Optimal Dispatch for Microgrid with Demand Response using PSO

Ch. Leela Sowjanya, P.kantarao

Abstract: ***In this paper, we perform economic load dispatch for microgrid. The Microgrid consists of three conventional generators and a solar power source and a wind power source and three rural consumers. Along with the economic load dispatch we have performed demand response for the given microgrid. we have used incentive based demand response for the microgrid. The objective function is to minimize the conventional diesel generators fuel cost, minimize the transaction cost of transferable power between microgrid and power grid and to increase the benefit of utility. The Optimization strategy used in this paper is particle swarm optimization (PSO) in which the problem moves to best by eliminating all the worst solutions. Results show that consumers curtail certain amount of power and relieving that power from the microgrid will bring optimality at both supply and demand side and optimal power for the three conventional generators and transferable power so that the optimal cost is obtained.***

INDEXWORDS: Demand response, Economic load dispatch, Microgrid, particle swarm optimization(PSO).

I. INTRODUCTION

Economic load dispatch and demand response are key factors for energy management in power system grid. Economic load dispatch is to optimally schedule the generators to meet the load. Demand response is the variation in electric usage by consumer at the load side from their normal patterns in response to variations in the price of electricity over time or on incentive payments given to consumers to reduce cost. There are many ways to obtain this, the most common process is to shift the controllable loads from peak hours to off peak hours of low cost. The main aim of economic load dispatch and demand response to reduce the electricity cost by meeting the load demand.

All over the world, due to the economic and reliability factors it is difficult to extend the power grid to remote areas. So because of this reasons, the remote area people use independent diesel generators and firewood for daily energy needs[1]. Due to the high cost and environmental issues the power supply to the remote areas are limited but the remote areas have high potential of nonconventional energy resources which can be easily dispatchable to the community over there.

Microgrid, as one of the most important forms of distributed generation, not only can be operated in parallel with large power grid, but also provide power for local load independently called as islanded mode of operation. The power generators of the microgrid can be either conventional or non-conventional energy source generators. Microgrid also have storage devices and controllable loads located nearer to the consumers.

Regarding the credibility of microgrids, there are lot of works on design, control and operation of microgrid [2,3]. Microgrid can improve the reliability of large power grid [4,5],can have direct economic benefits because of solar wind and other renewable energy sources.

Ref. [6] established a model of the power output of wind energy and impact on reliability on power system is analyzed. The output model of solar PV is discussed in [7,8]. The appropriate control plan for hybrid microgrid with solar power source and diesel power and battery storage was suggested [9]. The model predictive control and switched model predictive control are incorporated in microgrid in [10,11]. However, the above mentioned papers does not include demand response.

Few demand response incorporated works are discussed below. Peak load management in various industries like steel plants and electrolytic industry with time of use tariffs are analyzed in [12,13]. Demand response of hydrokinetic system using TOU tariff is analyzed in [14]. In [15] an optimal economic dispatch with incentive based demand response for grid connected microgrid.

In this paper is proposed to obtain better results of the work done in [15]. In this paper we used optimized technique called Particle Swarm optimization (PSO). PSO based DR for domestic consumers are analyzed in [16]. Furthermore, we also included penalty factors in our program.

The remaining paper is categorized as follows, Section II presents mathematical model of both microgrid and demand response. Section III provides proposed optimization technique. Section IV presents the methodology. Section V presents the Results. Conclusion and future work is included in section VI of the paper.

II. MATHEMATICAL MODELLING

A. Microgrid:

The Objective function is to minimize the fuel cost of conventional generators and

Revised Manuscript Received on June 01, 2019.

Ch.leela sowjanya, Department of Electrical & Electronics Engineering, SRKR Engineering college, Andhra Pradesh, India, sowjanyachennam@gmail.com.
P.Kantarao, Department of Electrical & Electronics Engineering, SRKR Engineering college, Andhra Pradesh, India,dr.p.kantarao@gmail.com

transaction costs of transferable power and is given by:

$\min \sum_{t=1}^{T}\sum_{n=1}^{q} C_n(P_{n,t}) + \sum_{t=1}^{T} C_r(Tp_t)$ (1)

subject to

$\sum_{t=1}^{T} P_{n,t} + Tp_t + Wp_t + Sp_t = Pd_t - \sum_{i=1}^{N} Cp_{i,t}$ (2)

$P_{i,min} \le P_{i,t} \le P_{i,max}$ (3)

$0 \le Wp_t \le Fwp_t$ (4)

$0 \le Sp_t \le Fsp_t$ (5)

$-Tp_{max} \le Tp_t \le Tp_{max}$ (6)

$-RD_n \le P_{n,t+1} - P_{n,t} \le RU_n$ (7)

Where

1. $P_{n,t}$ is the power generated in MW by 'n'th conventional generator during time interval 't'.

2. $C_n(P_{n,t})$ is the fuel cost in \$ of 'n'th conventional generator while producing P_n power during time interval 't'.

Where $C_n(P_{n,t}) = a_n P_{n,t}^2 + b_n P_{n,t}$ (8)

3. Tp_t is the power transferred in MW between the microgrid and main grid during the time interval 't'.

4. $C_r(Tp_t)$ is the transaction cost in \$ for transferring power Tp_t during the time interval 't'.

Where $C_r(Tp_t) = \alpha_t * Tp_t \quad Tp_t > 0$

$= 0 \quad Tp_t = 0$ (9)

$= \alpha_t * Tp_t \quad Tp_t < 0$

α_t – locational marginal prices [17]

5. q- number of conventional generators.

6. Wp_t is the wind power generated in MW during time interval 't'.

7. Sp_t is the solar power generated in MW during time interval 't'.

8. Fwp_t is the forecasted wind power from the wind generator.

$Fwp_t = 0.5 * \eta_w * \rho_{air} * C_p * V_{hub}^3 * A$ (10)

Where η_w- efficiency of wind generator.

ρ_{air}-air density

C_p-wind turbine power coefficient

V_{hub}-wind velocity at hub height.

A-rotor swept area of wind turbine.

9. Fsp_t is the forecasted solar power from the PV array.

$$Fsp_t = \eta_{pv} * A_{pv} * Ipv_t \quad (11)$$

Where η_{pv}-efficiency of solar PV generator/array.

A_{pv}-PV array area in (m^2).

Ipv_t-hourly incident solar irradiation on the PV array in (hr/m^2).

10. $P_{n,min}$ and $P_{n,max}$ are the minimum and maximum capacity of conventional generator 'n'.

11. TP_{max} is the maximum transferred power between microgrid and main grid.

12. RD_n and RU_n are the ramp down and ramp up rates of 'n'th conventional generator .

13 N- number of consumers connected to the microgrid who participate in demand response.

Constraint (2) is the electric power balance equation and make sure that total power generated and power curtailed is equal to the consumer demand.

Remaining constraints (3),(4),(5),(6),(7) represents the maximum and minimum limits which should not be violated.

B. Demand response model:

The objective function is to maximize the utility benefit function and is given by:

$\max_{cp,ic} \sum_{t=1}^{T}\sum_{i=1}^{N}[\gamma_{i,t} Cp_{i,t} - Ic_{i,t}]$ (12)

Subject to:

$\sum_{t=1}^{T}[Ic_{i,t} - (K_{1,i} Cp_{i,t}^2 + K_{2,i} Cp_{i,t} - K_{2,i} Cp_{i,t} \theta_i)] \ge 0$ for i=1,2,…..,N (13)

$\sum_{t=1}^{T}\sum_{i=1}^{N} Ic_{i,t} \le UB$ (14)

$\sum_{t=1}^{T}\sum_{i=1}^{N} Cp_{i,t} \le CM_i$ (15)

Where

1. γ is the cost of not supplying power to a location on grid in \$.

2. $Cp_{i,t}$ is the power curtailed by the customer 'i' at time 't' in MW.

3. $Ic_{i,t}$ is the incentive given to the customer 'i' at time 't' in \$.

4. K_1 and K_2 are the cost coefficients.

5. θ is the type of customer who is willing to participate in demand response and its value varies between 0 and 1.

6. UB is the total budget of utility which is \$500.

7. CM_i is the limit of interruptible power for customer, I. in MW.

C. Combination of microgrid and demand response model:

Now the objective function became multi objective function. First one is to minimize the diesel generator's cost of fuel and cost of transaction power. Second one is to maximize the utility benefit. In the multi objective function, the weightage of the function depends on its importance. The total objective function is given by

$\min wt\,[\sum_{t=1}^{T}\sum_{n=1}^{q} C_n(P_{n,t}) + \sum_{t=1}^{T} C_r(Tp_t) +$

$(1-wt)[\sum_{t=1}^{T}\sum_{i=1}^{N}(\gamma_{i,t} Cp_{i,t} - Ic_{i,t})$ (16)

Subject to all the above constraints from equation (2-7) and (13-15).

Where wt are the weights.

The value of weights vary from 0 to 1 depending on our importance and application of the particular objective function.

III. OPTIMIZATION ALGORITHM

Particle swarm optimization is the optimization technique that progress a problem by iteratively trying to make the solution better corresponding to available measure of quality. In this algorithm, the particles are spread in the search space, over the particle's position and velocity updated subsequently to reach towards the best solution.

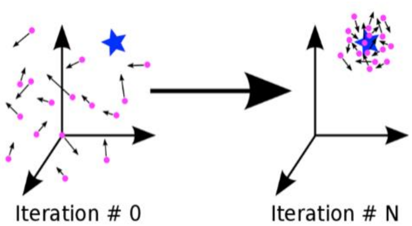

Fig.1-particles reaching global best.

Methodology:

In this paper, we performed economic load dispatch for microgrid which consists of three conventional diesel generators, solar, wind and three rural consumers. Along with this we performed demand response based on incentives and the incentives are based on penalties. The optimization strategy used in this paper is particle swarm optimization. We computed the program for ten times and among them three results are considered which are best, better and moderate. PSO is computed with population of 20,000 and with 1000 iterations. The utilities daily budget is $ 500. [15]

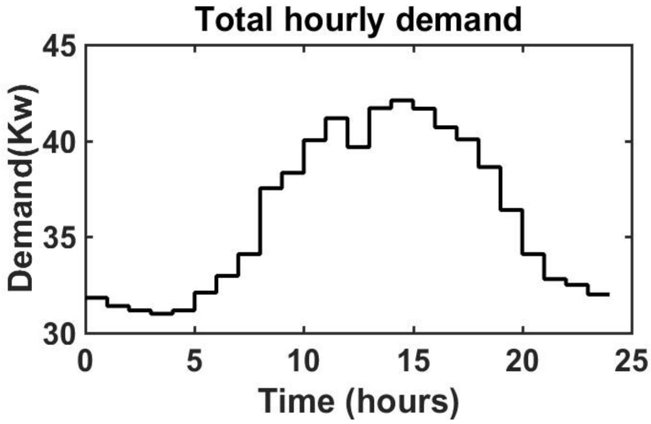

Fig.2-Total hourly demand of the consumer.

IV. RESULTS

The below results show the optimal power from wind and solar generators which are common for three results.

Table.1: Optimal power from wind and solar generators

Time(hr)	Wp_t	Sp_t
1	7.56	0
2	7.50	0
3	8.25	0
4	8.48	0
5	8.48	0
6	9.42	0
7	9.82	0
8	10.35	7.99
9	10.88	10.56
10	11.01	13.61
11	10.94	14.97
12	10.68	15
13	10.42	14.78
14	10.15	14.59
15	9.67	13.56
16	8.98	11.83
17	8.37	10.17
18	7.61	7.66
19	6.70	0
20	5.72	0
21	7.21	0
22	7.75	0
23	7.88	0
24	7.69	0

Table.2: Case 1

Table.2a: Optimal power from conventional generators and power transfer.

Time (hr)	$P_{n,t}$(KW)			Tp_t
	n=1	n=2	n=3	
1	1	6	7.3052	3.9996
2	3.9984	1	8.389	0.3204
3	1.0002	5.9957	7.92	4
4	2.1976	5.927	6.3911	3.9997
5	1.2703	6	7.3123	4
6	3.8788	6	3.4585	4
7	4	6	8.7584	0.8302
8	4	6	9	-3.2977
9	4	6	8.1901	-3.0101
10	1.1458	5.9633	8.144	-4
11	4	6	7.1731	-3.39
12	3.0029	6	8.8436	-2.3865
13	4	5.7155	8.1342	-4
14	3.7603	6	8.8702	-3,1758
15	4	6	8.1882	-3.056
16	4	6	4.7163	4
17	3.7465	6	8.0969	0.3166
18	4	5.3417	9	-1.5338
19	4	5.9913	7.183	4
20	4	6	7.9821	0.8255
21	3.997	5.9978	8.4774	0.4209
22	4	6	7.0454	3.9963
23	4	5.9828	5.2355	4
24	3.9985	5.9171	8.7669	1.6312

Table.2b: Optimal power curtailed

Time(hr)	$Cp_{i,t}$		
	i=1	i=2	i=3
1	0	1.9652	4
2	2.1922	4	4
3	0	0.0041	4
4	0.0046	4	0
5	0	0.1078	3.9996
6	3.5089	1.8338	0
7	3.541	0	0.0204
8	0.0577	0	0
9	0.8561	0	0.0539
10	0.0016	2.4553	0
11	0	0.2791	0.0578
12	0	0.009	0.0210
13	0	0.6203	0
14	1.5053	0	0
15	0	0.0061	3.7321
16	2.1437	0	0
17	0	4	0
18	4	0	3.9921
19	3.3491	3.7814	3.6252
20	4	3.9542	3.9182
21	0	4	3.9969
22	0.0083	0	4
23	0.8352	3.9837	0.5828
24	3.9963	0	0

Table.2c: Optimal incentive received by consumer

Time(hr)	$Ic_{i,t}$		
	i =1	i =2	i =3
1	0	5.8956	12
2	6.5766	12	12
3	0	0.0123	12
4	0.0138	12	0
5	0	0.3234	11.9988
6	10.5267	5.5014	0
7	10.623	0	0.0612
8	0.1731	0	0
9	2.5683	0	0.1617
10	0.0048	7.3659	0
11	0	1.1164	0.2312
12	0	0/036	0.084
13	0	2.4812	0
14	6.0212	0	0
15	0	0.0244	14.9284
16	8.5748	0	0
17	0	16	0
18	16	0	15.9684
19	13.3964	15.1256	14.5008
20	16	15.8168	15.6728
21	0	16	15.9876
22	0.0249	0	12
23	2.5056	11.9511	1.7484
24	11.9889	0	0

Table 3: Case 2

Table.3a: Optimal power from conventional generators and power transfer.

Time (hr)	$P_{n,t}$(KW)			Tp_t
	n=1	n=2	n=3	
1	3.9907	6	6.8381	4
2	1.1721	6	8.7279	4
3	1.5873	6	3.2949	4
4	4	6	0.52	4
5	4	6	8.4379	4
6	4	6	9	-3.8287
7	1.9225	6	7.228	4
8	4	5.3207	9	-2.5607
9	3.0416	6	7.6396	-4
10	3	5.9716	3.4272	-3.9858
11	3.9058	6	2.3924	-2.1782
12	4	6	8.49	-3
13	1	6	7.47	-4
14	3.026	6	8.934	-1
15	4	6	8.776	-3.999
16	4	6	9	-3.2875
17	3.289	6	9	-0.129
18	4	6	4.2469	4
19	4	6	7.1667	4
20	4	6	8.68	4
21	4	6	8.98	4
22	4	6	7.05	4
23	4	6	8.122	4
24	4	6	6.31	4

Table.3b: Optimal power curtailed

Time(hr)	$Cp_{i,t}$		
	i=1	i=2	i=3
1	0	0	3.4412
2	4	0	0
3	3.976	3.3187	0.7431
4	0	4	4
5	0	0.2521	0
6	4	0	3.5087
7	0	3.9995	0
8	0	0	0
9	1.058	1.126	1.2248
10	1.297	0	4
11	0	4	0
12	0	0	0
13	0	0	4
14	0	0	0
15	1.1903	0	2.9027
16	1.1623	3.8057	0.1795
17	0	0	4
18	2.5531	4	0
19	2.7633	4	4
20	4	4	0
21	0	0	4
22	0	0	4
23	0	2.498	0
24	4	0	0

Table.3c: Optimal incentive received by consumer

Time(hr)	$Ic_{i,t}$		
	i =1	i =2	i =3
1	0	0	10.3236
2	12	0	0
3	11.928	9.9561	2.2293
4	0	12	12
5	0	0.7563	0
6	12	0	10.5261
7	0	11.9985	0
8	0	0	0
9	3.174	3.378	3.6744
10	3.891	0	12
11	0	12	0
12	0	0	0
13	0	0	16
14	0	0	0
15	4.7612	0	11.6106
16	4.6492	15.2228	0.718
17	0	0	16
18	10.2124	16	0
19	11.0532	16	16
20	16	16	0
21	0	0	16
22	0	0	12
23	0	7.494	0
24	12	0	0

Table.4: Case 3

Table.4a:Optimal power from conventional generators and power transfer.

Time (hr)	$P_{n,t}$(KW)			Tp_t
	n=1	n=2	n=3	
1	4	5.9853	6.3551	4
2	4	6	5.9064	-0.0015
3	3.9979	6	4.9221	4
4	4	6	5.4714	4
5	1	6	7.69	4
6	2.4333	5.999	6.1324	0.07211
7	4	6	4.9116	4
8	4	4.73262	8.7486	-2.01
9	1.4532	5.92	4.7228	-0.006
10	3.5729	6	8.1371	-4
11	4	5.9986	8.1214	-4
12	3.7722	6	8.7178	-3
13	3.8618	6	7.2982	-4
14	3.593	6	8.8067	-2
15	2.8033	6	6.0667	4
16	3.5304	6	7.3296	4
17	4	6	8.3961	0.0666
18	3.8	6	9	-2
19	4	6	8.8755	1.0594
20	4	6	5.3943	4
21	4	6	8.623	0.267
22	2.392	6	5.7234	3.9982
23	4	6	5.0269	4
24	4	1	7.2316	4

Table.4b: Optimal power curtailed

Time(hr)	$Cp_{i,t}$		
	i=1	i=2	i=3
1	0	3.9296	0
2	3.9951	0	4
3	4	0	0
4	0.3629	2.6857	0
5	0	4	0
6	0.04319	4	4
7	4	0	0.2384
8	0.28878	0	0
9	0	0	4
10	0	0	0
11	0	0	0
12	0	0	0
13	1.31	0	0
14	0	0	0.5603
15	0	0	0
16	0	0	0
17	0	0	3.6973
18	0	4	4
19	4	3.9951	4
20	4	3.2957	3.99
21	0	4	4
22	4	2.9364	0
23	0	2.0691	3.524
24	4	0.0884	3.99

Table.4c: Optimal incentive received by consumer

Time(hr)	$Ic_{i,t}$		
	i =1	i =2	i =3
1	0	11.7888	0
2	11.9853	0	12
3	12	0	0
4	1.0887	8.0571	0
5	0	12	0
6	0.129	12	12
7	12	0	0.7152
8	0.86634	0	0
9	0	0	12
10	0	0	0
11	0	0	0
12	0	0	0
13	5.24	0	0
14	0	0	2.2412
15	0	0	0
16	0	0	0
17	0	0	14.7892
18	0	16	16
19	16	15.9804	16
20	16	13.1828	15.96
21	0	16	16
22	16	8.8092	0
23	0	6.2073	10.572
24	12	0.2652	15.96

Table 5 gives the comparison between all the above three cases and AIMMS method used in other paper to obtain the best result out of them. From the Table 5 it can be noted that case 3 is providing best compared to all others. Fig 3,4,5 represents the plots of Optimal power curtailed by three consumers in case 3. Fig 6,7,8 represents the Optimal incentives received by three consumers in case 3. Fig 9 gives the PSO fitness plot.

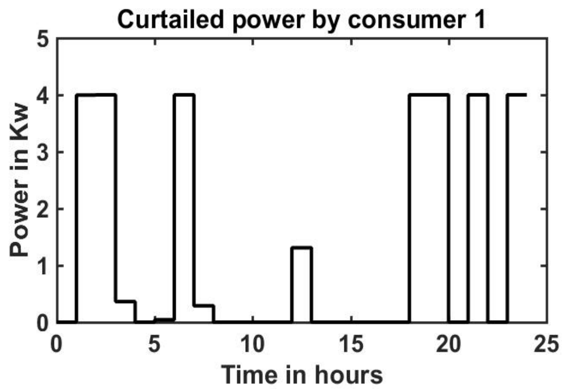

Fig.3- Power curtailed by consumer 1

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

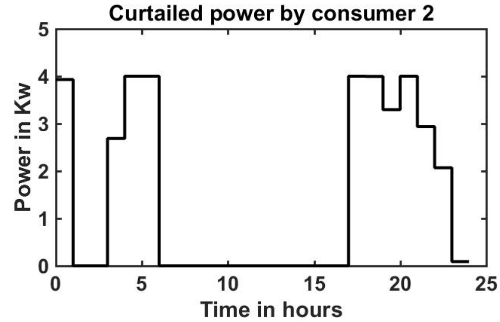

Fig.4- Power curtailed by consumer 2

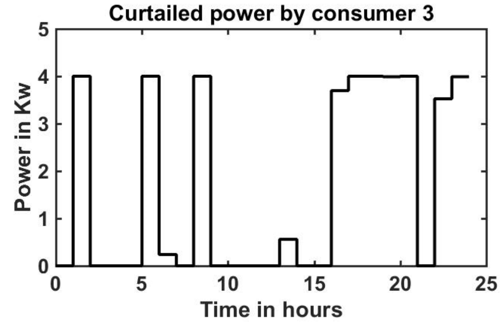

Fig.5- power curtailed by consumer 3

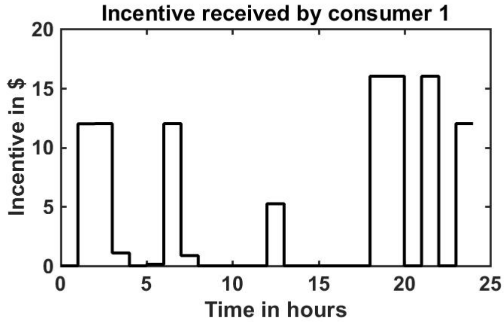

Fig.6-Incentive received by consumer 1

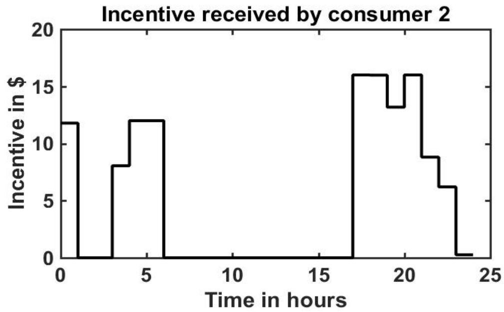

Fig.7- Incentive received by consumer 2

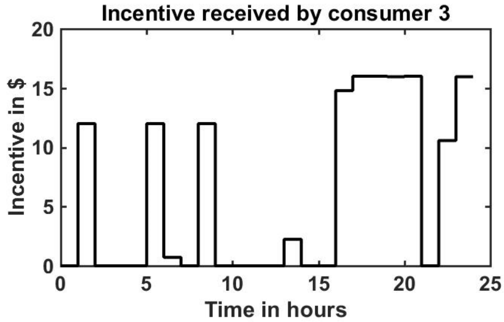

Fig.8- Incentive received by consumer 3

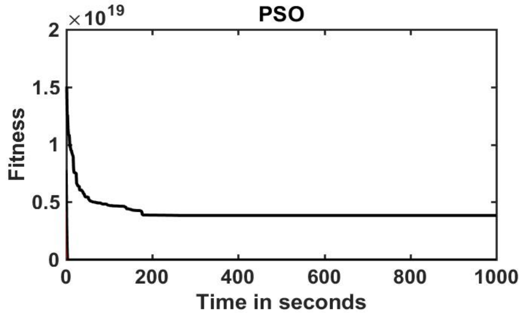

Fig.9- PSO fitness plot

Table.5. comparison of all the cases and AIMMS method.

	Case 1	Case 2	Case 3	AIMMS
Total curtailed energy by consumers (Kwh)	105	105	105	105
Total transferred energy (Kwh)	68.191	83.969	66.481	84.5
Total incentive received by consumer ($)	365.98	361.55	367.82	371
Total transferred power transaction cost ($)	340.955	424.04	335.72	427
Total conventional power cost($)	226.88	224.03	218.87	250

V. CONCLUSIONS

In this work, Economic load dispatch and demand response is performed on the microgrid by using Particle swarm optimization technique. The objective function is to minimize the conventional generator fuel cost, minimize the transaction cost of power transferred, and maximize the utility benefit. There was a significant amount of 105 kW of power curtailed by consumers with the incentive of 367.82$ with the value of weight as 0.5. The results show that case 3 obtained by PSO is giving better results compared to other results.

REFERENCES

1. FS Tidjani, A.Chandra, "Optimization of standalone Microgrid considering active damping technique and smart power management using Fuzzy logic supervisor" IEEE trans on smart grid DOI 10.1109/TSG.2016.2610971.
2. Paolo P, Lasseter RH, Microgrid: A conceptual solution in:proc,power electron, specialists conf., June. Vol 6; 2004,p,4285-90.
3. Lasseter RH, control and design of microgrid components, PSERC Final Project Reports.
4. Wang Chengshan, Xiao Zhaoxia,Wang Shouxiang. Synthetical contro and analysis of microgrid [J].Automtion of electric power systems,2008,32(7):98-103.
5. Lu Zongxiang, Wang Caixia, Min Yong, et al. Overview on Microgrid Research [J]. Automation of Electric Power systems ,2007,19: 100-107.
6. B.O Bilal, V Sambou, P A Ndiaye ,et al," Optimal design of a hybrid solar-wind battery system using the minimization of the annualized cost system and the minimization of loss of power supply probability (LPSP),"Renewable energy vol.35,n0.2,pp.2388-2390,oct.2010.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

7. N.Kumar, T.K.Saha, J.Dey, "Modelling, control and analysis of cascaded inverter based grid- connected photovoltaic system," International Journal of Electric power & Energy systems,Vol.78,pp.165-173,jun.2016.
8. H. Fathima, K.Palanisamy,"Optimized sizing, selection and economic analysis of battery energy storage for grid –connected wing-PV hybrid systems," Modelling & Simulation in Engineering, vol.2015,pp. 1-16,jan. 2015.
9. H.Tazvinga, X.Xia, J.Zhang, Minimum cost solution of photovoltaic diesel battery hybrid power systems for remote consumers,sol.Energy 96(2013) 292-299.
10. H.Tazvinga, B.Zhu, X.Xia, Energy dispatch strategy for a photovoltaic wind diesel battery hybrid power system,sol. Energy 108 (2014) 412-420.
11. B.Zhu, H.Tazvinga, X.Xia,Switched model predictive control for energy dispatching of a photovoltaic-diesel-battery hybrid power system,IEEE trans.Control syst.Technol.23 (2015) 1229-1236.
12. S.Ashok, "Peak load management in steel plants",2005 Elsevier doi:10.1016/j.apenergy.2005.05.002.
13. C.A.Babu and S.Ashok, "Peak load management in electrolytic process industries",IEEE trans. on power systems,vol 23,NO. 2,may 2008.
14. Kanzumba Kusakana, "Energy management of a grid- connected hydrokinetic system under time of use tariff," Renewable energy 101(2017)1325-1333.
15. N.Nwulu and X.Xia, "Optimal dispatch for a microgrid incorporating renewables and demand response,"Renewable energy, vol.101,pp.16-28,2017.
16. Nandkishor K,Naryana Prasad P, "Particle swarm optimization based demand response for residential consumers"IEEE 2015.
17. N.I.Nwulu, M.Fahrioglu, "A soft computing approach to projecting locational marginal price neural comput.Appl." 22(2012)1115-1124.

AUTHORS PROFILE

Ch.Leela sowjanya is a student of Mtech in Power system and automation, JNTUK, Andhra Pradesh, India. She received Bachelor's Degree from Andhra University in 2017, Andhra Pradesh, India. Her research interests include economic load dispatch, demand response, renewable energy.

Dr.P. Kantarao received Bachelor's degree from Sri Venkateswara University in 1991, Andhra Pradesh, India. He received Master's degree from Sri Venkateswara University in 1994, Andhra Pradesh, India. He received Ph.D., from Andhra University in Optimal reactive power dispatch area in 2011. His research interests are reactive power Dispatch, Hydrothermal rescheduling, Microgrid optimization, Economic load dispatch. Currently he is working in SRKR engineering college as Head of the department of electrical and electronics engineering.