Energy Management in Smart Inter-Connected Micro-Grids Using Archimedes Optimization Algorithm

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Abstract- This paper produces a modern meta-heuristic optimization technique based on the buoyancy principle called the Archimedes optimization algorithm (AOA). The proposed algorithm is used here to determine the optimal economic operation of interconnected micro-grids (IMGs). Each micro-grids (MG) includes different types of distributed generation (DG) units such as solar photovoltaic (PV), wind turbine (WT), and micro-turbine (MT) and aims for achieving minimization of total power generation cost as the main objective function taking into consideration the power exchange between the IMGs and utility with special emphasis on technical constraints. To prove the effectiveness of the proposed AOA algorithm, it is compared with another optimization method based on the particle swarm optimization algorithm (PSO). Results obtained with the AOA algorithm show how managing energy transfer between utility and each MG. For various daily loads, it can reduce electricity consumption while lowering the cost of overall electricity generation, minimizing utility bills, and maximizing MT efficiency.

Keywords Energy management, smart grid, interconnected micro-grids (IMGs), Archimedes optimization algorithm (AOA), distributed generation (DG).

List of abbreviation:

Symbol	abbreviations
AOA	Archimedes optimization algorithm
IMGs	interconnected micro-grids
MG	micro-grids
DG	distributed generation
PV	photovoltaic
WT	wind turbine
MT	micro-turbine
PSO	particle swarm optimization algorithm
PGs	power grids
SSERs	small-scale energy resources
EMS	Energy Management System
PSA	Porcellio Scaber algorithm
SSA	sparrow search algorithm
SB	storage batteries
P&O	Perturbation and Observation

1. Introduction

With the growth of population and development, it is estimated that the energy demand may grow by 3% at the end of the year 2021 [1] Traditional power grids (PGs) powered by fuels, produce 64.5% of power worldwide These PGs emit a larger amount of carbon, where the generation sector and transport sector almost release 40% and 24% carbon respectively [2] According to the Energy Information Administration, the average electric bill households could increase by 2.3% next year [3]. Author [4] Explains the most used renewable energies and shows the efficient applications related to solar, wind, geothermal and biomass energy and includes manoeuvring and managing energy sources on opportunities related to the development of renewable energies. The name of the future power grid is a smart grid that satisfies the electrical infrastructure and intelligent information networks [5,6]. A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it (generators, consumers, and those that do both in order to efficiently deliver sustainable, economic and secure electricity supplies) [7]. A review has been made about the advantages of using renewable energy sources and energy efficiency in smart grids in [8].

A method that treats generation and related loads as a subsystem, or "micro-grid," is a better way to grasp distributed generation's rising potential. An MG is a section of the grid with a combination of multiple small-scale energy resources (SSERs) [including renewable energy sources like PV, WT], energy storage, and loads. The MG is operated in two modes: grid-connected and isolated types [9]. 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 [10, 11]. In [12] demonstrate the benefits of real-time energy measurement, and how such a system can help tackle Pakistan's energy crisis. The system is powered by the power line, and by a battery backup system to prevent data loss in the event of an outage/fault. In addition, this trend could provide extra benefits of power supply quality for the customers such as enhanced stability, local reliability, and improved power quality by reducing voltage dips [13, 14].

One of the energy management definitions is" the process of monitoring, controlling, and conserving energy in a building, organization, or distribution system" [15]. Energy management can also be applied at different scales by:

application of a limited Energy Management System (EMS) to buildings and organizations

Whole-system EMS workouts performed on a utility or micro-grid. EMSs for micro-grids optimize the sharing power flow between each micro-grid and the main grid. This is the purpose of our study.

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 …etc. are all analytic and heuristic optimization methods that are reviewed in [16]. In [17], To reduce the operational costs of a micro-grid energy management problem while taking into account the start-up and shut-down durations of the DGs, a hybrid GA and Interior Point algorithm was employed. Numerous approaches are used in the literature [18, 19] to solve the economic dispatch optimization problem. For instance, [18] employs the particle swarm optimization algorithm in the grid-connected mode of the MG, and [19] considers the economic dispatch problem as a multi-objective optimization problem without taking into account sold and bought power. In [20] provides a comparison performance between perturbation and observation [P&O] and PSO algorithms to get MPP for the PV system.

The active power of the DG units and the power exchange with the upstream distribution network were both optimized to determine the best operating of the MG. [21]. The cost of MG operation and battery charge states are optimized using a linear programming algorithm. [22]. In order to address the multi-operation management issue in a typical MG using renewable energy sources, a professional multi-objective adaptive modified PSO optimization algorithm is proposed. [23]. In [24] 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 authors of [25] suggested an artificial neural network ANN-based model for the integration of RESs that would minimize costs and limit carbon emissions. The authors of [26] have taken into account a smart house that is linked to a grid and has various equipment that require power from an external grid. The integration of a mix energy system that uses solar energy, renewable energy sources, and energy storage has been discussed.

The effectiveness of the smart energy management system is investigated in [27] with the aim of minimizing operation costs and applying SSERs in the best way possible. In [28] describes the load demand management of connected MGs as a power dispatch optimization problem. In [29] outlines an effective PSO based technique for managing the energy and operations of a micro-grid that includes various distributed generation units and energy storage devices. developed a modified version of Global basic Porcellio Scaber algorithm (PSA) is 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. [30]. A recent metaheuristic approach of sparrow search algorithm (SSA) is employed to manage the operation of MG in an optimal manner [31]. In [32] a control of a photovoltaic system connected to the grid is presented, where The main components of the studied system are solar arrays connected through a DC bus to a grid side inverter. proposes a charging/discharging algorithm suitable for the power management of the MG configured with EVs. Multi-objective optimization is taken to MG to minimize the maintenance cost and the grid dependency while maximizing the use of photovoltaic (PV) power and the utilization of EVs as energy storage systems (ESSs) [33].

The main contribution of this paper is to investigate the application of a search algorithm in the management of energy exchanged between the utility and each MG. The proposed method is utilized to establish the most cost-effective operation of IMGs. It can lower electricity consumption for a variety of daily loads while also lowering the price of overall electricity output, lowering utility costs, and raising micro turbine efficiency.

2. Mg Architecture

A micro-grid is a section of the electrical system that may run both connected and isolated from the utility by seeing generating and related loads as a subsystem. It can be connected to another MG or the utility and can supply or absorb power to other MG or utility

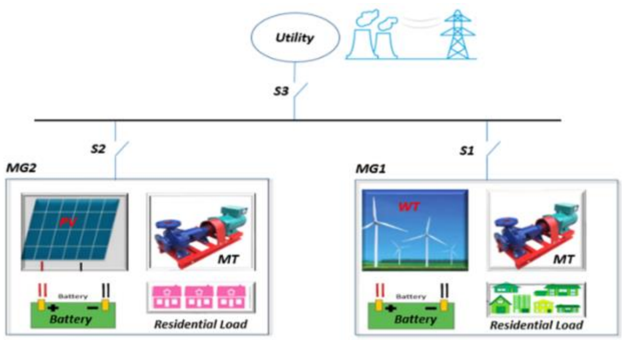

Fig. 1. System components of the network with two MGs.

. In this paper, there are two micro-grids with renewable energy resources, the first of them consists of WT, MT, and storage batteries (SB). The second consists of PV, MT, and SB. Each MG can buy and sell from the other or from the utility. The structure of the system is indicated in Fig.1.

2.1. Demand Load Model

The load model for each MG is constant and illustrated in Figure.2.

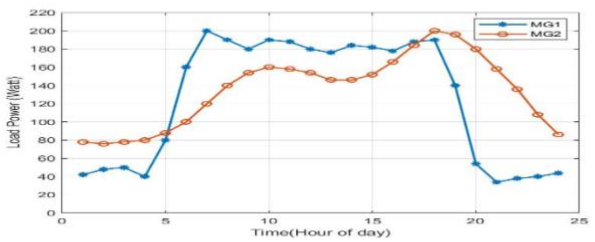

Fig. 2. Daily load curve for two MGs.

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. [34].

2.2. Power Generation Model

The amount of electricity generation by WT in MG1 and PV in MG2 all over the day is respectively illustrated in Fig.3 and Fig.4. The maximum generation capacity of both WT and PV is 100 kW.

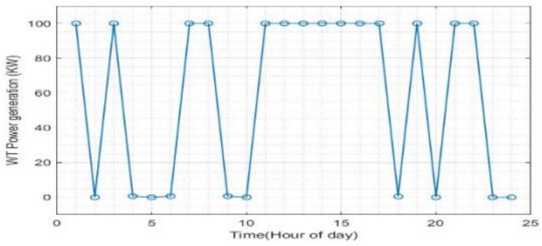

Fig. 3. WT Power Generation.

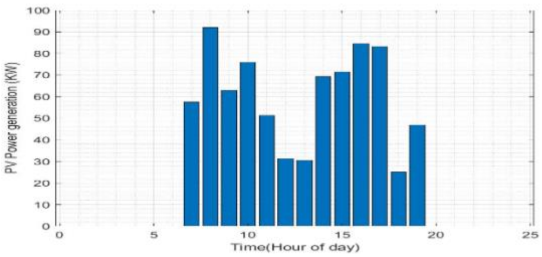

Fig. 4. PV Power Generation

The power output of MT and SB is chosen as the decision variables of the energy management problem, and two algorithms techniques are used to optimize it. But, some limitations can be clarified in Table 1. If, $P_{SB} \geq 0$ SB is in discharging mod, $P_{SB} \prec 0$ SB is in charging mode. Then, equality (1) can be applied in calculating the value of the power output from the utility [35].

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

item	SB (kW)		MT (kW)	
	Min	Max	Min	Max
MG1 & MG2	-80	100	0	100

$$P_{utility} = P_{load} - \left(P_{PV} + P_{WT} + P_{MT} + P_{SB}\right) \quad (1)$$

2.3. Cost Mode

- ***MT Cost Function [36]***

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

Where:

$F_{t,MT}$	Total operation cost of MT
C_{MT}	Cost of natural gas (fuel cost of MT)= 0.36 \$/m3
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 (\$)

- ***Utility Cost Function***

$$\sum_{t=1}^{t=24} F_{t,utility} = C_{utility} . \sum_{t=1}^{t=24} P_{t,utility} \quad (3)$$

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 system's main goal is to reduce the cost of total power generation from each mg while taking into account the power exchange between IMGs and utilities. So, The main objective function Min(f) of the optimization problem in each MG.

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

3. Review of The AOA Algorithm

Archimedes' principle states that when an object is completely or partially immersed in a fluid, the fluid exerts an upward force on the object equal to the weight of the fluid displaced by the object. Fig.5 shows that when an object is immersed in a fluid, it will be experienced by an upward force, called buoyant force, equal to the weight of the fluid displaced by the object. [36]. If the buoyant force F2 equals the weight F1 of the object, the object will be in equilibrium.

3.1. Archimedes' Principle

Assume that numerous items are submerged in the same fluid and that each one is attempting to attain the equilibrium state. Varied densities and volumes of the submerged items result in different accelerations. The object will be in the equilibrium state as in Fig.5 if the upward thrust force on the body is equal to the Wight of the liquid. It is the algorithm fundamental concept.

Pressure acting on the body upper surface

$$P1 = l * \rho * a \qquad (5)$$

Pressure acting on the body lower surface

$$P2 = (l+h) * \rho * a \qquad (6)$$

Where,

$$Pressure = \frac{Force}{Area} \qquad (7)$$

Force on upper face of body

$$F1 = P1 * A = l * \rho * a * A \qquad (8)$$

Force on lower face of body

$$F2 = P2 * A = (l+h) * \rho * a * A \qquad (9)$$

Net upward thrust on the body

$$F_{th} = F2 - F1 = (l+h) * \rho * a * A - l * \rho * a * A \qquad (10)$$

$$\therefore F = \rho * a * A(l+h-l) = \rho * a * A * h \qquad (11)$$

But the volume of the body = $V = A * h$ (12)

Net upward thrust on the body

$$F_{th} = \rho * a * A * h = \rho * a * V \qquad (13)$$

The Wight of the liquid $F_w = m * g$ (14)

Finally if $F_w = F_{th}$ body will be equilibrium

m	Mass of the body immersed in liquid
ρ	The density of the liquid
l	Depth of upper force of body from free surface of body
h	Height of the body
A	Area of upper and lower force
a	Acceleration

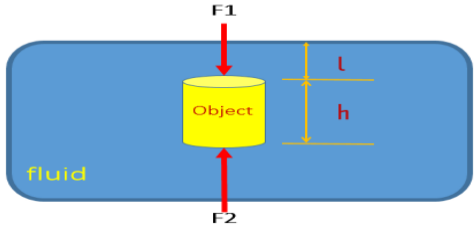

Fig. 5. An object immersed in a fluid

3.2. Archimedes' Optimization Algorithm Steps

Step 1: Initialize algorithm parameter: total objects, max iteration, search space boundary, and constants C1, C2, C3, C4.

Step 2: Initialize positions of the object randomly with their volume, density, and acceleration where initialize volume (V_i) random , initialize density (ρ_i) random, and initialize acceleration

$$acc_i = lb_i + rand * (ub_i - lb_i) \qquad (15)$$

,i=1,2,3,……,N
The search-lower space's and upper are, respectively, lb_i and ub_i.

Step 3: Calculate fitness value for each object and select the best then assign best position.
(X_{best}), V_{best}, ρ_{best}, acc_{best}.
Start population, for i=1: total objects.

Step 4

Step 5: Set generating counter for j=1: max iteration.

Step 6: Update density, volume for each object.

$$\rho_i^{t+1} = \rho_i^t + rand * (\rho_{best} - \rho_i^t) \qquad (16)$$

$$V_i^{t+1} = V_i^t + rand * (V_{best} - V_i^{t+1}) \qquad (17)$$

where V_{best} and ρ_{best} are the volume and density pertaining to the best object found, rand is uniformly distributed random number , i is object , t is current iteration ,and t+1 is next iteration .

Step 7

Calculate transfer factor (TF) and decreasing density.

$$TF = \exp\left(\frac{t_c - t_{\max}}{t_{\max}}\right) \quad (18)$$

where transfer T F steadily rises until it reaches 1. it using to switch the exploration and exploitation phases and next calculate the density decreasing factor (d) that is used to find out the global solution density factor along Archimedes' Optimization to find out the optimal solution .Here t_c, $t_{\max}$ are the current iteration and maximum iterations, respectively.

$$d^{t+1} = \exp\left(\frac{t_{\max} - t_c}{t_{\max}}\right) - \left(\frac{t_c}{t_{\max}}\right) \quad (19)$$

Step 8

Algorithm exploration phase.

If $TF \leq 0.5$, then update object's acceleration, normalize acceleration and object's position .when $TF \leq 0.5$ it means the collision between objects occurs and the algorithm perform exploration phase .If this condition is not true it means there is no collision between the objects and the algorithm perform the exploitation phase.

Update object's acceleration:

$$acc_i^{t+1} = \frac{\rho_{mr} + V_{mr} * acc_{mr}}{\rho_i^{t+1} * V_i^{t+1}} \quad (20)$$

Where mr is random material,

Normalize acceleration:

$$acc_{i-nor}^{t+1} = u * \frac{acc_i^{t+1} - \min(acc)}{\max(acc) - \min(acc)} + l \quad (21)$$

Step 9

Algorithm exploitation phase.

If the condition mentioned in step 8 not true, the algorithm perform the exploitation phase. Again it will update object 'acceleration, normalize acceleration, flag direction and after that update object's position.

$$acc_i^{t+1} = \frac{\rho_{best} + V_{best} * acc_{best}}{\rho_i^{t+1} * V_i^{t+1}} \quad (23)$$

$$acc_{i-nor}^{t+1} = u * \frac{acc_i^{t+1} - \min(acc)}{\max(acc) - \min(acc)} + l \quad (24)$$

Update flag direction

$$Flag(F) = \begin{cases} +1 \rightarrow if: p \leq 0.5 \\ -1 \rightarrow if: p \succ 0.5 \end{cases} \quad (25)$$

where=2*rand-C4

Then, update object's position

$$X_i^{t+1} = X_{best}^t + F * C2 * rand * acc_{i-nor}^{t+1} * d * \left(T * X_{best} - X_i^t\right) \quad (26)$$

Where : T=C3*TF

The process of AOA to solve the specific problems in this paper is shown in Fig.6

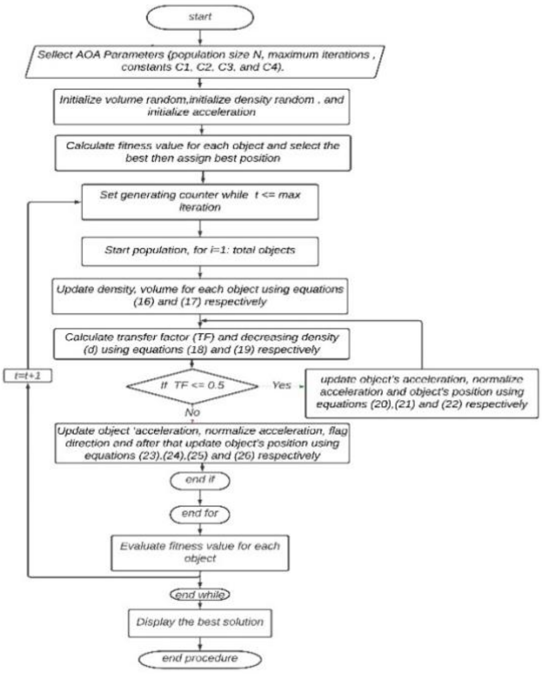

Fig. 6. AOA Flowchart

4. Simulation Results and Discussion

This section tests the proposed IMGs ability to distribute power among MG loads. The utility and two IMGs network are shown in Fig.1 structure. Two renewable energy resources and storage battery make up each MG's power production system. 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 and AOA and PSO parameter setup can be explained as follows in Table 2:

Table 2. The parameters used for PSO and AOA.

PSO		AOA	
Iteration Number	100	Max Iteration	100
Correction Factor	1.5	C1=C4	2
Inertia Weight	1	C3 , C2	1 , 6
Population-Size	50	Objects Number	50

There are two main scenarios followed in the buying and selling process from the utility and MGs. Scenario I The purchased/selling price from/to the utility and price between two MGs is constant throughout the day (Cutility = 0.0001 $/kW, Cutility.sell = 0.00008 $/kW, CMG = 0.0001 $/kW) as shown in Table 3. While, scenario II The price between two MGs equal to the selling price to the utility and is constant throughout the day (Cutility.sell = CMG = 0.000075 $/kW), but the purchased price from the utility is variable as shown in Table 3 [37]. The costs in all scenarios can be summarized in the following Table 3.

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

item	Description	Scenario I	Scenario II
		Fixed Purchasing Cost ($/kW)	Profile Purchasing Cost ($/kW)
1	Utility purchase price (Cutility)	0.0001	[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 to the utility (Cutility.sell)	0.00008	0.000075
3	purchase and sale prices between two MGs (CMG)	0.0001	0.000075

- **Case Study 1:** (No power share between IMGs according to Scenario I)

Case Study 1 is applied to the system of Fig.1 when no power exchange between IMGs. while The energy produced from each MG throughout the day is insufficient for or exceeds its demand load. So, it is only exchanged with the utility through purchases or sales in accordance with the prices displayed in Table 3 scenario I. Figure 7, and Figure 8 show the convergence of the PSO and AOA optimization algorithms used in this study. The objective function described above takes the minimum value -363.463 $,292.440 $ for PSO and AOA respectively in MG1 and 416.367 $, 369.183 $ for PSO and AOA respectively in MG2. In accordance with the specific set of the optimized power outputs of each MG and utility illustrated in Tables 4, and 5.

Table 4. Case study 1 PSO optimized power outputs of each MG and utility in watt

(a) MG1

Hr.	MG1 - PSO		
	MT	BS	Utility
1	26793.13	17438.03	-102231
2	37739.35	51117.03	-40856.4
3	28216.93	15879.04	-94096
4	63769.25	-2467.39	-21942.4
5	23321.99	-42828.7	99506.72
6	14170.91	26002.9	119132
7	27513.08	23393.25	49093.67
8	11611.62	-52573.8	130962.2
9	72031.23	55193.78	52116.85
10	99847.94	-8249	98401.07
11	35811.39	-36247.4	88436.01
12	37048.89	19049.99	23901.12
13	61026.93	25695.84	-10722.8
14	28127.59	-858.744	56731.15
15	69124.34	-25848.1	38723.8
16	10379.66	26152.2	41468.14
17	62684.42	-63627.7	88943.3
18	67332	25921.34	96353.15
19	5668.048	28142.75	6189.204
20	37730.07	-13668.3	29938.18
21	27533.08	9952.895	-103486
22	58466.47	6706.76	-127173
23	19326.1	-557.316	21231.21
24	51622.69	-14826.5	7203.823

(b) MG2

Hr.	MG2- PSO		
	MT	BS	Utility
1	90328.59	27735.67	-40064.26
2	2061.364	50146.65	23791.99
3	8601.215	-16676.98	86075.76
4	40863.02	13959.69	25177.29
5	46420.97	8944.62	32634.41
6	56548.51	-38105.73	81557.22
7	25182.67	44161.77	-6845.01
8	81337.46	-35557.70	2223.81
9	2838.888	15871.85	72440.32
10	36692.52	19472.09	27924.03
11	35546.53	-54873.63	125943.69
12	74.56977	45970.07	76600.33
13	81840.31	-44565.76	78126.53
14	48392.14	32279.20	-3920.65
15	17471.25	21947.64	41047.39
16	43954.45	-35416.51	72844.59
17	11937.14	16637.24	72191.08
18	56186.93	2346.46	116337.86
19	51972.15	2236.47	95035.77
20	3141.488	1582.44	175276.07
21	10976.45	3711.42	143312.13
22	92044.19	-28098.76	72054.57
23	47547.11	21353.52	39099.36
24	39646.5	2722.36	43631.14

Table 5. Case study 1 AOA optimized power outputs of each MG and utility in watt

(a) MG1

Hr.	MG1 - AOA		
	MT	BS	Utility
1	44066.89	16859.00	-118925.89
2	35175.62	48346.14	-35521.77
3	28061.11	24926.37	-102987.48
4	22009.73	-50375.41	67725.14
5	35670.27	12542.09	31787.64
6	46634.77	6021.50	106649.55
7	38639.94	19690.65	41669.41
8	23816.97	-1825.31	68008.33
9	24663.06	16086.54	138592.26
10	38660.08	-26145.02	177484.94
11	59125.68	28147.46	726.86
12	20302.64	-49119.13	108816.49
13	43398.54	39587.47	-6986.00
14	24202.48	-5658.14	65455.66
15	21675.04	15308.51	45016.45
16	32406.68	-44679.57	90272.89

17	23620.11	41602.57	22777.32
18	26027.88	-2856.26	166434.87
19	22349.86	-16722.00	34372.13
20	57872.58	25035.58	-28908.16
21	23909.86	-21609.68	-68300.18
22	22330.21	6749.79	-91080.00
23	29407.79	-51212.48	61804.69
24	38714.33	57624.11	-52338.43

(b) MG2

Hr.	MG2- AOA		
	MT	BS	Utility
1	12400.42	18263.01	47336.57
2	23116.61	30205.17	22678.22
3	45068.58	37982.74	-5051.33
4	34217.37	-25430.72	71213.35
5	36118.89	31720.54	20160.57
6	21173.77	-44471.70	123297.93
7	40590.05	4425.28	17484.10
8	16686.11	38553.14	-7235.69
9	23393.41	-40855.16	108612.81
10	53937.54	5917.21	24233.90
11	34225.84	35438.13	36952.62
12	56662.82	-38747.02	104729.17
13	44429.47	5967.84	65003.77
14	37662.52	4897.61	34190.56
15	26263.83	25209.58	28992.86
16	50820.16	-2299.66	32862.02
17	13507.43	-59401.12	146659.15
18	46609.39	63885.23	64376.63
19	49088.77	-11150.90	111306.52
20	31720.19	5585.67	142694.14
21	17219.22	-15802.74	156583.53
22	31383.43	21627.26	82989.31
23	29642.68	-62963.75	141321.06
24	28275.94	57554.45	169.60

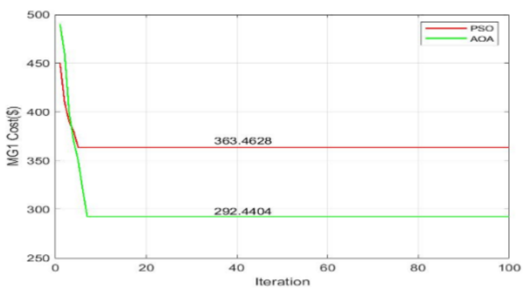

Fig. 7. Case study 1 Optimization cost of PSO and AOA for MG1

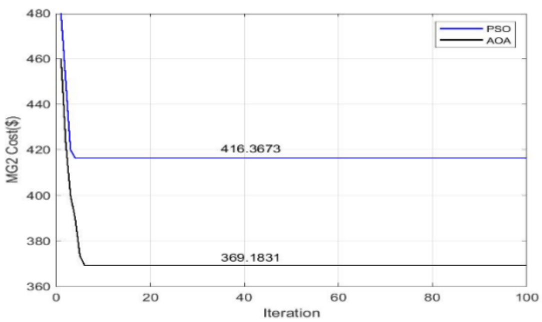

Fig. 8. Case study 1 Optimization cost of PSO and AOA for MG2

Figures 9 and 10. show the total power generation and demand load for MGs 1 and 2 throughout the day, respectively.

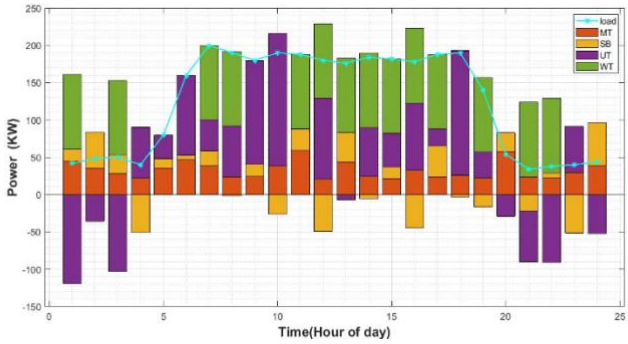

Fig. 9. Case study 1 AOA Output Power and demand load of MG1

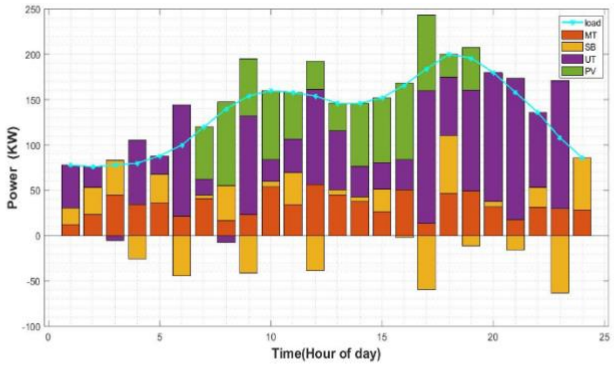

Fig.10. Case study 1 AOA Output Power and demand load of MG2

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 utility, and sold electricity will have a negative value, or through charging the battery storage system. In the latter case, the capacity designated for charging the battery will have a negative value. Assuming that the capacity generated power is less than the entire load hence, the power is bought from the utility. In the present occasion, the network power purchase value is positive.

- **Case Study 2:** (No power share between IMGs according to Scenario II)

Case Study 2 is applied to the system of Fig.1 when no power exchange between IMGs. In the event that the energy produced from each MG throughout the day is insufficient for or exceeds its demand load, the energy is only exchanged with the utility through purchases or sales in accordance with the prices displayed in scenario II of Table 3. Figures 11 and 12 show the convergence of the PSO and AOA optimization algorithms used in this study. The objective function described above takes the minimum value 354.840 $, 284.778 $ for PSO and AOA respectively in MG1 and 411.088 $, 350.532 $ for PSO and AOA respectively in MG2 according to the specific set of the optimized power outputs of each MG and utility illustrated in Table 6, and Table 7.

Table 6. Case study 2 PSO optimized power outputs of each MG and utility in watt

(a) MG1

Hr.	MG1 - PSO		
	MT	BS	Utility
1	55685.54	17996.92	-131682.46
2	15386.70	12771.90	19841.40
3	15985.71	3603.53	-69589.24
4	64253.24	5471.29	-30365.07
5	49054.47	10649.92	20295.60
6	66916.96	39327.02	53061.84
7	38131.57	-68653.07	130521.50
8	58377.71	36000.18	-4377.89
9	2721.56	26264.41	150355.89
10	87099.62	-47890.38	150790.76
11	71613.42	33942.25	-17555.67
12	46968.96	21000.64	12030.40
13	30425.13	-62923.93	108498.79
14	18207.38	0.00	65792.62
15	46398.07	48710.90	-13108.96
16	11961.16	-37851.94	103890.78
17	31808.27	6088.58	50103.15
18	35909.05	25987.22	127710.22
19	1619.58	3143.04	35237.38
20	17880.79	17131.57	18987.65
21	79920.21	-56702.68	-89217.53
22	37485.82	4095.45	-103581.26
23	25150.41	30888.70	-16039.11
24	41321.35	24328.38	-21649.73

(b) MG2

Hr.	MG2- PSO		
	MT	BS	Utility
1	26240.93	33677.57	18081.50
2	2895.32	43459.21	29645.47
3	43789.96	-16678.38	50888.41
4	22884.16	25951.14	31164.70
5	2509.38	-37081.10	122571.72
6	5929.19	27596.91	66473.90
7	98893.35	9176.55	-45570.47
8	8188.45	-26302.75	66117.86
9	63652.43	21391.91	6106.72
10	98751.48	-35557.85	20895.02
11	3829.15	23949.07	78838.37
12	19562.59	22502.23	80580.14
13	45217.67	-17925.11	88108.51
14	13745.75	10418.90	52586.05
15	9150.13	-46109.37	117425.52
16	32631.90	28500.92	20249.70
17	67124.47	1822.54	31818.45
18	47174.29	24378.58	103318.38
19	2439.67	-21699.81	168504.53
20	18648.54	12857.06	148494.41
21	99340.41	-10114.75	68774.35
22	31543.06	18357.20	86099.73
23	82455.94	-60898.95	86443.02
24	54222.77	11832.57	19944.66

Table 7. Case study 2 AOA optimized power outputs of each MG and utility in watt

(a) MG1

Hr.	MG1 - AOA		
	MT	BS	Utility
1	56884.34	26237.84	-141122.18
2	47374.24	21490.17	-20864.41
3	25556.78	38454.23	-114011.01
4	14022.29	-49311.66	74648.83
5	41433.97	22228.54	16337.49
6	38793.58	11575.59	108936.65
7	22570.18	5628.12	71801.69
8	22863.07	9312.07	57824.86
9	29674.99	-4893.01	154559.88
10	17156.51	-54067.70	226911.19
11	52235.83	3855.96	31908.21
12	37464.66	53169.64	-10634.30
13	32300.39	-17987.04	61686.65
14	47886.56	9627.19	26486.24
15	28994.53	2524.52	50480.95
16	32450.39	3254.61	42295.00
17	48846.29	-25990.92	65144.62
18	26961.03	4285.72	158359.74
19	49482.65	742.38	-10225.03
20	16071.51	12792.15	25136.34
21	16302.86	1109.62	-83412.48
22	30774.26	10375.69	-103149.95
23	26637.32	-57388.24	70750.92
24	23835.53	77949.80	-57785.33

(b) MG2

Hr.	MG2- AOA		
	MT	BS	Utility
1	36249.89	13919.67	27830.44
2	19900.29	21761.63	34338.08
3	36738.46	48573.16	-7311.62
4	25014.56	-30422.34	85407.79
5	53652.64	38873.37	-4526.01
6	27407.19	-64697.93	137290.74
7	26596.19	4442.87	31460.36
8	59721.57	7694.04	-19412.04
9	25902.02	47953.79	17295.25
10	27682.01	-54369.39	110776.03
11	52642.77	39485.86	14487.96
12	18831.49	1943.22	101870.26
13	43129.67	18194.93	54076.48
14	77981.13	-245.23	-985.20
15	36911.35	-47007.44	90562.37
16	44542.72	13843.07	22996.73
17	47866.24	17060.00	35839.22
18	38561.16	5860.05	130450.04
19	23516.19	-13131.16	138859.36
20	34740.27	9503.87	135755.86

21	33381.88	-3792.78	128410.90
22	59765.29	11691.09	64543.63
23	27480.00	-44489.28	125009.28
24	52645.25	61138.04	-27783.28

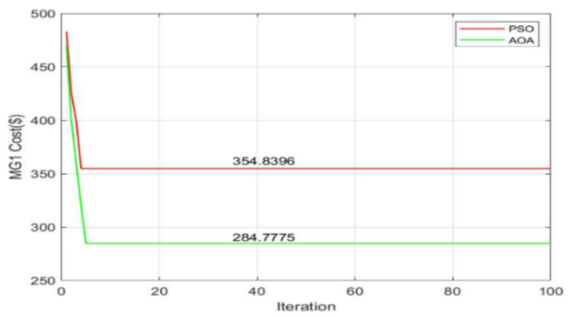

Fig. 11. Case study 2 Optimization cost of PSO and AOA for MG1

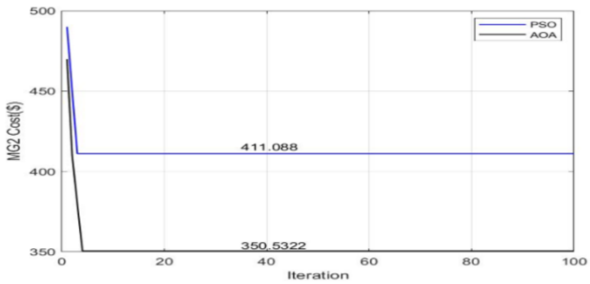

Fig. 12. Case study 2 Optimization cost of PSO and AOA for MG2

Figures 13 and 14 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 utility, and sold electricity will have a negative value, or through charging the battery storage system. In the latter case, the capacity designated for charging the battery will have a negative value. Assuming that the capacity generated power is less than the entire load hence, the power is bought from the utility. In the present occasion, the network power purchase value is positive.

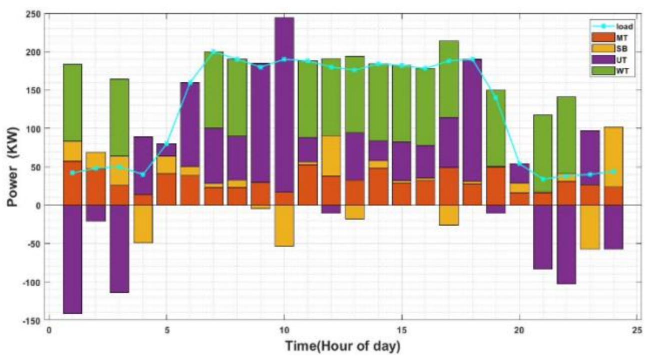

Fig. 13. Case study 2 AOA Output Power and demand load of MG1

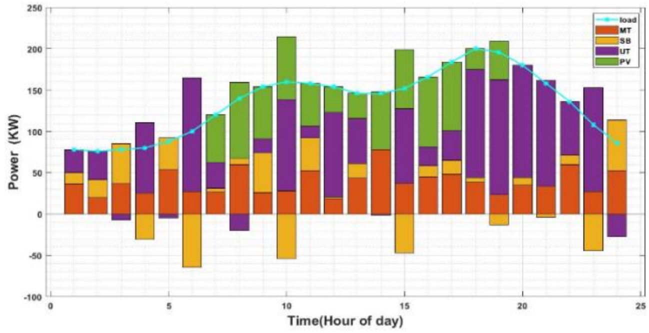

Fig. 14. Case study 2 AOA Output Power and demand load of MG2

- **Case Study 3** (power sharing between IMGs according to Scenario I)

When power sharing between IMGs, is applied to the system in Fig 1. 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 scenario I. The PSO and AOA optimization techniques employed in this study can be seen as convergent in Fig.15 and 16. The objective function mentioned above gives the minimum values of 346.9694 $, 258.3546 $, for PSO and AOA in MG1 while giving 407.96 $, 307.31 $ for PSO and AOA in MG2. Tables 8 and 9 illustrate the precise set of each MG, sharing between IMGs, and utility optimal power outputs.

Table 8. Case study 3. PSO optimized power outputs of each MG, sharing line and utility in watt

(a) MG1

Hr.	MG1 - PSO			
	MT	BS	Share	Utility
1	22723.2	35311.20	-19050.7	-96983.69
2	744.16	47466.90	0.00	-211.06
3	91874.88	-23721.03	0.00	-118153.9
4	1457.93	29170.59	0.00	8730.94
5	80766.04	-40329.47	0.00	39563.43
6	33153.26	32228.19	0.00	93924.37
7	19534.58	-30210.53	21945.07	88730.88
8	60890.33	3980.56	25129.11	0.00
9	19724.53	12282.39	0.00	147334.94
10	48750.96	16736.40	0.00	124512.65
11	22114.04	-10725.08	0.00	76611.04
12	815.26	22055.09	0.00	57129.65
13	61652.51	-23081.38	0.00	37428.87
14	52791.26	4156.47	16560.20	10492.07
15	69197.64	3071.79	0.00	9730.57
16	9913.57	5071.14	0.00	63015.29
17	29561.97	-38919.63	0.00	97357.66
18	19167.84	8336.60	0.00	162102.05
19	71832.34	8011.34	-39843.68	0.00
20	24806.32	19353.38	0.00	9840.30
21	18048.52	-35544.06	-48504.47	0.00
22	48301.08	0.00	-82121.51	-28179.58
23	76421.20	11793.96	-48215.16	0.00
24	24057.45	22532.85	-2590.30	0.00

(b) MG2

Hr.	MG2- PSO			
	MT	BS	Share	Utility
1	21638.9	37310.4	19050.7	0.00
2	90189.73	7006.54	0.00	-21196.27
3	87194.42	3325.52	0.00	-12519.94
4	2288.05	18917.99	0.00	58793.96
5	42416.24	14069.21	0.00	31514.55
6	546.61	-24293.82	0.00	123747.21
7	84159.68	284.81	-21945.07	0.00
8	67912.26	26347.62	-25129.11	-21127.21
9	82872.88	-50993.11	0.00	59271.29
10	46366.57	25554.33	0.00	12167.75
11	19124.84	13605.89	0.00	73885.86
12	71666.65	17522.86	0.00	33455.45
13	28833.62	-44510.39	0.00	131077.86
14	50802.16	42508.74	-16560.20	0.00
15	20160.07	-38643.67	0.00	98949.87
16	3260.49	30169.83	0.00	47952.21
17	9834.56	-26695.30	0.00	117626.20
18	2974.23	0.00	0.00	171897.02
19	4485.34	26844.36	39843.68	78071.00
20	29513.41	-52436.48	0.00	202923.06
21	5376.46	24744.55	48504.47	79374.53
22	31429.70	22448.79	82121.51	0.00
23	40212.18	5407.08	48215.16	14165.58
24	47381.08	7031.68	2590.30	28996.95

Table 9. Case study 3. AOA optimized power outputs of each MG, sharing line and utility in watt.

(a) MG1

Hr.	MG1 - AOA			
	MT	BS	Share	Utility
1	41411.06	14796.75	-27933.59	-86274.22
2	19912.05	46292.03	0.00	-18204.09
3	53197.72	16966.17	-62538.39	-57625.50
4	15935.85	9784.92	0.00	13638.69
5	22827.52	-4475.63	0.00	61648.11
6	60111.14	-39924.32	0.00	139119.00
7	55292.69	23014.22	0.00	21693.09
8	25666.70	8745.65	51623.62	3964.04
9	42563.15	5133.74	0.00	131644.98
10	41204.79	-2895.28	0.00	151690.50
11	45322.75	14333.73	0.00	28343.52
12	17357.58	-68863.59	0.00	131506.00
13	9150.86	0.00	0.00	66849.14
14	32757.93	43387.25	0.00	7854.82
15	26963.19	17503.70	0.00	37533.11
16	7024.96	-43945.71	0.00	114920.75
17	44282.49	46357.86	-2640.36	0.00
18	54226.10	-50172.94	0.00	185553.34
19	23226.85	35937.24	-19164.09	0.00
20	31094.76	12591.38	0.00	10313.86
21	20404.91	-22210.71	-64194.20	0.00
22	43216.47	16481.08	-71291.21	-50406.35
23	49563.50	-58355.49	0.00	48791.99
24	55774.33	15617.15	0.00	-27391.49

(b) MG2

Hr.	MG2- AOA			
	MT	BS	Share	Utility
1	37536.31	12530.10	27933.59	0.00
2	21890.02	63320.33	0.00	-9210.35
3	42980.57	-27518.96	62538.39	0.00
4	54692.26	16813.09	0.00	8494.65
5	38792.48	29680.81	0.00	19526.71
6	49050.14	-5717.01	0.00	56666.86
7	30937.52	-51557.18	0.00	83119.09
8	46305.62	53321.56	-51623.62	0.00
9	30654.92	-59631.86	0.00	120128.00
10	7097.81	59804.15	0.00	17186.69
11	23770.47	-15245.99	0.00	98092.10
12	34875.93	0.00	0.00	87769.03
13	30772.45	18953.85	0.00	65674.78
14	32583.86	-36819.03	0.00	80985.86
15	37873.58	29132.08	0.00	13460.62
16	28321.66	-3314.04	0.00	56374.90
17	10936.22	-30583.59	2640.36	117772.48
18	44405.24	39416.41	0.00	91049.61
19	26370.58	-54699.17	19164.09	158408.89
20	34981.01	8738.83	0.00	136280.16
21	42197.60	15392.58	64194.20	36215.62
22	47600.25	17108.54	71291.21	0.00
23	43153.18	-64515.93	0.00	129362.75
24	43925.61	53218.21	0.00	-11143.82

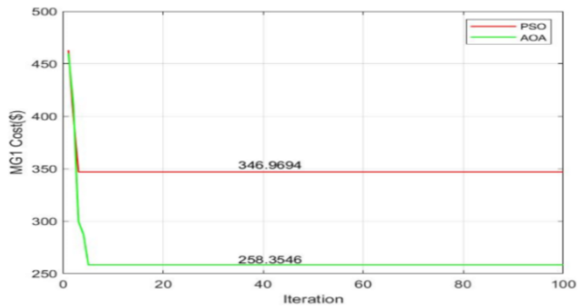

Fig. 15. Case study 3 Optimization cost of PSO and AOA for MG1

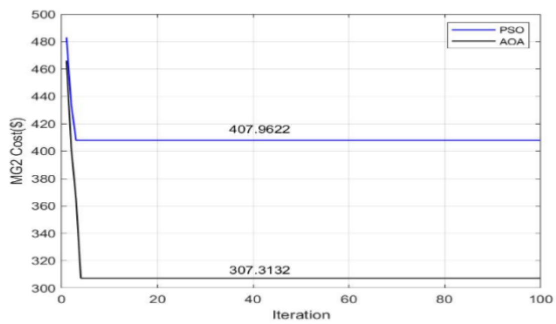

Fig. 16. Case study 3 Optimization cost of PSO and AOA for MG2

Figures 17 and 18 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 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 network power purchase value is positive.

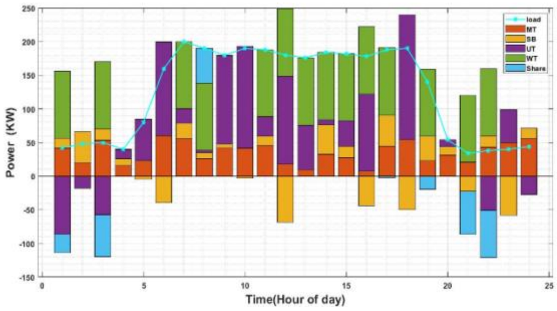

Fig. 17. Case study 3 AOA Output Power and demand load of MG1

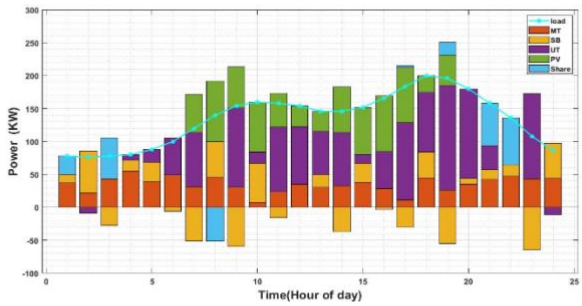

Fig. 18. Case study 3 AOA Output Power and demand load of MG2

- **Case Study 4** (power sharing between IMGs according to Scenario II)

When power sharing between IMGs, is applied to the system in Fig.1. 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 scenario II. The PSO and AOA optimization techniques employed in this study can be seen as convergent in Fig.19 and 20. The objective function mentioned above gives the minimum values of 346.9694 $, 258.3546 $, for PSO and AOA in MG1 while giving 407.96 $, 307.31 $ for PSO and AOA in MG2. Tables 10 and 11 illustrate the precise set of each MG, sharing between IMGs, and utility optimal power outputs.

Table 10. Case study 4. PSO optimized power outputs of each MG, sharing line and utility in watt

(a) MG1

Hr.	MG1 - PSO			
	MT	BS	Share	Utility
1	36634.07	25396.91	0.00	-120030.9
2	15396.42	43607.42	0.00	-11003.84
3	63073.52	14174.58	-92158.33	-35089.77
4	27197.97	-52681.4	0.00	64842.93
5	8539.43	40900.94	0.00	30559.63
6	5717.80	17615.94	0.00	135972.08
7	23417.05	-63553.9	13553.69	126583.16
8	10980.17	0.00	0.00	79019.83
9	40846.09	62476.54	7164.25	68854.99
10	30373.03	-68954.9	0.00	228581.81
11	71110.21	13294.54	0.00	3595.25
12	13226.58	40161.74	0.00	26611.68
13	53798.53	17624.73	0.00	4576.73
14	247.83	-7427.59	45703.52	45476.24
15	29985.76	-1528.97	0.00	53543.21
16	51001.32	-27364.7	0.00	54363.35
17	39561.71	25795.89	0.00	22642.40
18	43261.24	-51829.3	0.00	198174.56
19	53888.65	31011.89	-44900.53	0.00
20	78861.70	14648.41	-39510.10	0.00
21	72918.01	4967.91	-34533.4	-109352.6
22	54932.54	16570.29	-133502.9	0.00
23	38425.00	-60534.1	0.00	62109.06
24	25574.19	36971.34	-18545.53	0.00

(c) MG2

Hr.	MG2- PSO			
	MT	BS	Share	Utility
1	56461.84	23691.29	0.00	-2153.13
2	14281.33	64232.18	0.00	-2513.51
3	28318.00	-42476.3	92158.33	0.00
4	23978.20	7595.84	0.00	48425.96
5	11122.74	31370.68	0.00	45506.58
6	21885.56	-53793.86	0.00	131908.30
7	27895.84	48157.27	-13553.69	0.00
8	25895.49	-26530.13	0.00	48638.21
9	75118.89	23196.42	-7164.25	0.00
10	7985.32	1755.96	0.00	74347.37
11	59117.73	19348.22	0.00	28150.64
12	48120.86	-60371.98	0.00	134896.08
13	19973.39	0.00	0.00	95427.69
14	91103.04	31351.18	-45703.52	0.00
15	28414.91	10565.57	0.00	41485.79
16	12450.88	4622.89	0.00	64308.75
17	9837.92	-64197.02	0.00	155124.57
18	98071.71	36798.79	0.00	40000.75
19	10923.04	35090.16	44900.53	58330.65
20	43111.42	-62221.09	39510.10	159599.56
21	61574.07	61892.58	34533.35	0.00
22	26184.86	-47296.41	133502.84	23608.71
23	6779.71	47324.66	0.00	53895.63
24	55946.81	-56681.35	18545.53	68189.01

Table 11. Case study 4. AOA optimized power outputs of each MG, sharing line and utility in watt

(a) MG1

Hr.	MG1 - AOA	

	MT	BS	Share	Utility
1	41411.06	14796.75	-27933.6	-86274.22
2	19912.05	46292.03	0.00	-18204.09
3	53197.72	16966.17	-62538.4	-57625.50
4	15935.85	9784.92	0.00	13638.69
5	22827.52	-4475.63	0.00	61648.11
6	60111.14	-39924.3	0.00	139119.00
7	55292.69	23014.22	0.00	21693.09
8	25666.70	8745.65	51623.62	3964.04
9	42563.15	5133.74	0.00	131644.98
10	41204.79	-2895.28	0.00	151690.50
11	45322.75	14333.73	0.00	28343.52
12	17357.58	-68863.6	0.00	131506.00
13	9150.86	0.00	0.00	66849.14
14	32757.93	43387.25	0.00	7854.82
15	26963.19	17503.70	0.00	37533.11
16	7024.96	-43945.7	0.00	114920.75
17	44282.49	46357.86	-2640.36	0.00
18	54226.10	-50172.9	0.00	185553.34
19	23226.85	35937.24	-19164.1	0.00
20	31094.76	12591.38	0.00	10313.86
21	20404.91	-22210.7	-64194.2	0.00
22	43216.47	16481.08	-71291.2	-50406.35
23	49563.50	-58355.5	0.00	48791.99
24	55774.33	15617.15	0.00	-27391.49

(b) MG2

Hr.	MG2- AOA			
	MT	BS	Share	Utility
1	37536.31	12530.10	27933.59	0.00
2	21890.02	63320.33	0.00	-9210.35
3	42980.57	-27518.96	62538.39	0.00
4	54692.26	16813.09	0.00	8494.65
5	38792.48	29680.81	0.00	19526.71
6	49050.14	-5717.01	0.00	56666.86
7	30937.52	-51557.18	0.00	83119.09
8	46305.62	53321.56	-51623.62	0.00
9	30654.92	-59631.86	0.00	120128.00
10	7097.81	59804.15	0.00	17186.69
11	23770.47	-15245.99	0.00	98092.10
12	34875.93	0.00	0.00	87769.03
13	30772.45	18953.85	0.00	65674.78
14	32583.86	-36819.03	0.00	80985.86
15	37873.58	29132.08	0.00	13460.62
16	28321.66	-3314.04	0.00	56374.90
17	10936.22	-30583.59	2640.36	117772.48
18	44405.24	39416.41	0.00	91049.61
19	26370.58	-54699.17	19164.09	158408.89
20	34981.01	8738.83	0.00	136280.16
21	42197.60	15392.58	64194.20	36215.62
22	47600.25	17108.54	71291.21	0.00
23	43153.18	-64515.93	0.00	129362.75
24	43925.61	53218.21	0.00	-11143.82

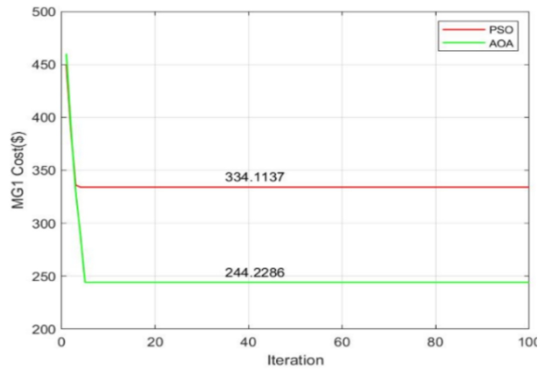

Fig. 19. Case study 4 Optimization cost of PSO and AOA for MG1

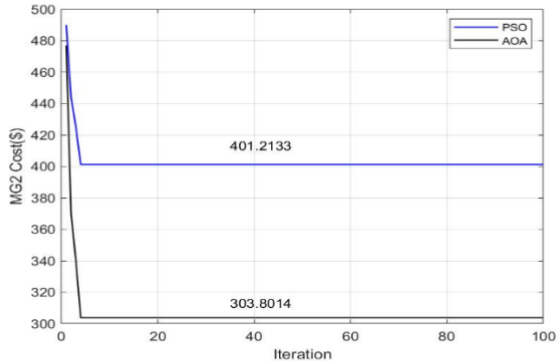

Fig. 20. Case study 4 Optimization cost of PSO and AOA for MG2

Figures 21 and 22 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 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 network power purchase value is positive.

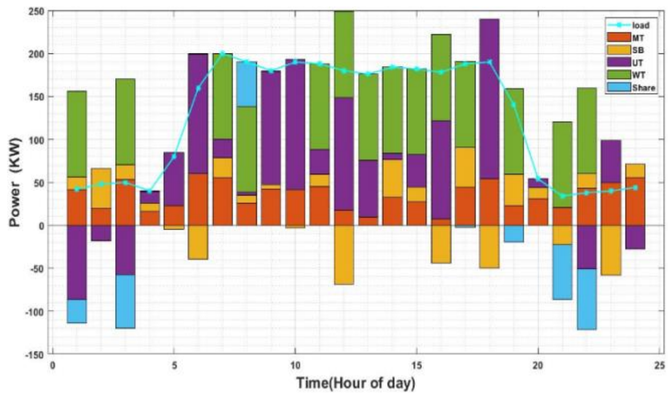

Fig. 21. Case study 4 AOA Output Power and demand load of MG1

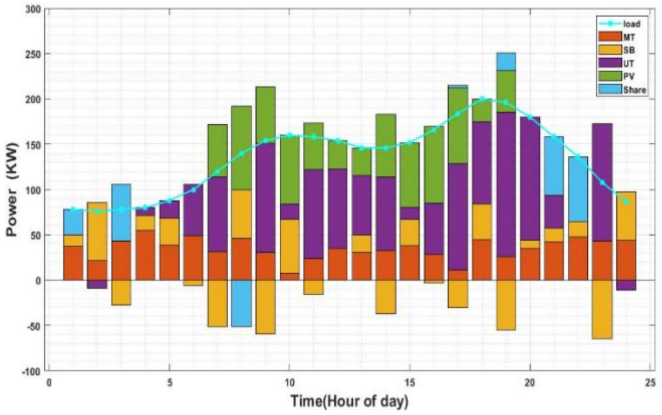

Fig. 22. Case study 4 AOA Output Power and demand load of MG2

5. Conclusion

The economic operation of IMGs is treated as an optimization issue in this paper. Based on an economic study of the power exchange between the MGs and the utility, the AOA algorithm is used to identify each MG's optimal operation at the lowest possible cost. Regarding the process of achieving a balance between the produced energy and the total load of each MG, a process of energy exchange between IMGs and the utility was carried out through buying and selling operations that are governed by prices that were referred to in the backward cases that were studied. 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 the overall operating costs of the future distribution network. It also achieves a savings price, unlike if the required energy is purchased from the utility only. This is illustrated by case study 4 using the PSO algorithm, a savings price value reaches 6.74 $ and 1.38 $ in both MGs 1 and 2, respectively. Whereas in the case of using the AOA algorithm, a savings price value reaches 10.07 $ and 1.68 $ in both MGs 1 and 2, respectively.

In the future the proposed AOA algorithm can be modified or mixed with other metaheuristic algorithms to tackle an extremely dynamic MG network with large integration of unpredictable energy sources and a range of scenarios.

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