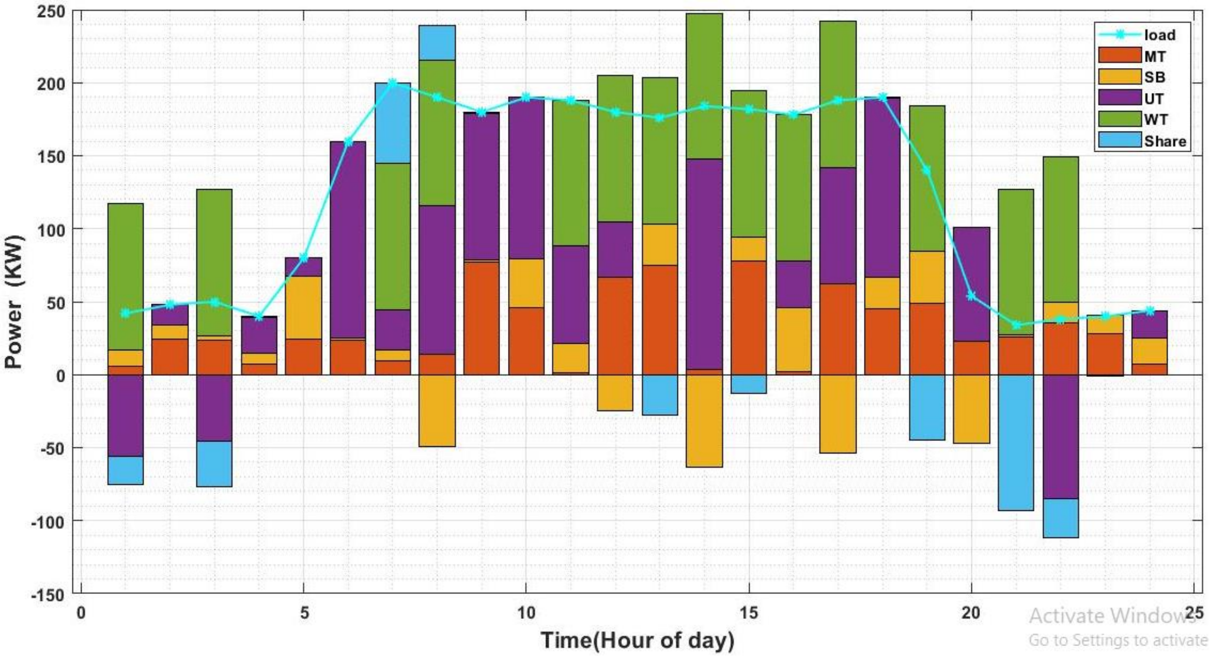

Figure 7. Case study 1. HSSOGSA Output Power and demand load of MG1

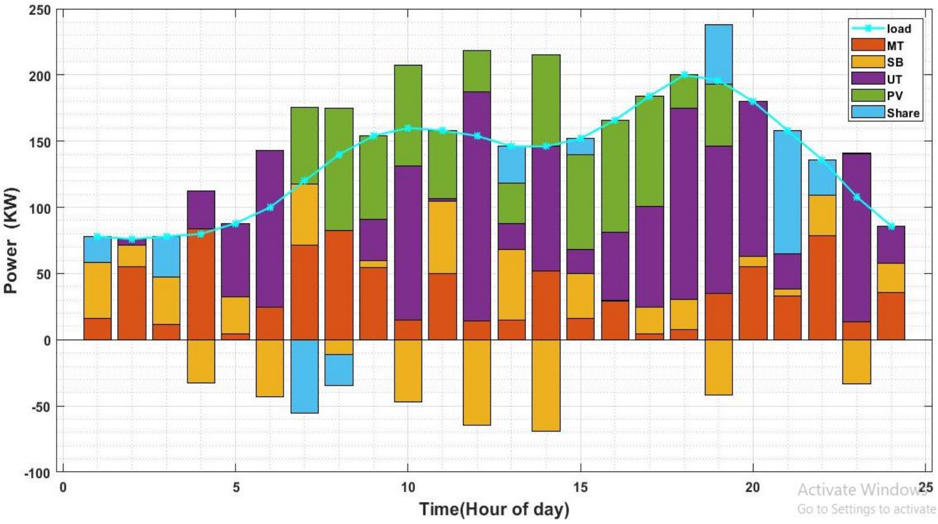

Figure 8. Case study 1. HSSOGSA Output Power and demand load of MG2

Case Study2 (Management of the IMGs Energy system with adding EVs according to Table3) Case study 2 use the system in figure 1 to implement power sharing across IMGs and power-the utility in the presence of an electric vehicle charging system in MG1. Generally, If the energy generated by each MG during the day is either insufficient for or exceeds the demand load., it is traded with IMGs and utility through sales or purchases in accordance with the cost values shown in Table 3. The SSO, WSO, and HSSOGSA optimization techniques employed in this study can be seen as convergent in Fig.9 and 10. The objective function mentioned above gives the minimum values of 347.4707 $, 340.0377 $, and 326.4195 $, for SSO, WSO, and HSSOGSA in MG1 respectively, while gives 432.3173 $, 428.7181 $, and 413.1033 $ for SSO WSO, and HSSOGSA in MG2 respectively. Tables 7,8 and 9 illustrate the precise set of each MG, sharing between IMGs, and utility optimal power outputs.

Table 7. Case study 2. SSO optimized power outputs of each MG, sharing line and utility in kW

Hr.	MG1 - SSO					MG2 - SSO			
	MT	*BS*	*EV*	*Share*	*Utility*	*MT*	*BS*	*Share*	*Utility*
1	15.1	6.4	6.5	-55.3	-17.8	9.1	13.5	55.3	0.0
2	8.0	27.3	44.2	14.1	42.9	44.5	45.6	-14.1	0.0
3	18.0	10.5	16.3	0.0	-62.2	60.0	27.9	0.0	-9.9
4	54.9	46.2	23.4	-38.4	0.0	38.0	-9.3	38.4	12.9
5	54.2	-2.7	7.6	0.0	36.2	21.9	19.4	0.0	46.7
6	63.2	-71.7	10.0	0.0	177.8	40.7	-41.1	0.0	100.4
7	38.2	64.7	0.0	0.0	-3.0	64.4	0.8	0.0	-2.7
8	32.2	-43.0	0.0	3.5	97.2	46.3	5.2	-3.5	0.0
9	2.0	0.0	10.0	0.0	187.4	34.3	20.6	0.0	36.2
10	8.7	38.2	0.0	0.0	143.1	92.3	-23.8	0.0	15.6
11	85.1	-21.7	0.0	0.0	24.7	72.9	26.8	0.0	6.9
12	20.0	2.6	10.0	0.0	67.5	12.2	-69.0	0.0	179.4
13	18.6	13.9	5.4	0.0	48.9	23.6	12.7	0.0	79.2
14	80.8	1.9	0.0	1.3	0.0	51.6	27.0	-1.3	-0.5
15	67.6	11.1	10.0	0.0	13.3	11.0	1.0	0.0	68.5
16	72.1	-27.1	10.0	0.0	43.0	27.9	15.7	0.0	37.8
17	20.1	35.2	0.0	0.0	32.7	77.5	18.5	0.0	4.7
18	10.6	-26.2	0.0	0.0	205.2	12.6	-31.8	0.0	194.1
19	39.5	26.3	10.0	-15.8	0.0	12.8	17.5	15.8	103.1
20	9.9	-48.3	11.5	0.0	103.9	86.0	1.3	0.0	92.7
21	41.5	21.4	43.1	-85.8	0.0	4.3	18.7	85.8	49.2
22	14.0	24.4	36.4	-64.0	0.0	78.5	-50.2	64.0	43.7
23	4.5	-0.6	30.5	0.0	66.6	7.1	41.0	0.0	59.9
24	44.0	-42.5	15.0	0.0	57.4	75.9	-13.0	0.0	23.0

Table 8. Case study 2. WSO optimized power outputs of each MG, sharing line and utility in kW

Hr.	**MG1 - WSO**					**MG2 - WSO**			
	MT	***BS***	***EV***	***Share***	***Utility***	***MT***	***BS***	***Share***	***Utility***
1	10.8	7.3	2.0	0.0	-74.1	65.9	40.1	0.0	-28.0
2	57.7	32.0	15.9	-25.7	0.0	31.4	15.3	25.7	3.6
3	7.2	47.7	42.6	-59.5	-2.9	0.0	18.5	59.5	0.0
4	8.2	-3.2	44.0	10.7	67.6	80.6	10.1	-10.7	0.0
5	81.7	-51.2	28.1	0.0	77.5	92.8	-67.5	0.0	62.8
6	50.8	11.9	5.2	32.1	69.6	84.5	47.6	-32.1	0.0
7	65.3	43.1	0.0	-8.4	0.0	34.2	17.0	8.4	2.9
8	10.6	-16.9	0.0	0.0	96.3	57.1	-10.2	0.0	1.1
9	31.9	17.0	10.0	0.0	140.4	7.9	3.7	0.0	79.6
10	19.0	-71.5	0.0	0.0	242.5	56.1	3.7	0.0	24.2
11	90.7	22.4	0.0	-25.2	0.0	38.4	2.2	25.2	40.9
12	9.8	38.5	10.0	0.0	41.7	7.7	-14.1	0.0	129.1
13	10.6	-12.8	10.0	0.0	88.2	52.5	11.0	0.0	51.9
14	0.4	20.4	0.0	2.9	60.3	76.9	2.8	-2.9	0.0
15	70.9	-39.9	0.1	0.0	51.1	14.0	-12.1	0.0	78.5
16	29.3	18.4	10.0	0.0	40.2	4.1	26.1	0.0	51.2
17	29.9	10.9	0.0	0.0	47.2	58.2	-16.0	0.0	58.5
18	10.3	11.8	0.0	0.0	167.5	46.9	8.8	0.0	119.2
19	47.5	-46.0	10.0	0.0	48.5	24.0	-33.2	0.0	158.5
20	14.6	35.4	39.8	0.0	43.8	2.4	0.0	0.0	177.6
21	57.6	18.3	17.1	-109.2	-15.6	12.2	36.5	109.2	0.0
22	81.5	-13.3	15.1	-93.6	-21.5	57.0	-14.6	93.6	0.0
23	7.9	10.6	0.0	0.0	21.6	25.0	17.1	0.0	65.9
24	18.8	-2.5	0.5	0.0	28.2	65.5	-26.2	0.0	46.7

Table 9. Case study 2. HSSOGSA optimized power outputs of each MG, sharing line and utility in kW

Hr.	**MG1 - HSSOGSA**					**MG2 - HSSOGSA**			
	MT	***BS***	***EV***	***Share***	***Utility***	***MT***	***BS***	***Share***	***Utility***
1	87.0	4.4	29.6	-57.4	-62.5	16.3	4.2	57.4	0.0
2	97.9	14.6	41.6	-20.4	-2.5	29.8	25.8	20.4	0.0
3	22.3	18.5	41.9	0.0	-48.9	30.7	48.3	0.0	-1.1
4	21.9	11.6	37.8	0.0	43.6	24.6	-65.2	0.0	120.7
5	19.4	29.8	5.2	36.0	0.0	82.7	47.9	-36.0	-6.5
6	41.7	-0.8	10.0	0.0	128.5	81.0	17.5	0.0	1.6
7	45.5	6.5	0.0	0.0	48.0	18.5	-40.1	0.0	84.1
8	21.0	-47.7	0.0	59.5	57.1	79.4	28.1	-59.5	0.0
9	28.1	20.1	10.0	18.1	123.1	89.5	19.7	-18.1	0.0
10	76.4	29.7	0.0	0.0	83.9	44.6	-56.4	0.0	95.9
11	22.6	-24.6	0.0	0.0	90.0	42.6	56.5	0.0	7.5
12	45.3	4.4	4.7	0.0	34.9	15.6	-13.2	0.0	120.3
13	13.3	0.3	10.0	0.0	72.4	24.5	21.0	0.0	69.9
14	40.5	24.5	0.0	0.0	19.1	56.7	-22.2	0.0	42.2
15	78.9	-50.9	10.0	0.0	63.9	24.7	22.6	0.0	33.2
16	10.9	44.4	10.0	0.0	32.7	22.9	-65.9	0.0	124.4
17	5.3	-31.4	0.0	0.0	114.1	0.8	25.1	0.0	74.8
18	6.5	34.6	0.0	0.0	148.5	3.2	8.5	0.0	163.2
19	28.6	-42.0	0.7	0.0	54.2	2.0	2.8	0.0	144.5
20	13.2	17.1	36.7	0.0	60.4	28.7	8.8	0.0	142.5
21	44.9	16.8	15.7	-112.0	0.0	15.6	4.9	112.0	25.5
22	11.1	-35.0	36.1	-2.0	0.0	74.6	1.0	2.0	58.5
23	24.5	13.0	0.0	0.0	2.5	72.2	17.5	0.0	18.3
24	4.9	30.8	0.0	0.0	8.3	39.8	-34.9	0.0	81.1

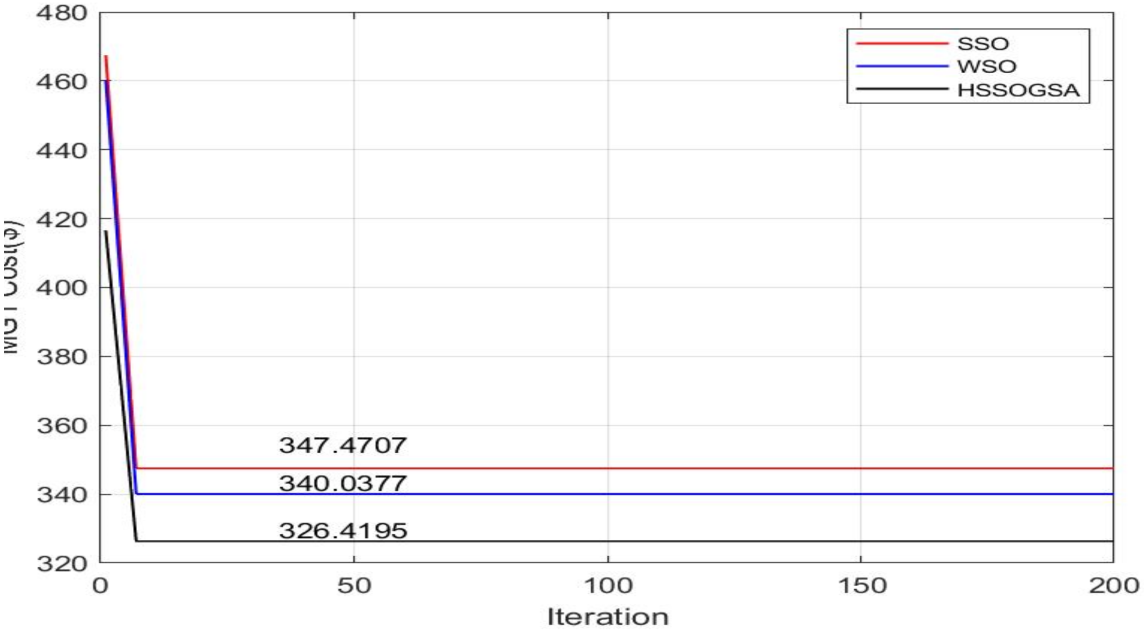

Figure 9. Case study 2. Optimization cost of SSO,WSO and HSSOGSA for MG1

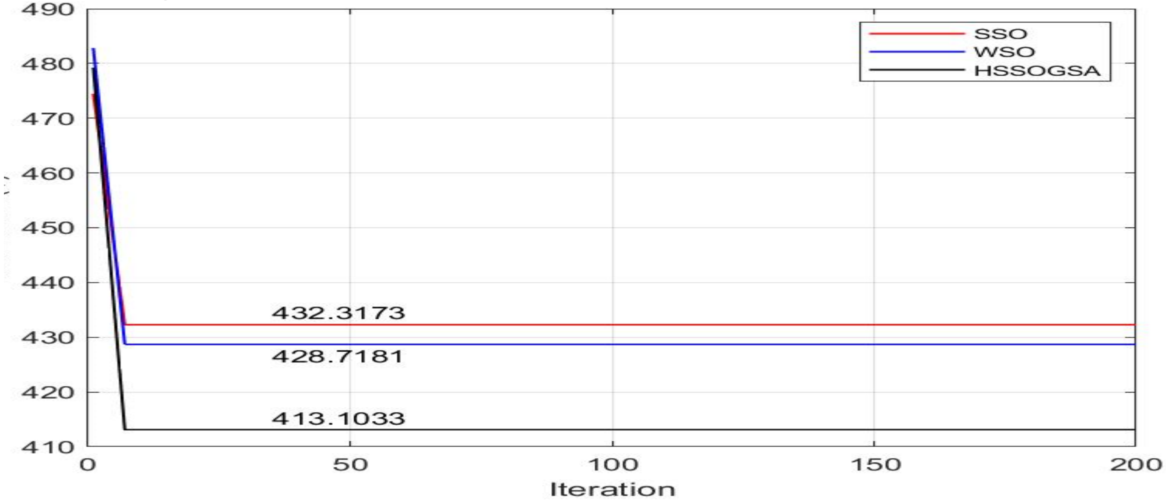

Figure 10. Case study 2. Optimization cost of SSO,WSO and HSSOGSA for MG2

Figure 11 shows the total power generation, demand load, and EV charging system for MG 1 throughout the day also, Figure 12 shows the total power generation and demand load, in MG2 at all hours of the day. Taking into account some technical constraints of the EV charging process in MG1, where the total power capacity used to charge EV throughout the day does not exceed 300 kilo watts which represents a value of 0.01% of the MG 1 total load. In addition to that, if the load on the MG1 exceeds 92% of its maximum value, the charging value for EV is zero. Also note that, the charging value does not exceed 10 kilo watts at times when MG 1 load exceeds 70 percent. It is clear from the results that, there are a few hours of the day when more power capacity is produced than there is overall demand. In this instance, the sale is made to the other MG, or to utility and sold electricity will have a negative value. It can also be used in charging the battery storage system and the capacity designated for charging the battery will have a negative value. On the other side, when the capacity generated power is less than the entire load hence, the power is bought from the other MG or the utility. In the present occasion, the utility power purchase value is positive.

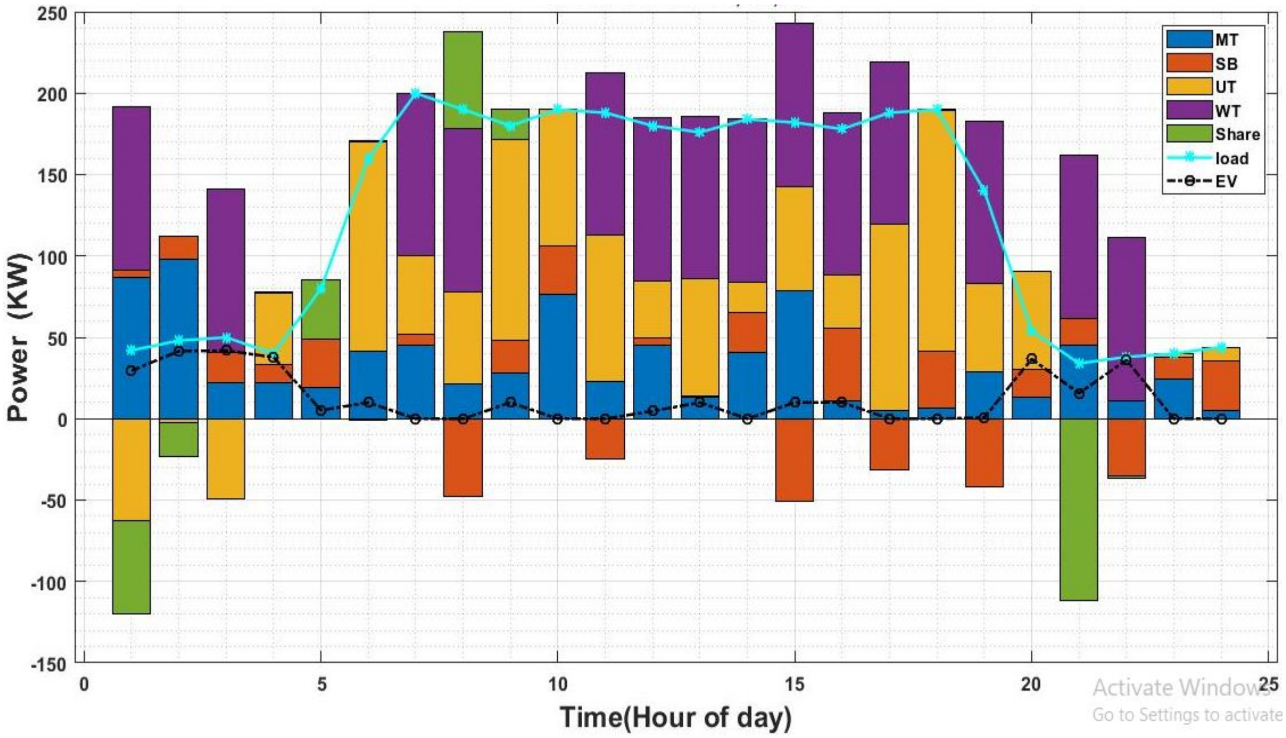

Figure 11. Case study 2. HSSOGSA Output Power,demand load,and EV load of MG1

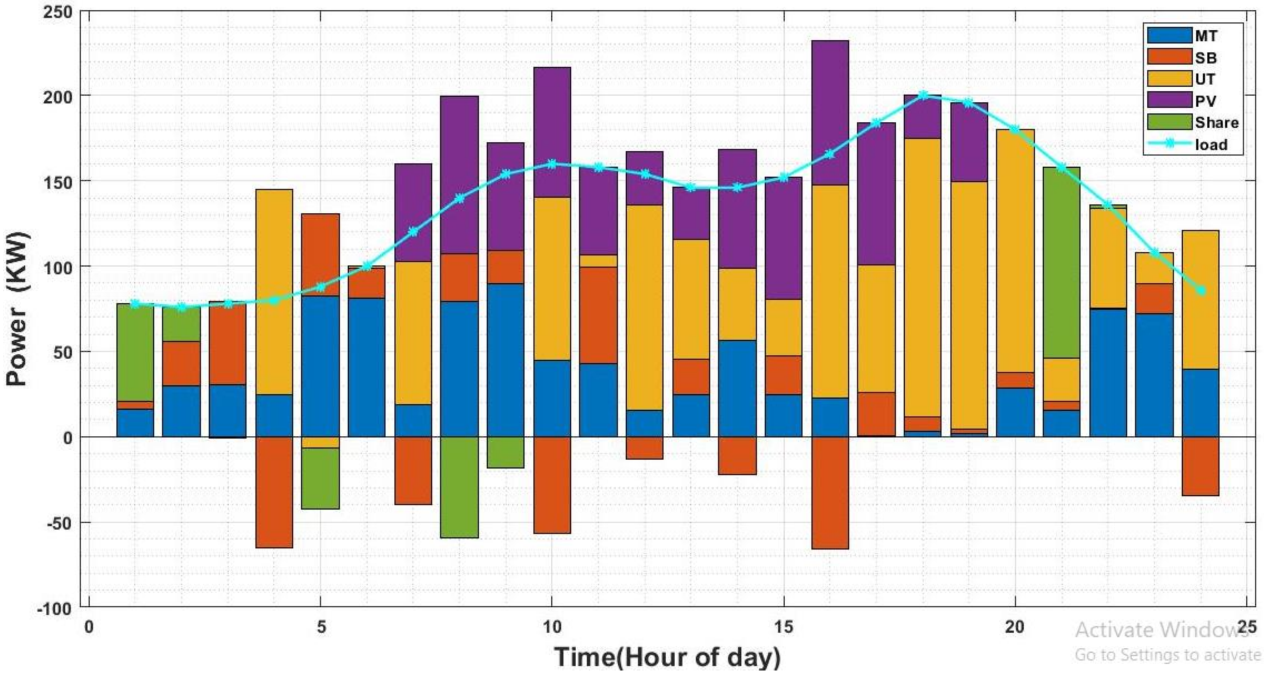

Figure 12. Case study 2. HSSOGSA Output Power and demand load of MG2

7. CONCLUSIONS

In this study, the economic operation of IMGs has been studied as an optimization problem. The HSSOGSA algorithm has been employed to determine each MG's optimal operation at the lowest cost based on an economic analysis of the power exchange between the MGs and the utility. A process of energy exchange between IMGs and the utility has been conducted in order to achieve a balance between the produced energy and the total load of each MG. This process involved buying and selling operations that has been controlled by prices referenced in the studied backward cases. Results indicate that power sharing between each MG and its neighbors as well as between each MG and the utility can be controlled. Additionally, it has been noted that power-sharing between IMGs can lower than the overall operating costs of the future distribution network where, in the absence of power sharing between IMGs, and the energy sources in one of the two MGs are unable to feed all of its loads. Then the rest of the load is covered only by purchasing energy from the utility. While in the case of power sharing between the two MGs, the buying and selling price between them is less than the utility price, this leads to save in the total cost even if the electric EV charging system uses as additional load in MG1. This is illustrated by case study 2 using the HSSOGSA. algorithm as the total daily savings in the two MGs is 17.4912 $ therefore, the annual savings has been interested which can be reaches 6384.288 $.

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