International Journal of Electrical and Electronics Engineering (IJEEE)
ISSN(P): 2278–9944; ISSN(E): 2278–9952
Vol. 9, Issue 5, Jul–Dec 2020, 33–46

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

OPTIMAL SCHEDULING OF DISTRIBUTED POWER SOURCES IN A MICROGRID CONSIDERING MANAGEMENT ON DEMAND SIDE

P. Grace[1] & P. Kantarao[2]

[1]Research Scholar, S.R.K.R Engineering College (Autonomous), Affliated to JNTUK, Bhimavaram, Andhra Pradesh, India

[2]Professor, Department of EEE, S.R.K.R. Engineering College, Bhimavaram, Andhra Pradesh, India

ABSTRACT

Nowadays, the efficient use of renewable sources is more significant to decrease the cost for generating electricity. In this view, Micro-Grid has the ability to make use of various energy sources and supply as a single device to reach the preferred objectives. The drawback in scheduling the available generation and storage capacities in a microgrid on account of existence of renewable sources with a goal to optimize the generation cost is considered in the paper. Two scenarios are created by utilizing the verified uncertainty model due to uncertainty in available generation from renewable sources and loads. AWCPSO (Adaptive weight control particle swarm optimization) technique is employed to work out the optimization portion. The aimed method is examined on a statistical example consisting of conventional and renewable generators. The outcomes acquired from the aimed method are evidence for the utilization of low-priced generators to the coverage of 100% and remaining generators utilized in the reducing percentage with raising their generation cost. Power taken from grid in the statistical example is consumed very carefully as it is high-priced source. The planned algorithm gives the best possible answer for scheduling the generators and it also realize load discarding if required. The generation cost acquired by the proposed method is less than by using the AFS (Artificial fish swarm) intelligence technique.

KEYWORDS: *Microgrid, Scheduling, Optimization, Renewable Energy Sources (RESs), Adaptive Weight Control Particle Swarm Optimization (AWCPSO)*

Article History

Received: 01 Oct 2020 | Revised: 06 Oct 2020 | Accepted: 10 Oct 2020

INTRODUCTION

The usage of distributed generators (DGs) like photovoltaic (PV), wind turbine (WT), micro-turbine (MT), biomass, fuel cell (FC) etc. are extensively improved due to the requirements of low cost, better reliability and healthier environment [1-3]. The application of micro-grid plays a significant role in producing electricity with renewable energy sources (RES). Microgrid consists of DGs, storage units and loads and replicate as a one generating unit. It can be operated in connected mode in which a micro-grid is linked to the power grid and also in islanded mode that can work autonomously disconnected from main grid. Furthermore, the microgrid worker not able to control the generation capacity from RES but it can limit under additional generation [4-5]. The generation in micro-grid can controlled by using methods like storing energy in a device for backup, day-ahead scheduling, demand response, load shifting, load discarding etc. Thus inspired, the present paper is planned to work out the problems in microgrid. The recent energy balance procedures comprise of numerous objective functions with various constraints. The problems contain linear programming model (LPP) [5, 6], mixed–integer linear programming [7-9], Quadratic programming [10] models etc. Likewise, so many uncertainty models developed to take care of uncertainty in power available from RES and are explained in literature [11-13]. The strategies for charging/discharging of storage systems to balance supply with load [14-16]. The excess or insufficient generation is controlled from load side by demand side energy management (DSEM) techniques. Different DSM methods are developed to maintain energy balance contains demand response programs [17-19], load shedding [20], load shifting [21] etc. Day ahead energy bidding problem solved in [22-23].

The problem in this paper concentrates on two tasks. One is to minimize the generation cost and second is to balance the generation and load which in excess is discarded from microgrid for that hour. This article plans an energy management method for optimal scheduling of generation and storage capacity in a microgrid using AWCPSO algorithm. The conventional generators cost function is in quadratic form whereas it is in linear form for renewable sources. The algorithms like particle swarm optimization (PSO) and genetic algorithm (GA) takes more time for computation [24]. The disadvantage of AFS algorithm is that the information of group elements is not helpful for next movement in search. The modified PSO method is employed to work out the optimization portion for the planned algorithm. The AWCPSO algorithm has the following advantages which are high computational speed and provide high quality solution.

Energy management (EM) algorithm is planned for scheduling the renewable, conventional energy generations and distributed storage capacity in a microgrid allowing demand side energy management. AWCPSO algorithm is employed to optimize the generation cost and EM method balances the available generation and load. The additional energy stores in the distributed storage device for back-up whereas the energy is discharged from storage unit under deficit condition. The power is taken from main grid after full consumption of distributed sources. DSEM technique is utilized for discarding the extra load under insufficiency generation.

MODELLING OF MICROGRID COMPONENTS

Microgrid is a small size electrical grid which has the ability to operate both autonomously and in combination with the main grid. Microgrid contains renewable generators, non-renewable generators, dispatchable distributed generators, energy storage devices, loads which are controllable and uncontrollable and a connection of main electrical grid. The modelling of different components in the microgrid is as described below.

Distributed Energy Generators

Distributed energy generation is broadly used due to the requirements for improved reliability, less cost, more flexibility and cleaner environment. The amount of power generated by distributed generators must be within the maximum and minimum limits.

Let $P_{Ri}(t)$ and $P_{Cj}(t)$ be the amount of power production by i^{th} renewable generator and j^{th} conventional generator at the t^{th} time interval. The minimum and maximum limits of renewable generator are $P_{Ri,min}(t)$ and $P_{Ri,max}(t)$ however for conventional generator are $P_{Ci,min}(t)$ and $P_{Ci,max}(t)$.

$$P_{Ri,min} \leq P_{Ri}(t) \leq P_{Ri,max}\ , \ t \in T,\ i \in I \quad (1)$$

$$P_{Cj,min} \leq P_{Cj}(t) \leq P_{Cj,max}\ , \ t \in T,\ j \in J \quad (2)$$

Where I is number of the renewable generators, J is number of conventional energy generators and T is number of time intervals.

Renewable energies like wind and solar has uncertainty in availability of power due to the climatic variations. To draw a definite result for a problem by any optimization algorithm majorly depends on the perfectness of uncertainties in available power of RES that are calculated. By ignoring the impact of uncertainty does not give the optimal result to the problem. An appropriate modelling and approximating these uncertainties in microgrid environment is done by different techniques []. One type of uncertainty model is considered to create several scenarios for calculating the available power of RES and loads.

Storage Units

Energy storage unit is used as backup power supply for the system which minimizes the power consumption from the main electrical grid. It plays a critical role in cost minimization. Storage unit charges whenever additional energy available from the renewable generators and is discharged by the worker under scarcity generation situation.

Let $P_{SCn}(t)$ and $P_{SDn}(t)$ are the quantity of power charged and discharged from n^{th} storage unit at t^{th} time interval. The maximum charge and discharge rates of storage units are restricted by (3) and (4).

$$0 \leq P_{SCn}(t) \leq P_{SCn,max}, \; t \in T, n \in N \tag{3}$$

$$0 \leq P_{SDn}(t) \leq P_{SDn,max}, \; t \in T, n \in N \tag{4}$$

The state of charge of each storage unit is limited by (5). The state of charge (SoC) of storage unit during charging at any time is given by (6) and in the case of discharging is given by (7). Where N is the total number of storage devices.

$$SoC_{n,min} \leq SoC_n(t) \leq SoC_{n,max}, t \in T, n \in N \tag{5}$$

$$SoC_n(t+1) = SoC_n(t) + \eta_n P_{SCn}(t), \; t \in T, n \in N \tag{6}$$

$$SoC_n(t+1) = SoC_n(t) - \eta_n P_{SDn}(t), \; t \in T, n \in N \tag{7}$$

Loads

Loads are of two types which are controllable loads and uncontrollable loads. To apply energy management on demand side at every instant needs the controllable type of load. The quantity of load that is in additional to the total generated power from all distributed generators plus storage units plus power taken from main grid is known as extra load. The extra load is discard from the system with reward payment by the owner of microgrid to the consumer on behalf of the trouble occurred.

$$\sum_{m=1}^{M} L_{LDm}(t) = \sum_{m=1}^{M} L_m(t) - [\sum_{i=1}^{I} P_{Ri}(t) + \sum_{j=1}^{J} P_{Cj}(t) + \sum_{n=1}^{N} P_{SDn}(t) + P_{grid}(t)], \; i \in I, j \in J, m \in M, n \in N, t \in T \tag{8}$$

Where, M is number of loads.

Table 1: Details of Energy Resources

Type of System	Capacity (KW)	Min Power (KW)	Max Power (KW)
PV 1	600	0	200
PV2	500	0	200
WT	800	0	800
MT	300	0	300
FC	300	0	300
Diesel	600	30	600
Grid	500	0	300
Battery	300	Min Soc-30	100(ch/dch)
		Max SoC-300	

FORMULATION OF MICROGRID PROBLEM

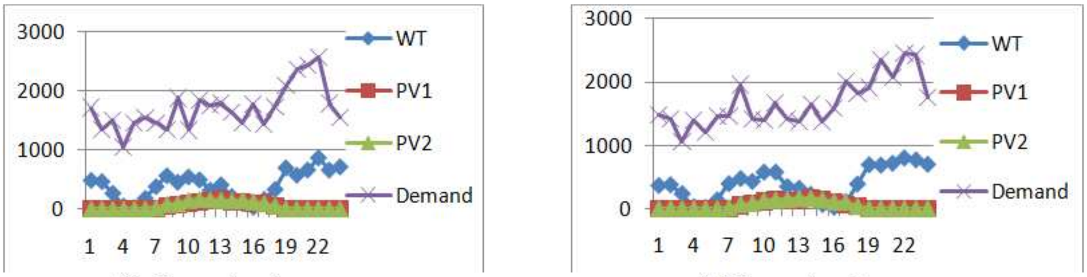
The problem should be formulated in such a way that the total generation cost is to be minimized with satisfying constraints. The mathematical formulation of the problem to establish the best operating plan is as follows.

Objective Function

$$F_1 = \text{Min} \sum_{t=1}^{T} \{ \sum_{j=1}^{J} [X_{Cj}(t)*\{ \alpha*(P_{Cj}(t))^2 + \beta*(P_{Cj}(t))+\gamma \} + Y_{Cj}(t)*SU_{Cj} + Z_{Cj}(t)*SD_{Cj}] + \sum_{i=1}^{I} [X_{Ri}(t)*C_{Ri}(t)*P_{Ri}(t)+Y_{Ri}(t)*SU_{Ri}+ Z_{Ri}(t)*SD_{Ri}+OM_{Ri}(t)]+ \sum_{n=1}^{N} [U_{Sn}(t)*C_{Sn}(t)*P_{Sn}(t)*\eta_n] + C_{grid}(t)*P_{grid}(t) + \sum_{m=1}^{M} [V_{LDm}(t)*C_{LDm}(t)*L_{LDm}(t)]\}, i \in I, j \in J, m \in M, n \in N, t \in T \quad (9)$$

Table 2: Available Capacity of Renewable Energy Sources and Hourly Electrical Load Demand in Two Scenarios

	Scenario 1				Scenario 2			
Time (h)	PV1 (KW)	PV2 (KW)	WT (KW)	Demand (KW)	PV1 (KW)	PV2 (KW)	WT (KW)	Demand (KW)
1	0	0	485	1721	0	0	369	1486
2	0	0	464	1352	0	0	380	1405
3	0	0	262	1503	0	0	238	1048
4	0	0	46	1045	0	0	35	1389
5	0	0	21	1463	0	0	22	1204
6	0	0	178	1559	0	0	141	1466
7	0	17	377	1449	0	12	398	1449
8	39	77	564	1347	50	69	479	1946
9	67	84	453	1872	75	86	433	1408
10	103	146	544	1332	114	126	580	1397
11	124	163	493	1841	138	138	579	1660
12	144	157	318	1751	120	142	351	1404
13	162	150	407	1783	131	160	325	1366
14	120	134	208	1639	165	160	229	1639
15	121	147	88	1460	151	136	69	1378
16	96	120	25	1771	102	107	26	1574
17	93	88	160	1425	66	101	115	1994
18	38	52	328	1728	34	41	392	1805
19	0	1	697	2081	0	1	697	1904
20	0	0	574	2358	0	0	691	2334
21	0	0	664	2430	0	0	720	2072
22	0	0	870	2560	0	0	804	2443
23	0	0	661	1783	0	0	773	2413
24	0	0	718	1558	0	0	704	1751



(a) Scenario – 1 (b) Scenario – 2

Figure 1: Available Generation from RESs and Hourly Demand.

Table 3: Bid Rate of Distributed Energy Resources in Euros/kwh

Time (h)	PV1, PV2	WT	MT	FC
1	0	0.021	0.0823	0.1277
2	0	0.017	0.0823	0.1277
3	0	0.0125	0.0831	0.1285
4	0	0.011	0.0831	0.129
5	0	0.051	0.0838	0.1285
6	0	0.085	0.0838	0.1292
7	0	0.091	0.0846	0.1292
8	0.0646	0.11	0.0854	0.13
9	0.0654	0.14	0.0862	0.1308
10	0.0662	0.143	0.0862	0.1315
11	0.0669	0.15	0.0892	0.1323
12	0.0677	0.155	0.09	0.1315
13	0.0662	0.137	0.0885	0.1308
14	0.0654	0.135	0.0885	0.1308
15	0.0646	0.132	0.0885	0.1308
16	0.0638	0.114	0.09	0.1315
17	0.06538	0.11	0.0908	0.1331
18	0.0662	0.0925	0.0915	0.1331
19	0	0.091	0.0908	0.1338
20	0	0.083	0.0885	0.1331
21	0	0.033	0.0862	0.1315
22	0	0.025	0.0846	0.1308
23	0	0.021	0.0838	0.13
24	0	0.017	0.0831	0.1285

Grid power – 0.572 Euros/kwh

The cost of power generated from conventional energy generators like diesel power g enerator is represented in quadratic form and for the renewable generators, it is in linear form. The state variables X_{Cj} and X_{Ri} give the information about the state of the conventional and renewable generators whether it is ON or OFF. The value of X_{Cj} and X_{Ri} is '1' when the generator is start up or shut down and it is '0' when the generator is already in running condition or OFF state. If the microgrid owner purchasing power from photovoltaic and wind energy operators then the cost OM_{Ri} is fix to zero. Otherwise, if the operator of microgrid owns the PV and wind energy generators then the cost OM_{Ri} is only considered for cost calculation.

The vector U_{Sn} gives the information about exchanging power between microgrid and battery. The state of exchanging power specifies that battery is charging, discharging or unused. The term η_n indicates the discharging and charging efficiency of a battery.

The value of V_{LDm} is ‘1’ for the OFF state of m^{th} load and it is ‘0’ for ON state of the m^{th} load. The power is drawn from main grid only when the power generated from all distributed generators and storage devices is not enough to provide the full load.

Constraints

Power Balance

The total generated power from distributed generators, storage devices and power taken from grid must matches with the loads which are in ON state.

$$\sum_{i=1}^{I} P_{Ri}(t) + \sum_{j=1}^{J} P_{Cj}(t) + \sum_{n=1}^{N} P_{SDn}(t) + P_{grid}(t)$$

$$= \sum_{m=1}^{M} [L_m(t) - L_{LDm}(t)] + \sum_{n=1}^{N} P_{SCn}(t), \qquad i \in I, j \in J, m \in M, n \in N, t \in T \quad (10)$$

Generation Capacity

For steady operation, the output power of every DG is restricted by maximum and minimum generated power limits.

$$P_{Ri,min} \leq P_{Ri}(t) \leq P_{Ri,max}, \ t \in T, i \in I \quad (11)$$

$$P_{Cj,min} \leq P_{Cj}(t) \leq P_{Cj,max}, \ t \in T, j \in J \quad (12)$$

$$P_{grid\_min} \leq P_{grid}(t) \leq P_{grid\_max}, \ t \in T \quad (13)$$

Table 4: Optimal Scheduling of Energy Resources in KW for scenario-1 (Total Operation Cost = 4010.2 Euros)

Time (h)	P_{PV1}	P_{PV2}	P_{WT}	P_{MT}	P_{FC}	P_{Diesel}	P_{Grid}	P_{Ch}	P_{Disch}	SoC	Demand	Load shed
1	0	0	485	300	300	600	0	0	36	130	1721	0
2	0	0	464	300	88	600	0	100	0	94	1352	0
3	0	0	262	300	300	600	0	0	41	194	1503	0
4	0	0	46	300	199	600	0	100	0	153	1045	0
5	0	0	21	300	300	600	142	0	100	253	1463	0
6	0	0	178	300	300	600	81	0	100	153	1559	0
7	0	17	377	300	255	600	0	100	0	53	1449	0
8	39	77	431	300	0	600	0	100	0	153	1347	0
9	67	84	453	300	300	600	0	0	68	253	1872	0
10	103	146	0	300	283	600	0	100	0	185	1332	0
11	124	163	369	300	300	600	0	15	0	285	1841	0
12	144	157	250	300	300	600	0	0	0	300	1751	0
13	162	150	271	300	300	600	0	0	0	300	1783	0
14	120	134	185	300	300	600	0	0	0	300	1639	0
15	121	147	88	300	204	600	0	0	0	300	1460	0
16	96	120	25	300	300	600	230	0	100	300	1771	0
17	93	88	160	300	284	600	0	100	0	200	1425	0
18	38	52	328	300	300	600	10	0	100	300	1728	0
19	0	1	697	300	300	600	83	0	100	200	2081	0
20	0	0	574	300	300	600	300	0	70	100	2358	214
21	0	0	664	300	300	600	300	0	0	30	2430	266
22	0	0	870	300	300	600	300	0	0	30	2560	190
23	0	0	661	300	300	600	0	78	0	30	1783	0
24	0	0	718	300	40	600	0	100	0	108	1558	0

Storage Capacity

The quantity of energy that a storage unit charges and discharges at time‘t’ must satisfy the following constraints

$$0 \leq P_{SCn}(t) \leq P_{SCn,max}\ ,\ t \in T,\ n \in N \tag{14}$$

$$0 \leq P_{SDn}(t) \leq P_{SDn,max}\ ,\ t \in T,\ n \in N \tag{15}$$

$$SoC_{n,min} \leq SoC_{n}(t) \leq SoC_{n,max}\ ,\ t \in T,\ n \in N \tag{16}$$

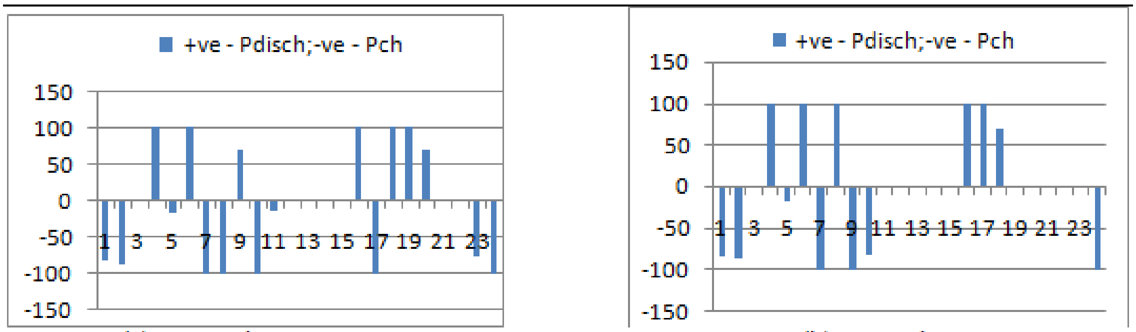
AWCPSO ALGORITHM

Optimization algorithm is used to get the desired output for the problem in the microgrid. PSO algorithm is extensively used in multi-objective problems due to its numerous advantages. It is a population-based search algorithm and it gives superior value results to the problem with less computational effort. This was introduced by Eberhart and Kennedy [25] on the basis of collective behavior of animals like birds, fishes, and insects. PSO imitates the activities done by flock of bird or number of bees called “swarm” and each bird is called as “particle”. A particle in swarm reaches to optimum point by way of its current velocity, earlier occurrence and based on the knowledge of its adjacent particles.

A modified PSO algorithm is used to get the optimal solution faster than a standard PSO method .The updated velocity of the particle ‘p’ is

Table 5: Optimal Scheduling of Energy Resources in KW for Scenario-2 (Total Operation Cost = 3968.6)

Time (h)	P_{PV1}	P_{PV2}	P_{WT}	P_{MT}	P_{FC}	P_{Diesel}	P_{Grid}	P_{Ch}	P_{Disch}	SoC	Demand	Load shed
1	0	0	369	300	300	600	0	83	0	130	1486	0
2	0	0	380	300	212	600	0	87	0	213	1405	0
3	0	0	238	210	0	600	0	0	0	300	1048	0
4	0	0	35	300	300	600	54	0	100	300	1389	0
5	0	0	22	300	300	600	0	18	0	200	1204	0
6	0	0	141	300	300	600	25	0	100	218	1466	0
7	0	12	398	300	239	600	0	100	0	118	1449	0
8	50	69	479	300	300	600	48	0	100	218	1946	0
9	75	86	147	300	300	600	0	100	0	118	1408	0
10	114	126	39	300	300	600	0	82	0	218	1397	0
11	138	138	184	300	300	600	0	0	0	300	1660	0
12	120	142	0	300	242	600	0	0	0	300	1404	0
13	131	160	0	300	175	600	0	0	0	300	1366	0
14	165	160	114	300	300	600	0	0	0	300	1639	0
15	151	136	0	300	191	600	0	0	0	300	1378	0
16	102	107	26	300	300	600	39	0	100	300	1574	0
17	66	101	115	300	300	600	300	0	100	200	1994	112
18	34	41	392	300	300	600	68	0	70	100	1805	0
19	0	1	697	300	300	600	6	0	0	30	1904	0
20	0	0	691	300	300	600	300	0	0	30	2334	143
21	0	0	720	300	300	600	152	0	0	30	2072	0
22	0	0	804	300	300	600	300	0	0	30	2443	139
23	0	0	773	300	300	600	300	0	0	30	2413	140
24	0	0	704	300	247	600	0	100	0	30	1751	0



(a) Scenario – 1 (b) Scenario - 2

Figure 2: Battery Exchange Power Values from Tables 4 and 5.

Table 6: Available Energy of each Generator within 24 Hours and Their Consumption in Percentage

Source	Available within 24	Energy Hours (KW)	Total Energy within 24	Consumed Hours (KW)	Energy	Consumption (%)
	Scenario-1	Scenario-2	Scenario-1	Scenario-2	Scenario-1	Scenario-2
P_{PV1}	1107	1146	1107	1146	100%	100%
P_{PV2}	1336	1279	1336	1279	100%	100%
P_{Diesel}	14400	14400	14400	14400	100%	100%
P_{MT}	7200	7200	7200	7110	100%	98.75%
P_{FC}	7200	7200	6153	6406	85.45%	88.97%
P_{WT}	9605	9550	8577	7468	89.29%	78.19%
P_{Grid}	7200	7200	1446	1592	20.08%	22.11%

Table 7: Optimal Scheduling of Energy Resources in KW Considering the Cost of PV1, PV2 and WT Power Generation as 0.0307 Euros/kwh over 24 Hours for Scenario-1 (Total Operation Cost = 3520.7 Euros)

Time (h)	P_{PV1}	P_{PV2}	P_{WT}	P_{MT}	P_{FC}	P_{Diesel}	P_{Grid}	P_{Ch}	P_{Disch}	SoC	Demand	Load shed
1	0	0	485	300	300	600	0	0	36	130	1721	0
2	0	0	464	300	88	600	0	100	0	94	1352	0
3	0	0	262	300	300	600	0	0	41	194	1503	0
4	0	0	46	300	199	600	0	100	0	153	1045	0
5	0	0	21	300	300	600	142	0	100	253	1463	0
6	0	0	178	300	300	600	81	0	100	153	1559	0
7	0	17	377	300	255	600	0	100	0	53	1449	0
8	39	77	564	167	0	600	0	100	0	153	1347	0
9	67	84	453	300	300	600	0	0	68	253	1872	0
10	103	146	544	39	0	600	0	100	0	185	1332	0
11	124	163	493	300	176	600	0	15	0	285	1841	0
12	144	157	318	300	232	600	0	0	0	300	1751	0
13	162	150	407	300	164	600	0	0	0	300	1783	0
14	120	134	208	300	277	600	0	0	0	300	1639	0
15	121	147	88	300	204	600	0	0	0	300	1460	0
16	96	120	25	300	300	600	230	0	100	300	1771	0
17	93	88	160	300	284	600	0	100	0	200	1425	0
18	38	52	328	300	300	600	10	0	100	300	1728	0
19	0	1	697	300	300	600	83	0	100	200	2081	0
20	0	0	574	300	300	600	300	0	70	100	2358	214
21	0	0	664	300	300	600	300	0	0	30	2430	266
22	0	0	870	300	300	600	300	0	0	30	2560	190
23	0	0	661	300	300	600	0	78	0	30	1783	0
24	0	0	718	300	40	600	0	100	0	108	1558	0

Table 8: Optimal Scheduling of Energy Resources in KW Considering the Cost of PV1, PV2 and WT Power Generation as 0.0307 Euros/kwh over 24 Hours for Scenario-2 (Total Operation Cost = 3490.6 Euros)

Time (h)	P_{PV1}	P_{PV2}	P_{WT}	P_{MT}	P_{FC}	P_{Diesel}	P_{Grid}	P_{Ch}	P_{Disch}	SoC	Demand	Load shed
1	0	0	369	300	300	600	0	83	0	130	1486	0
2	0	0	380	300	212	600	0	87	0	213	1405	0
3	0	0	238	210	0	600	0	0	0	300	1048	0
4	0	0	35	300	300	600	54	0	100	300	1389	0
5	0	0	22	300	300	600	0	18	0	200	1204	0
6	0	0	141	300	300	600	25	0	100	218	1466	0
7	0	12	398	300	239	600	0	100	0	118	1449	0
8	50	69	479	300	300	600	48	0	100	218	1946	0
9	75	86	433	300	14	600	0	100	0	118	1408	0
10	114	126	580	59	0	600	0	82	0	218	1397	0
11	138	138	579	205	0	600	0	0	0	300	1660	0
12	120	142	351	191	0	600	0	0	0	300	1404	0
13	131	160	325	300	0	450	0	0	0	300	1366	0
14	165	160	229	300	185	600	0	0	0	300	1639	0
15	151	136	69	300	122	600	0	0	0	300	1378	0
16	102	107	26	300	300	600	39	0	100	300	1574	0
17	66	101	115	300	300	600	300	0	100	200	1994	112
18	34	41	392	300	300	600	68	0	70	100	1805	0
19	0	1	697	300	300	600	6	0	0	30	1904	0
20	0	0	691	300	300	600	300	0	0	30	2334	143
21	0	0	720	300	300	600	152	0	0	30	2072	0
22	0	0	804	300	300	600	300	0	0	30	2443	139
23	0	0	773	300	300	600	300	0	0	30	2413	140
24	0	0	704	300	247	600	0	100	0	30	1751	0

Table 9: Available Energy of each Generator within 24 Hours and Their Consumption in Percentage Considering the Generation Cost of PV1, PV2 and WT as 0.0307 Euros

Source	Available within 24	Energy Hours (KW)	Total Energy within 24	Consumed Hours (KW)	Energy	Consumption (%)
	Scenario-1	Scenario-2	Scenario-1	Scenario-2	Scenario-1	Scenario-2
P_{PV1}	1107	1146	1107	1146	100%	100%
P_{PV2}	1336	1279	1336	1279	100%	100%
P_{WT}	9605	9550	9605	9550	100%	100%
P_{Diesel}	14400	14400	14400	14400	100%	100%
P_{MT}	7200	7200	6806	6665	94.52%	92.56%
P_{FC}	7200	7200	5519	4919	76.65%	68.31%
P_{Grid}	7200	7200	1446	1592	20.08%	22.11%

$$V_p(i+1) = \omega * V_p(i) + C_1 * rand_1 * (Pbest_p(i) - X_p(i)) + C_2 * rand_2 * (Gbest(i) - X_p(i)) \quad (17)$$

$$X_p(i+1) = X_p(i) + V_p(i+1) \quad (18)$$

Where $X_p(i)$ and $V_p(i)$ is the point and velocity of the particle ‘p’ at iteration ‘i’. ω is the weight control factor. $Pbest_p(i)$ is the optimal point of a particle ‘p’ at iteration ‘i’ and Gbest(i) is the optimal point of the crowd until iteration ‘i’.

Weight controlling factor is

$$\omega = ((\omega_{ma}*(iter_{max}-iter))+(\omega_{min}*iter))/iter_{max} \quad (19)$$

IMPLEMENTATION OF ENERGY MANAGEMENT (EM) ALGORITHM

The algorithm applied to the microgrid using AWCPSO technique is in the subsequent steps:

Step 1: Defining input data which is needed to start the process.

Step 2: If $\sum_{m=1}^{M} L_m(t) < \sum_{i=1}^{I} P_{Ri}(t) + \sum_{j=1}^{J} P_{Cj,max}(t)$, apply AWCPSO technique for the available resources and arrange the sources as follows, supply electrical load and provide charging to a battery.

- Randomly produce the primary population and their primary velocities by way of satisfying respective constraints.
- Acquire arbitrary generations and verify balance equation.
- Calculate objective function then find the each particle fitness. Obtain Pbest , Gbest.
- Select the iterth iteration.
- Calculate the weight controlling factor as from equation (19).
- Update velocity and obtain the next location of particle. Calculate the fitness.
- If current best Pbest of resultant value is better than earlier, fix it. In the same way, evaluate Gbest also.
- Do step 6 and step 7 for every particle in the swarm.
- Verify convergence criteria. Increase the value of iteration and move to step 5 until the maximum iteration value is reached.
- Print the global best value.

Step 3: If $\sum_{i=1}^{I} P_{Ri}(t) + \sum_{j=1}^{J} P_{Cj,max}(t) < \sum_{m=1}^{M} L_m(t) < \sum_{i=1}^{I} P_{Ri}(t) + \sum_{j=1}^{J} P_{Cj,max}(t) + \sum_{n=1}^{N} P_{SDn,max}$, discharge the battery and then supply load.

Step 4: If $\sum_{i=1}^{I} P_{Ri}(t) + \sum_{j=1}^{J} P_{Cj,max}(t) + \sum_{n=1}^{N} P_{SDn,max} < \sum_{m=1}^{M} L_m(t) < \sum_{i=1}^{I} P_{Ri}(t) + \sum_{j=1}^{J} P_{Cj,max}(t) + \sum_{n=1}^{N} P_{SDn,max} + P_{grid,max}$, discharge battery and take power from main grid to supply the entire load.

Step 5: If $\sum_{m=1}^{M} L_m(t) > \sum_{i=1}^{I} P_{Ri}(t) + \sum_{j=1}^{J} P_{Cj,max}(t) + \sum_{n=1}^{N} P_{SDn,max} + P_{grid,max}$, discharge battery, take maximum power from grid, apply load discarding and supply the remaining load.

RESULT ANALYSIS

Microgrid which is linked to a main grid with one wind energy generator, two PV panels, single diesel generator, single fuel cell, single micro-turbine generator and a battery is allowed for examining the output to the problem. The quadratic function is employed for diesel generator to evaluate the price with cost parameters α = 0.0000073, β = 0.066, γ = 0.00454. The boundary limits for generation capacity of sources are in the table 1. To point out uncertainty involved in PV panels and wind turbine generator, the available generation capacity and the electrical load for each hour on microgrid [20] are expressed in two scenarios tabulated in table 2 and represented graphically in figure 1(a), 1(b). Bid rate of wind turbine micro-turbine, PV panels and fuel cell [26] are tabulated in table 3.

Table 10: Comparison of results of AMPSO and AFS Algorithms for Scenario-1

Energy Consumed by each Generator in Percentage (%)								
Optimization Algorithm	P_{PV1}	P_{PV2}	P_{WT}	P_{Diesel}	P_{MT}	P_{FC}	P_{Grid}	**Total Operation Cost (Euros)**
AFS [20]	100	100	100	93.97	88.75	88.91	20.08	3540.0
AWCPSO	100	100	100	100	94.52	76.65	20.08	3520.7

Table 11: Comparison of Results of AMPSO and AFS Algorithms for Scenario-2

Energy Consumed by each Generator in Percentage (%)								
Optimization Algorithm	P_{PV1}	P_{PV2}	P_{WT}	P_{Diesel}	P_{MT}	P_{FC}	P_{Grid}	**Total Operation Cost (Euros)**
AFS [20]	100	100	100	97.02	93.11	71.65	22.11	3514.04
AWCPSO	100	100	100	98.95	92.56	68.31	22.11	3490.60

The generation capacity of microgrid is the sum of available generation from renewable and conventional generators and the discharging power from storage unit. The extra load which is unable to supply by microgrid is discarded. The scheduled problem is solved by aimed energy management method for both scenarios. The outputs obtained from two scenarios are tabulated in tables 4, 5. The output tabulated in tables 4, 5 proves that the planned algorithm is successful in holding a power balance between generation and load at every time interval considered. From tables 4, 5 make known that the aimed algorithm is intelligent to allocate the maximum portion of generation to the low-priced power generator. The aimed method is successful in using the low-priced generator to the greatest level and high cost generator very scarcely as noticed from a result which is primary objective in optimization.

The total available energy of each generator and the quantity of energy that is consumed over 24 hrs is illustrated in table 6. The low-priced sources, PV1, PV2 panels and diesel generator make use of 100% of available capacity in both scenarios. The high-priced source, grid power used very scarcely to the level of 20.08% and 22.11% of available capacity in two scenarios correspondingly. The consumption percentage of the remaining sources is inversely proportional to their price of generation. Consumption percentages in table 6 show the aimed EM algorithm performance in minimizing the cost of generation.

Tables 7 and 8 tabulate the optimal scheduling of energy resources considering the generation cost of PV1, PV2 and WT as 0.0307 Euros. Table 9 shows the consumption percentage of PV1, PV2 and wind generators is 100% which are low-priced sources. It indicates that the planned algorithm is successful in minimizing the overall generation cost.

Figures 2(a) and 2(b) shows the power exchange between microgrid and the battery in two scenarios. Table 10 shows the comparison of results obtained from AWCPSO and AFS algorithms for scenario-1 and table 11 for scenario-2. It shows that the overall generation cost by AWCPSO algorithm is less than the generation cost by using AFS algorithm [20].

CONCLUSIONS

Energy management method is planned using AWCPSO technique to work out the scheduling problem in a micro-grid allowing renewable, conventional energy generators, storage units and load discarding over 24 hours with a goal to minimize the generation cost. The proposed method is applied to plan the sources, storage and load discarding. Two PV panels, one wind turbine, one micro-turbine, one fuel cell and a diesel generator are utilized as sources and a storage unit for backup. Due to the uncertainty of RES, two scenarios are considered to approximate the available generation capacity from renewable resources and load. Results obtained from the proposed method shows that the algorithm is successfully scheduling sources, battery exchange power and power from main grid. Load discarding is done to balance the load with available generation if required due to the implementation of DSEM. The proposed algorithm is efficient as it uses the cheapest power sources to the maximum level and costliest power sources very scarcely. The high-priced grid power is utilized only when the remaining sources and power discharge from battery is exhausted. The percentage of utilization of power from the sources in the algorithm is inversely propotional to their generation cost. The generation cost for scenario-1 / scenario-2 using AWCPSO technique is 3520.7 / 3490.6 Euros which is less than the generation cost calculated from AFS technique [20] is 3540 /3514.04 Euros.

REFERENCES

1. *Basu Ashoke Kumar, S.P. Chowdhury, S. Chowdhury, S. Paul, Microgrids: energy management by strategic deployment of DERs-A comprehensive review, Renew Sustain Energy Rev 15 (2011) 4348–4356.*
2. *Ayres RU, Turton H, Casten T. Energy efficiency, sustainability and economic growth. Energy 2007;32(5):634e48.*
3. *K. Prakash Kumar, B. Saravanan, Recent techniques to model uncertainty in power generation from renewable energy sources in microgrids, J. Renew Sustain. Energy Rev 71 (May) (2017) 348–358.*
4. *Degeilh Yannick, Gross George, Stochastic simulation of power systems with integrated intermittent renewable resources, Electr. Power Energy Syst. 64 (2015) 542–550.*
5. *A.D. Hawkes, M.A. Leach, Modelling high level system design and unit commitment for a microgrid, Appl. Energy 86 (2009) 1253–1265.*
6. *P.K. Naraharisetti, I.A. Karimi, A. Anand, D. Lee, A linear diversity constraint–application to scheduling in microgrids, Energy 36 (2011) 4235–4243.*
7. *H. Ren, W. Gao, A MILP model for integrated plan and evaluation of distributed energy systems, Appl. Energy 87 (2010) 1001–1014.*
8. *J. Silvente, G.M. Kopanos, E.N. Pistikopoulos, A. Espuna, A rolling horizon optimization framework for the simultaneous energy supply and demand planning in microgrids, Appl. Energy 155 (2015) 485–501.*
9. *H.M. Khodr, N. El Halabi, M. Garcia-Gracia, Intelligent renewable microgrid scheduling controlled by a virtual power producer: a laboratory experience, Renew. Energy 48 (2012) 269–275.*
10. *S. Talari, M. Yazdaninejad, M. Haghifam, Stochastic-based scheduling of the microgrid operation including wind turbines, photovoltaic cells, energystorages and responsive loads, IET Gener. Transm. Distrib. 9 (2015) 1498–1509.*
11. *F. Najibi, T. Niknam, Stochastic scheduling of renewable micro-grids considering photovoltaic source uncertainties, Energy Convers. Manage. 98 (2015) 484–499.*
12. *R. Wang, P. Wang, G. Xiao, A robust optimization approach for energy generation scheduling in microgrids, Energy Convers. Manage. 106 (2015) 597–607.*
13. *M. Van der Kam, W. van Sark, Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a microgrid; a case study, Appl. Energy 152 (2015) 20–30.*

14. *Z. Zhang, J. Wang, X. Wang, An improved charging/discharging strategy of lithium batteries considering depreciation cost in day-ahead microgrid scheduling, Energy Convers. Manage. 105 (2015) 675–684.*

15. *R. Mallol-Poyato, S. Salcedo-Sanz, S. Jimenez-Fernandez, P. Diaz-Villar, Optimal discharge scheduling of energy storage systems in MicroGrids based on hyperheuristics, Renew. Energy 83 (2015) 13–24.*

16. *A. Zakariazadeh, S. Jadid, P. Siano, Smart microgrid energy and reserve scheduling with demand response using stochastic optimization, Int. J. Electr. Power Energy Syst. 63 (2014) 523–533.*

17. *L. Montuori, M. Alcazar-Ortega, C. Alvarez-Bel, A. Domijan, Integration of renewable energy in microgrids coordinated with demand response resources: economic evaluation of a biomass gasification plant by Homer Simulator, Appl. Energy 132 (2014) 15–22.*

18. *M. Mazidi, A. Zakariazadeh, S. Jadid, P. Siano, Integrated scheduling of renewable generation and demand response programs in a microgrid, Energy Convers. Manage. 86 (2014) 1118–1127.*

19. *Motevasel Mehdi, Seifi Ali Reza, Expert energy management of a microgrid considering wind energy uncertainty, Energy Convers. Manage. 83 (2014) 58–72.*

20. *Thillainathan Logenthiran, Dipti Srinivasan, Tan Zong Shun, Demand side management in smartgrid using heuristic optimization, IEEE Trans. Smart Grid 3 (3) (2012).*

21. *Gabriella Ferruzzi, Guido Cervone, Luca Delle Monache, Giorgio Graditi, Francesca Jacobone, Optimal bidding in a Day-Ahead energy market for Micro Grid under uncertainty in renewable energy production, Energy 106 (2016) 194–202.*

22. *Marialaura Di Somma, Giorgio Graditi, Pierluigi Siano, Optimal Bidding Strategy for a DER aggregator in the Day-Ahead Market in the presence of demand flexibility, IEEE Trans. Ind. Electron. (2018) April-2018.*

23. *Rania Hassan, Babak Cohanim, Olivier de Weck, A comparison of particle swarm optimization and the genetic algorihm, 46th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, April 18-21 (2005).*

24. *Kennedy J, Eberhart R. Particle Swarm Optimization. In: IEEE international conf. on neural networks. Piscataway, NJ, vol. 4; 1995. P. 1942-1948.*

25. *K. Prakash Kumar, B. Saravanan, Day ahead scheduling of generation and storage in a microgrid considering demand Side management, Journal of Energy Storage 21 (2019) 78–86*

Nomenclature

- $P_{Ri}(t)$ - Power generated from i^{th} renewable generator at t^{th} time interval
- $P_{Cj}(t)$ - Power generated from j^{th} conventional generator at t^{th} time interval
- $P_{Ri,min}$, $P_{Ri,max}$ - Min and max available capacity from i^{th} renewable generator
- $P_{Cj,min}$, $P_{Cj,max}$ - Min and max available capacity from j^{th} conventional generator
- $P_{SCn}(t)$, $P_{SDn}(t)$ - Quantity of power charged and discharged from n^{th} storage unit at t^{th} time interval

- $P_{SCn,max}(t)$, $P_{SDn,max}(t)$ Maximum charge and discharge rates of storage units
- $SoC_n(t)$ - State of charge of n^{th} storage unit at t^{th} time interval
- $SoC_{n,min}$, $SoC_{n,max}$ - Mininum and maximum boundary points of state of charge of n^{th} storage unit
- η_n - Charging or discharging efficiency of n^{th} storage unit
- $L_m(t)$ - m^{th} load at t^{th} time interval
- $L_{LDm}(t)$ - Discarded m^{th} load at t^{th} time interval
- $P_{grid}(t)$ - Power drawn from grid at t^{th} time interval
- $X_{Ri}(t)$, $X_{Cj}(t)$ - State vectors indicating ON or OFF condition of i^{th} renewable and j^{th} conventional generator at t^{th} time interval
- $Y_{Ri}(t)$, $Y_{Cj}(t)$ - State vectors indicating start up condition of i^{th} renewable and j^{th} conventional generator at t^{th} time interval
- $Z_{Ri}(t)$, $Z_{Cj}(t)$ - State vectors indicating shut down condition of i^{th} renewable and j^{th} conventional generator at t^{th} time interval
- SU_{Ri}, SU_{Cj} - Start up cost of i^{th} renewable and j^{th} conventional generator
- SD_{Ri}, SD_{Cj} - Shut down cost of i^{th} renewable and j^{th} conventional generator
- α , β, γ - Quadratic function cost parameters of diesel generator
- $C_{Ri}(t)$ - Bid rate of i^{th} renewable generator at t^{th} time interval
- $OM_{Ri}(t)$ - Operation and maintenance cost of i^{th} renewable generator at t^{th} time interval
- $U_{Sn}(t)$ - State vector indicating the nature of exchanging power of of n^{th} storage unit at t^{th} time interval
- $C_{Sn}(t)$ - Cost / kwh of power supplied by n^{th} storage unit at t^{th} time interval
- $C_{LDm}(t)$ - Compensation / kwh payable to m^{th} load at t^{th} time interval
- $C_{grid}(t)$ - Cost /kwh of power taken from grid
- $V_{LDm}(t)$ - State vector indicating the discarded condition of m^{th} load at t^{th} time interval