LOAD SHEDDING USING GA AND ACO IN SMART GIRD ENVIRONMENT

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Abstract: *Increasing pressure on the utilities to accommodate energy efficiency, load management and progress in advanced technology has led to transformations for existing grid into a smarter grid. Creating awareness among the end-users to participate in load management programs instead of capacity addition is the best solution for maintaining the stability in the grid. Load shedding is a strategy under load management in which load connected to the smart grid is individually controlled via two- way communication. In this paper, a Smart Load shedding approach is developed based on load prioritization. The required amount of load to be shed under lack of sufficient generation level is optimized by Genetic Algorithm (GA) and Ant Colony Optimization (ACO) algorithms. The proposed approach is implemented using a real time feeder data from the substation, India. The results reflect the effectiveness of proposed algorithms taken into practical applications.*

Key words: *Smart Load Shedding, Load Management, GA, ACO, Smart Grid.*

1. Introduction

Tremendous progress in the information and communication technology has led to transformations of existing grid into a smarter grid. Utilities around the world are under increasing pressure to accommodate energy efficiency, load control and integrate distributed energy resources such as renewable energy sources in the distribution sector. Increasing the capacity of generation by integrating the distributed energy resources to the grid is a long term program and quality of power supplied also is a major concern in this scenario. One way of mitigating such problems is by implementing short term programs such as Demand Response. According to Federal Energy Regulatory Commission, Demand Response is defined as:

"Changes in electric usage by end-use consumers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

Load flexibility is an alternative solution to adjusting generation levels, at almost all operational time scales in the electricity markets. Disparities in generation and demand is taken care of by implementing demand response models such as direct load control and price based control at the customer level. Load management is defined as a set of strategies that are designed to control and modify the demand patterns of various consumers of a power utility. Load shedding is one such strategy through which the load management is carried out whenever there is deficiency of supply. Load management can be done at different levels in different ways.

1.1 Load Management at the consumer level

In the conventional grid, whenever there is a shortage of supply, a round robin technique is employed for load shedding at the feeder level in the sub stations for duration of half an hour to one hour. Here, only technical problems such as variations in voltage and frequency are addressed when resorting to load shedding and no importance has been given to consumers connected to the feeders. As we are in the middle of a paradigm shift and towards a smart grid we can leverage the two way communication function enabled by the smart grid to facilitate automation in load management. In the smart grid era, each load connected to the feeder can be controlled by the power distribution company remotely. Since each load connected to the feeder is controllable, the load can be shed based on the criticality of the load, the revenue loss to Distribution Company and to the consumer, cost of alternative back up protection etc., In this paper a novel grading scheme is proposed for each consumer. Grading of loads facilitates the differentiation of various consumers based on the criticality and need of the consumer [6, 7].

Loads connected to a feeder can be classified on the following considerations.

- Priority time for usage of the load
- Number of units of power consumption by the consumer.
- Social impact of load shedding.

- Cost incurred by the consumer for alternative power sources
- Discomfort to the consumer.
- Revenue loss to the power distribution company.
- Any other consideration defined by the power distribution company.

Grade point is assigned to a load which represents relative importance of the load at a particular time, based on the above mentioned factors. Grade point can be dynamic based on the time priority of the load and flexible to accommodate any other factor which distribution company wants to add. The reader is referred to [6,7] for details on the grading scheme.

2. Full Load Shedding v/s Partial Load Shedding

The load connected to the gird are basically classified into two types i.e., critical and non-critical loads. Health care, data centers are critical loads whereas, residential loads, commercial loads, agricultural loads and industrial loads are non-critical loads. In the existing grid, these loads are connected to feeders, and whenever the there is a need for load shedding the entire feeder is cut off from the supply without checking whether the load is critical load and non-critical loads using round robin technique on hourly basis. Amongst the loads of the same criticality, grade point differentiates different consumers based on other issues as discussed earlier.

Even when load is shed in a controlled manner, the entire load to a consumer is cut off from the supply. With advent in smart home automation systems, it is now possible for the consumer to prioritize load within their premises in the event of a power shortage. Thus instead of shedding the load completely, each consumer can be given a fraction of their total power requirements based on the time of the day and the consumer's option. This way, the discomfort caused by load shedding is shared by all consumers; at the same time every consumer is assured of partial supply to meet his critical loads.

Based on the availability of the power, limits on the power consumption can be set effectively for individual consumer. Grading of loads based on several factors will help in setting these power consumption limits on each load connected to the grid.

This method forces the consumer to manage the loads internally. Consumer has to categorize his loads as critical and non-critical loads and use only those loads which are critical in the period with reduced power consumption limit.

Full Load shedding in Smart Grid means to cut-off supply to a group of load which are connected to the feeder to satisfy the generation deficit. Thus some loads are devoid of electrical power totally and the revenue to the utility from these loads is nil. In Partial Load shedding no load is completely cut-off and every load receives minimum amount of its full load. The consumer can determine which loads need to be connected when partial power is available.

The advantage of partial load shedding concept is, instead of cutting power supply off from consumer at peak load time periods consumer is forced to shift his loads to the time periods with less load on the load curve. So the partial load shedding concept tries to flatten load curve which has tremendous effect on demand side load management. If the load curve is flattened power demand can be met with less power generation capacity. Available power is utilized effectively and revenue is also increased through the partial load shedding concept. Since this concept forces the consumer to manage is load power wastage will be reduced from the utility side. As load is controlled at individual utility level power theft and power losses can be easily accounted and avoided. As most of the times power is channeled to critical loads efficacy of utilization of power is increased. Consumer is given freedom to choose his critical loads and critical time of the day and he is made to manage his loads throughout the day. Consumer participation in demand side load management is increased. So now power distribution is made as bidirectional control with consumer participation at a flow instead of unidirectional supplier driven control flow.
In this paper, the grade point of a consumer is fixed in the range of 0-100. The grade value is indicative of the hierarchical importance of the load based on the factors such as criticality, revenue and customer discomfort etc., Load shedding limits for different ranges of grade values for the implementation of partial load shedding of a consumer is shown in Table 1.

Table 1 Load Shedding Limits

Range of grade points	Limitation on % of Load Shed
0-20	>75%
21-50	50-75%
51- 70	25 – 50%
>71	<25%

From the table we see that consumers with high priority (grade point >71) have 75% of their demand met, while consumers with low priority (grade point

0-20) can have 75% of their load shed.

3. Optimization Techniques

Typically the number of consumers connected to a feeder is large. In the present case study it is 100. Hence, an optimization technique is necessary to decide on the loads to be shed and the limits of shedding to be decided as in table 2.1. Meta heuristic techniques such as swarm intelligence and evolutionary algorithms are applied to this problem, since the search space is large.

3.1 Ant Colony Algorithm

The first Ant colony algorithm (ACO) was introduced in the early 1990's by Marco Dorigo [8-10], and since then several improvements of the system has been made by Gambardella & Dorigo, in the year 1995. ACO is a meta heuristic algorithm which simulates the behavior of ants while searching for food. Ants travel in random direction in search of food. They lay trails called pheromone on the path they travel which evaporate with time. Ant which travelled in the minimum distance path comes back to the original location in minimum time traversing the path twice. The pheromone trails are more in the least distance path as pheromone update happens twice and evaporation of pheromone is less as time taken to traverse the path is less. Next set of ants chose the path to food source based on the pheromone trails on the path. More ants take least distance path and pheromone update further increases. After certain duration ants converge on the minimum distance path. The algorithm is most popular in routing problems.

Ant colony algorithm is capable of handling constraints dynamically and provides a unique opportunity to change the constraints of the algorithm based on the situation. The algorithm encourages customer participation in load management by assigning grade points and time priority to each load and assuring the power to the customer at his priority time.

3.2 Genetic Algorithm

In 1998, Goldberg et.al, proposed a new algorithm which finds applications where search space is huge and the precise results are not very important. Genetic Algorithm searches for the global optimum value of the objective function through a search space, which is called a population. The population is constituted from a number of possible solutions known as individuals, where each individual is also called as a chromosome. In this mathematical analysis, a set of chromosomes is randomly generated as initial population. The individuals are then ranked depending on their fitness and a suitable fitness value is assigned to each one. The fitness values are calculated depending on the position of the individuals within the population rather than their distinct performance. Fitness values between maximum and minimum limits are calculated with fixed incremental steps and assigned to the ranked individuals. Individuals with low fitness values are dropped and a new population generated using crossover and mutation. Using GA for load shedding application has the advantages that load shedding takes place in a probabilistic manner. The solution obtained is based on the initial chromosome pool. Since the objective function is an inequality more than one solution satisfying the problem is possible.

3.3 Implementation of Optimization Techniques

Partial load shedding of a consumer in the smart grid has been implemented using optimization techniques such as GA and ACO. Fig 1 shows the block diagram for Implementation of Load Shedding scheme in Smart Grid.

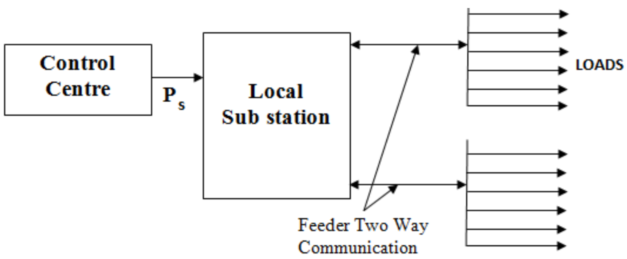

Fig. 1 Block diagram for Implementation of Load Shedding scheme in Smart Grid

The information about the amount of load to be shed at a particular time based on the available power from Control Centre is sent to Local Substation. Based on the load shedding requirement and grading of loads the algorithm will distribute the power to all the loads.

The algorithm for load shedding is developed based on the following assumptions:

1. The utility is assumed to be able to communicate continuously with the control center and data of the load is stored and available for processing.
2. Based on the amount of power deficiency the load dispatch center sends intimation to substation regarding the amount of load which has to be reduced by that substation.
3. The substation does load shedding in the blocks of 1 hour duration.
4. The input to the algorithm is current power consumption of each load, grade points assigned to each load and load shedding requirement
5. Based on the results obtained from the algorithm substation performs suitable control action for load shedding for the next hour.

3.4 Objective Function

To minimize the sum of load shedding error, we define the objective function as:

$$\text{Minimize } (P_E)$$

Where,

P_E = Error in load shedding
P_s = Amount of load to be shed in kW
P_a = Actual amount of load being shed in kW
Load Shedding Error, $P_E = P_s - P_a$

4. Results and Discussions

For testing the efficiency of the algorithms a test system of 100 loads is used based on the real time data from the Substation, India. The algorithms are simulated using MATLAB R2014a. The Load Profile of test system is as shown in Table 2.

Table 2 Power consumption of different loads

LT1	LT2a1			LT2a2		LT2b	LT3		LT4	LT5	LT6	LT7	HT1	HT2	HT3
0.9	1.62	0.04	1.5	0.63	3.89	3.63	13.28	9.61	6.58	74.51	21.16	35.42	56.46	68.26	85.36
0.95	1.5	1.84	0.46	1.62	3.06	4.46	12.4	7.82	13.58	33.01	24.39		79.24	102.36	160.58
	0.24	1.3	0.12	1.58	4.99	3.77	11.96	12.44		72.27	18.54			138.25	
	1.05	1.86	1.53	1.7	2.67	3.56	12.5	13.88		30.82	19.1				
	0.65	0.32	1.34	1.01	3.96	4.58	9.06	6.24		60.77	24.84				
	1.09	1.84	1.43	1.27	3.82	4.02	10.94			65.26					
	0.8	1.58	1.28	1.9	3.16	4.49	10.6			54.03					
	0.83	1.15	0.84	0.88	2.42	4.08	10.24			69.84					
	0.36	0.88	0.78	2.18	2.08		8.2			70.46					
	0.51	0.52	1.63	4.6	3.26		7.98			58.16					

Each column gives power consumption of a lumped load. E.g. LT2 represents Low tension non-commercial loads such as residential loads, institutional etc., with maximum power consumption 5 kW. Similarly, LT3 and LT5 represent Low tension commercial and industrial loads. Number of loads taken in one tariff category is proportional to substation data.

4.1 Partial load shedding solution using GA and ACO

For testing the efficiency of the algorithm for Partial Load shedding of the test system, Power consumption of loads is taken from Table 4.1. The priority time usage for a residential consumer is usually between 6am - 9am in the morning and during late evenings, whereas industrial and commercial consumer's priority time usage will be during 9am - 5pm and 6pm -10pm respectively. For example, at 7 am the priority is given to residential consumers and at 11 am industrial consumers will have more priority. The grade points assigned for each load lies in the range of 0-100 and varies at each and every hour of the day depending on the priority time usage. The priority table describing the grading points for each load at 7am and 11am are as shown in Table 3 and 4 respectively.

Table 3 Grade points of the loads at 7:00 am

LT1	LT2a1			LT2a2		LT2b	LT3		LT4	LT5	LT6	LT7	HT1	HT2	HT3
10	53	49	51	38	50	29	25	53	51	35	11	52	51	83	78
10	40	44	55	57	48	20	28	58	49	35	20		65	73	73
	56	46	50	52	60	24	35	52		36	27			75	
	40	52	53	51	55	29	39	52		48	45				
	45	46	53	57	60	15	33	44		31	45				
	49	48	22	50	47	27	32			36					
	58	57	19	51	41	28	33			43					
	45	47	31	58	11	29	45			31					
	49	47	13	47	25		53			26					
	49	51	26	57	38		54			67					

Table 4 Grade points of the loads at 11:00 am

LT1	LT2a1			LT2a2		LT2b	LT3		LT4	LT5	LT6	LT7	HT1	HT2	HT3
10	19	22	29	24	19	59	52	87	61	66	11	38	67	86	80
10	22	37	32	33	24	55	49	83	31	67	20		39	73	74
	27	22	16	18	13	55	68	77		63	56			76	
	18	31	19	17	19	52	66	34		68	53				
	26	34	12	23	30	51	64	70		66	43				
	23	15	42	21	17	46	50			54					
	32	19	29	31	46	49	68			68					
	22	27	41	28	14	49	60			68					
	27	28	26	19	11		84			63					
	18	23	21	21	32		80			46					

Partial Load Shedding Solution for Load shedding requirement of 600kW at 7am and 11am given by the ACO is as shown in Fig. 2 and Fig. 3 respectively. Similarly, Fig. 4 and Fig 5 shows the solutions given by the GA at 7am and 11am respectively.

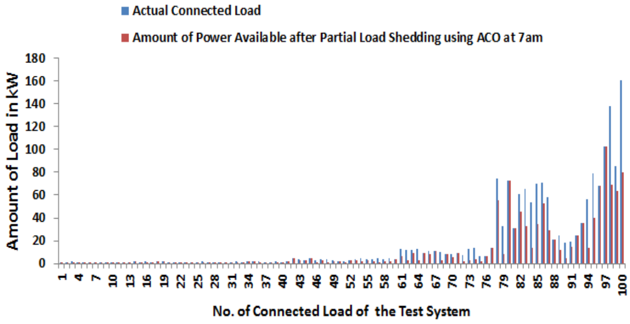

Fig. 2 Load shedding solution for 600kW at 7:00am using ACO

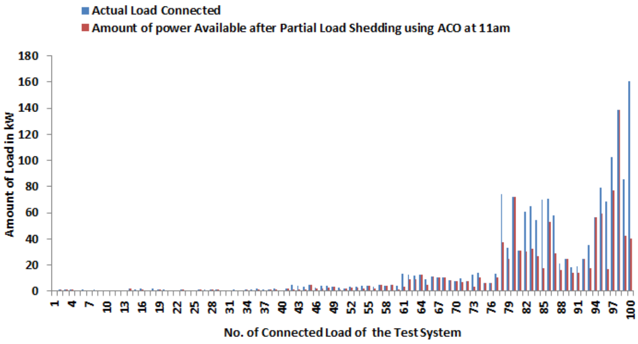

Fig. 3 Load shedding solution for 600kW at 11:00am using ACO

The results shows that the based on the priority time usage of the consumers the load is shed and also we can observe that the no load is completely shed a partial amount of power is supplied to each consumers.

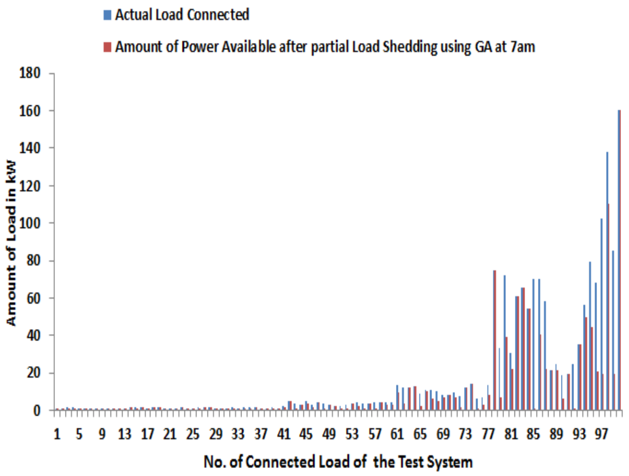

Fig. 4 Load shedding solution for 600kW at 7:00am using GA

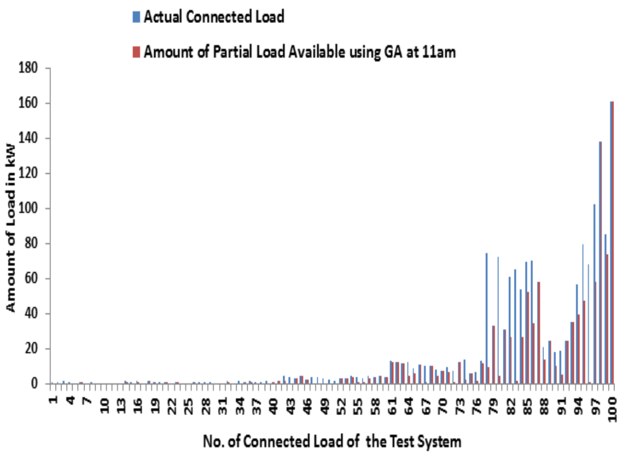

Fig. 5 Load shedding solution for 600kW at 11:00am using GA

Solutions show that the loads are given priority based on the grade points and each consumer is given a partial load instead of shedding the complete load. It can be observed that the loads which have minimum grade points at the time of load shedding are considered for partial load shedding. The results show that algorithm optimizes load shedding based on priority assigned to each load. The algorithm developed can handle dynamic constraints assigned.

4.2 Different load shedding requirement at same time of the day using GA and ACO

Different Load shedding requirements are considered at 7.00 a.m. and 11am is considered for testing algorithm. The algorithm computes grade points and loads are shed partially based on priority time usage of the consumers. The load shedding error and the % error partial load shedding using to different load shedding requirements at 7:00 am and 11 am using ACO and GA are shown in detail in Table 5 and Table 6.

Table 5 Comparison of % Error in Partial Load Shedding of a consumer at 7:00 am using ACO and GA

Sl. No.	Amount of Load to be Shed in kW	Error in Partial Load Shedding in kW at 7 am using ACO	% Error in Partial Load Shedding at 7 am using ACO	Error in Partial Load Shedding in kW at 7 am using GA	% Error in Partial Load Shedding at 7 am using GA
1	100	5.2225	5.2225	2.7881	2.7881
2	200	18.1175	9.05875	0.1309	0.06545
3	300	0.345	0.115	2.458	0.8193333
4	400	0.5525	0.138125	1.5059	0.376475
5	500	0.0225	0.0045	0.2639	0.05278
6	600	0.5425	0.090417	5.4181	0.9030167
7	700	1.6925	0.241786	1.301	0.1858571
8	800	1.9325	0.241563	10.7088	1.3386
9	900	4.43	0.492222	0.6026	0.0669556
10	1000	0.37	0.037	158.8622	15.88622
11	1100	51.545	4.685909	284.3379	25.8489
12	1200	87.3075	7.275625	535.7789	44.648242
13	1300	12.6925	0.976346	507.5689	39.043762

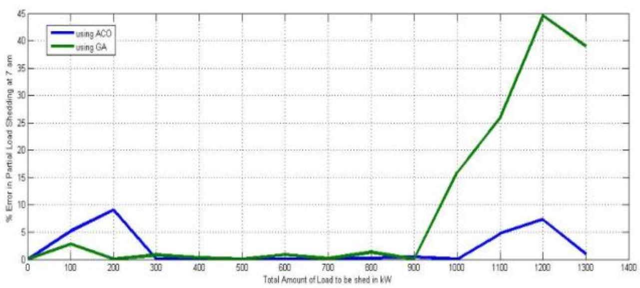

Fig 6 Comparison of % Error in Load Shedding for Partial Load Shedding of a consumer at 7:00 am using ACO and GA

Table 6 Comparison of % Error in Partial Load Shedding of a consumer at 11:00 am using ACO and GA

Sl. No.	Amount of Load to be Shed in kW	Error in Partial Load shedding in kW at 11 am using ACO	% Error in Partial Load Shedding at 11 am using ACO	Error in Partial Load Shedding in kW at 11 am using GA	% Error in Partial Load Shedding at 11 am using GA
1	100	1.945	1.945	0.3251	0.3251
2	200	1.85	0.925	2.219	1.1095
3	300	0.5175	0.1725	0.4489	0.14963
4	400	2.205	0.55125	1.6967	0.42418
5	500	0.1975	0.0395	1.7679	0.35358
6	600	0.5325	0.08875	2.9361	0.48935
7	700	0.635	0.09071	1.9202	0.27431
8	800	1.035	0.12938	0.87	0.10875
9	900	2.7325	0.30361	0.8846	0.09829
10	1000	1.695	0.1695	126.348	12.6348
11	1100	34.92	3.17455	264.339	24.0309
12	1200	87.3075	7.27563	384.367	32.0306
13	1300	12.6925	0.97635	430.277	33.0982

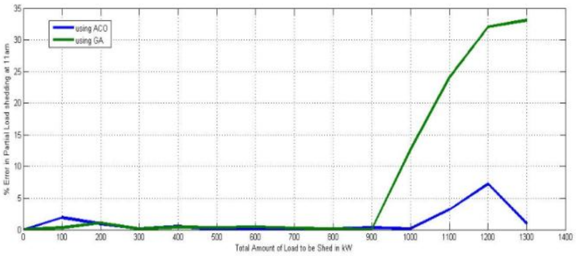

Fig 7 Comparison of % Error in Load Shedding for Partial Load Shedding of a consumer at 7:00 am using ACO and GA

The basic objective behind the implementation of partial load shedding scheme is to provide the consumers with some amount of power so as to satisfy their demands. In this way the revenue loss for both the consumers and the utilities can be reduced.

The results in Fig. 5 and Fig. 6 shows that the value of percentage error in Load shedding for Partial Load shedding using ACO and GA is less than 0.5% within the minimum and maximum amount of load being shed with minimal grade points. It can also be observed that ACO gives better solution compared to GA. For lesser values of load shedding requirements the utilities can resort to partial load shedding. The higher flexibility in load control and reduced impact of load shedding for consumers can be obtained from partial load shedding when compared to complete load shedding of a consumer.

4.3 Comparison of Opportunity loss with and without the deployment of the algorithms to the Utility

We consider a load shedding requirement of 600kW at 7:00 am and 11:00 am. Here we try to compare the opportunity loss to the utility with and without employing these algorithms. The load shedding solution that is obtained after running the program is given in Table 7 and Table 8.

Table 7 Partial Load Shedding solution for 600kW at 7:00 am and 11:00 am using ACO

Load Category	Tariff / unit (Rs)	Amount of Load Shed kW at 7am using ACO	Loss at 7am using ACO (Rs)	Amount of Load Shed kW at 11am using ACO	Loss at 11am using ACO (Rs)
LT1	0	1.15	0	1.3875	0
LT2	6	28.21	169.26	36.4975	218.985
LT3	6.5	49.75	323.375	37.89	246.285
LT4	0	0	0	1.645	0
LT5	5	174.04	870.2	159.95	799.75
LT6	4.5	53.3475	240.0638	32.6175	146.7788
LT7	9	8.855	79.695	17.71	159.39
HT1	4	39.62	158.48	28.23	112.92
HT2	6	103.255	619.53	163.4075	980.445
HT3	3.5	141.775	496.2125	120.4075	421.4263

Considering the tariff rates from BESCOM, we calculate the opportunity loss for the utility. For a load shedding requirement of 600kW at 7:00 am, opportunity loss calculated with the solution obtained from ACO & GA at 7am is Rs. 2956.816/- and Rs. 3060.42/- whereas for the same amount of load shed without the deployment of algorithm based on the time priority we assume 200kW to be shed from industrial and 400kW from commercial category the loss is Rs. 3250/-. Similarly, we can also observe at 11am with ACO & GA the loss is less compared without the deployment of algorithm which is as shown in Table 9.

Table 8 Partial Load Shedding solution for 600kW at 7:00 am and 11:00 am using GA

Load Category	Tariff / unit (Rs)	Amount of Load Shed in kW at 7am using GA in kW	Loss at 7am using GA (Rs)	Amount of Load Shed at kW 11am using GA in kW	Loss at 11am using GA (Rs)
LT1	0	0.915411	0	0.622446	0
LT2	6	36.0231	216.1386	41.79655	250.7793
LT3	6.5	45.53588	295.98322	44.2685	287.74525
LT4	0	8.765588	0	4.902911	0
LT5	5	203.6577	1018.2885	309.5876	1547.938
LT6	4.5	39.79182	179.06319	28.52902	128.38059
LT7	9	0	0	0	0
HT1	4	41.6312	166.5248	48.07037	192.28148
HT2	6	158.8587	953.1522	110.6858	664.1148
HT3	3.5	66.07653	231.267855	11.24951	39.373285

Table 9 Comparison of Opportunity losses with and without algorithms to the utility

Partial Load Shedding	Loss at 7 am (Rs)	Loss at 11am (Rs)
Using ACO	Rs. 2956.816/-	Rs. 3085.98/-
Using GA	Rs. 3060.42/-	Rs. 3110.62/-
Without algorithm	Rs. 3250/-	Rs. 3650/-

From the result we can conclude that both from perspective of error and cost, ACO provides a better solution than GA.

Conclusions

Partial load shedding of a consumer is implemented using Genetic Algorithm and Ant Colony Optimization. This method provides greater flexibility in load control compared to the complete load shedding of a consumer. Simultaneous optimization of load shedding error and social impact of load shedding is achieved. Ant colony algorithm applied for intelligent load shedding is a new approach which very efficiently handles a large number of loads in a substation. Ant colony algorithm applied for load shedding in smart grid environment provides a unique opportunity to treat an individual utility as single lumped load and efficiently minimizes the error in load shedding value and also minimizes the cost of load shedding. The algorithm tries to minimize the impact of load shedding to the possible extent by considering time priority of each load and the grade points assigned to each load. It also provides a unique opportunity to change the constraints of the algorithm based on the situation. The algorithm is highly flexible and easily modified to give a best solution in the given situation. The algorithm increases the efficacy of power distribution by routing the power to the right consumer at right time and ensures maximum usability and profitability of available power.

REFERENCES

1. Zahir J. Paracha, Parviz I Doulai, "Load management techniques & methods in electric power systems", IEEE Proceedings of Energy management and Power Delivery, 1998.
2. S. Hirodontis, H. Li, P.A. Crossley, "Load Shedding in a Distribution Network", International Conference on Sustainable Power Generation and Supply, 2009.
3. Farrokh Shokooh, J J Dai, Shervin Shokooh, Jacques Tastet, Hugo Castro, Tanuj Khandelwal, Gary Donner, "An Intelligent Load Shedding (ILS) System Application in a Large Industrial Facility", Industry Applications Conference 2005, vol. 1, no. 2, pp. 417-425, Oct. 2005.
4. Maiorano, R. Sbrizzai, F. Torelli and M. Trovato, “Intelligent Load Shedding Schemes for Industrial Customers with Cogeneration Facilities,” Power Engineering Society 1999 Winter Meeting, IEEE, Vol. 2, pp. 925- 930, 1999.
5. V S K Murthy Balijepalli, Vedanta Pradhan, S A Khaparde and R M Shereef, “Review of Demand Response under Smart Grid Paradigm”, IEEE PES Innovative Smart Grid Technologies, pp.236-243, 2011.
6. K. Uma Rao, Satyaram Harihara Bhat, Ganeshprasad G G, Jayaprakash G, Selvamani N Pillappa, "A Novel Grading Scheme for Loads to Optimize Load Shedding Using Genetic Algorithm in a Smart Grid Environment", IEEE Innovative Smart Grid Technologies - Asia (ISGT Asia), pp. 1-6, 10-13 Nov. 2013.
7. K. Uma Rao, Satyaram Harihara Bhat, Ganeshprasad G G, Jayaprakash G, Selvamani N Pillappa, "Time Priority Based Optimal Load Shedding Using Genetic Algorithm", Fifth International Conference on Advances in Recent Technologies in Communication and Computing (ARTCom 2013), pp. 301-308, 20-21 Sept. 2013.
8. V. Margaret, K. Uma Rao and G.G. Ganeshprasad, “Intelligent Load Shedding Using Ant Colony Algorithm in Smart Grid Environment”, Springer India 2015, Power Electronics and Renewable Energy Systems, Lecture Notes in Electrical Engineering 326, DOI 10.1007/978-81-322-2119-7_112.
9. M. Dorigo, M. Birattari, T. Stützle, “Ant Colony Optimization – Artificial Ants as a Computational Intelligence Technique”, IEEE Computational Intelligence Magazine, 2006.
10. M. Dorigo K. Socha, “An Introduction to Ant Colony Optimization”, T. F. Gonzalez, Approximation Algorithms and Meta heuristics, CRC Press, 2007.
11. M. Dorigo T. Stützle, “The Ant Colony Optimization Meta heuristic: Algorithms, Applications, and Advances”, Handbook of Meta heuristics, 2002.