GENETICALLY OPTIMIZED LOAD SHEDDING: A CASE STUDY

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Abstract— The demand for electricity is increasing day by day with the expansion of industries, advancements in the field of technology and improvements in the lifestyles of people. Electric utilities all around the world strive hard to maintain a balance between demand and generation of power. Utilities resort to load shedding whenever they experience such an imbalance. The present load shedding scheme is based on round robin technique which is incapable of shedding the correct amount of load to meet the power deficit. Also there is no consideration for the importance of the load being shed. In this paper a sample system of 100 loads have been considered for load shedding. They are prioritised based on some factors to reduce the impact of load shedding for both utilities and consumers. Simultaneous optimization of load shedding error and the social impact of shedding is done by applying the artificial intelligence technique of Genetic Algorithm. The algorithm is developed on a smart grid environment under the assumption that the loads can be individually controlled from the utility side. Several case studies have been presented to test the efficiency of the algorithm in optimizing the load shedding error as well as its cost.

Index Terms— Genetic Algorithm, Grading of Loads, Load Shedding, Smart Grid,

I. INTRODUCTION

Load shedding is an important strategy adopted by the electric utilities to maintain power system stability when they are faced with generation deficiencies , lack of sufficient transmission and distribution capabilities or faults [1,2]. There has been an ever increasing demand for power owing to the technological advancements, rapid industrialisation and urbanisation. Electric utilities all around the world strive hard to tackle the situation of power crisis and to combat the imbalance between the generation and demand of power. They resort to load shedding under such circumstances.

Most of the conventional methods of load shedding causes either excessive or insufficient load reductions and have slow response time [3,4]. This necessitates the importance of an intelligent load shedding scheme that can provide optimal load shedding solutions. Artificial intelligence techniques are also widely applied to load shedding applications nowadays [5].

When a power shortage occurs, the Load Dispatch Centre (LDC) which allocates power to different substations communicates with them to shed certain amount of load as per the requirement. Currently load shedding takes place at the feeder level by round robin technique. In this method feeders will be disconnected from the supply in a cyclic manner for intervals of an hour or half hour. All the loads connected to disconnected feeder will be denied power during this interval. Usually feeders whose power consumption is greater than the amount of load to be shed are selected for load shedding.

The present load shedding strategy suffers from many shortcomings. Since an entire feeder is disconnected it becomes impossible to shed the required amount of load. Another serious drawback is that load shedding is carried out without giving any consideration to the importance of load. Loads such as data centres, hospitals, cold storages should be exempted from load shedding to the maximum extent possible. Loads generally fall under categories such as commercial, industrial, residential etc. Each of them have a particular priority time of usage[9]. A consumer suffers from revenue loss as well as discomfort when he is neglected power during this period. At the same time distribution companies also incur revenue loss when consumers paying higher tariffs are shed. Since we cannot control the loads individually during the load shedding there is a probability that power is supplied to non critical loads rather than the important ones. Therefore the present load shedding scheme does not provide effective power distribution of available power[8].

The conventional grid system does not provide an opportunity for selective shedding of loads. However a smart grid environment provides greater flexibility for individual load control. In this paper an algorithm for load shedding in a smart grid framework is explained. Genetic Algorithm has been used for the simultaneous optimization of load shedding error as well as the impact of load shedding.

II. ANALYSIS OF PRESENT LOAD SHEDDING SCHEME

The present load shedding scheme i.e. the round robin technique is analysed based on economic and social considerations. For economic analysis we consider the real power consumption of feeders from a substation and decide the load shedding schedule based on this technique. The load profile for the feeders is noted from 10:00 am to 12:00 am and is given in Table I. Due to the peak power demand the substation receives an intimation to shed 3.1 MW for two hours. The entire load shedding duration is divided into blocks of half hour. Feeder/ feeders whose consumption is greater than the required amount are disconnected. A possible load shedding schedule for the feeders under this case is given in Table II.

Table I. Load Profile

Time	Power consumption of different feeders corresponding to the time interval(MW)							
	F1	F2	F3	F4	F5	F6	F7	F8
10:00 AM	2.9	1.5	3	1.5	2	1.3	2.3	2.7
11:00 AM	3.1	1.6	3.4	1.6	2.2	1.4	2.6	2.7
12:00 PM	2.8	1.5	3.3	1.5	2.1	1.4	2.5	2.6

Table II. Load shedding schedule using round robin technique

Load shedding time block	Feeder/ Feeders disconnected	Load shedding error(MW)
1	F5,F6	3.3 - 3.1 = 0.2
2	F2,F7	3.8 - 3.1 = 0.7
3	F3	3.4 - 3.1 = 0.3
4	F1	3.1 -3.1 = 0

From the load shedding schedule we can see that it is not possible to shed the correct amount of load. The extra units which are shed could have resulted in revenue generation for the utilities. While selecting the feeders for disconnection no consideration for the importance of the loads is given. Many a times non critical loads will receive supply than the critical loads. From the analysis we can see that there is a need for selectively shedding the loads which is possible only in smart grids.

III. LOAD SHEDDING IN SMART GRID SCENARIO

"A smart grid is defined as an electrical grid that uses information and communications technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity" [6].

Smart Grid allows two way communication between the utilities and the consumers [7]. Each electrical connection from the distribution company is taken as one lumped load in a smart grid environment. Smart meters are installed within the customer premises. They are capable of communicating the real time load data to the control centre at regular intervals. The loads can also be remotely controlled from a remote centre with the help of control signals. The major difference between load shedding in a conventional grid and that in smart grid environment is that, in a conventional load shedding system, load shedding takes place at the substation level by disconnecting an entire feeder whereas in a smart grid system load shedding takes place at the consumer end. Therefore it is possible to shed the exact amount of load required and also effectively distribute the available power to loads based on its importance and time of usage.

IV. CATEGORISATION OF LOADS

Based on the tariff structure loads are of two types- Low tension and High tension. The category of loads falling under various tariffs are given in Table III.

Table III. Category of Loads Based on Tariff

Tariff	Type of loads
LT1	Domestic (free up to 18 units)
LT2	Residential, Institutions
LT3	Commercial
LT4	Agricultural induction pumps
LT5	Industrial
LT6	Water works, Street lights
LT7	Temporary connections
HT1	Water works
HT2	Industrial ,Commercial
HT3	Agriculture and Horticulture Farms

V. GRADING OF LOADS

Grading is a method which is used to assign priorities to loads of various categories as well as those within a particular category [8]. It is done to differentiate the loads based on their importance at a given time of the day. Grading or prioritising the loads helps us to realize the selective shedding of loads. Following are the factors based on which loads are prioritised :

- Number of units of power consumption.
- Social Impact of load shedding.
- Revenue loss and discomfort suffered by the consumer.
- Revenue loss to the utilities.
- Other considerations by the distribution company.
- Time of the day.

Number of units of power consideration provides information on the size of the load as well as the number of people affected by shedding. The factor revenue loss to the distribution companies takes into account the tariff paid by the consumers. Economic loss to the consumers can be computed based on the revenue generated if he was supplied with power. Social impact of load shedding signifies the importance of the load being shed. Other factors can also be included to grade the loads based on the requirements of the distribution company. Each of these factors will be given some weightages and the loads are then graded. For each load we assign a grade point which is merely a number in the range of 0-100. A load will have high value as a grade point during its priority time compared to the less predominant ones.

VI. GENETIC ALGORITHM FOR LOAD SHEDDING

Genetic algorithms (GAs) are search methods which are based on the principles of natural selection and genetic[10]. They were originally developed by John Holland in 1975 and are inspired by the biological evolution process. Genetic algorithms use the principles of selection and evolution to produce several solutions to a given problem. GA has been used for many load shedding applications [11-13].The main reason for the use of GA in developing the algorithm is its robustness and efficiency in arriving at an optimal solution.

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

1. A two way communication is possible between the consumer and the utility.
2. The control centre receives real time power consumption with the help of smart meters at the customer site.
3. When a power shortage occurs, the load dispatch centres intimate the substation to shed some load.
4. The load shedding requirement, real time load profile and the grade points of the loads are given as input to the algorithm.

A. Algorithm

In Genetic Algorithms an objective function is to be defined first. The objective in this algorithm is to simultaneously optimize the error in load shedding and the cost of load shedding. Cost of load shedding is the sum of the grade points of all loads that are shed. The algorithm is briefly explained below:

1. Consider a sample system of 100 loads belonging to various tariff categories.
2. The real time input of the load to be shed, the time of the day, the load profile of the sample system and their grade tables are fed to the algorithm.
3. An initial pool of 32 chromosomes is created. The number of genes in each chromosome will be equal to the number of loads considered.
4. Binary numbers '0' and '1' represents ON and OFF state of the load.
5. The best 4 chromosomes from the initial chromosome pool are selected by using Tournament strategy.
6. The four chromosomes are subjected to objective function, crossover and mutation. We define a specific number of iterations for the convergence of the algorithm.
7. After a number of iterations the best solution for load shedding will be displayed.

VII.CASE STUDY AND RESULTS

The program for load shedding in a smart grid environment is developed using MATLAB R2012a. For testing the algorithm different case studies have been performed on a sample system of 100 loads from different categories. Load profile of the test system is shown in Table IV.

Table IV. Load Profile of the Sample System

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	13.3	9.61	6.58	74.51	21.2	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	24.4		79.24	102.36	160.58
	0.24	1.3	0.12	1.58	4.99	3.77	12	12.44		72.27	18.5			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	24.8				
	1.09	1.84	1.43	1.27	3.82	4.02	10.9			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	10.2			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					

The total power consumption of the loads is 1.716MW. The case studies done and the results obtained are presented in this section.

Case (i) Same load shedding requirement at different time of the day

We consider a load shedding requirement of 500kW at 7:00 am and 4:00 pm. The grade points for the sample system of loads and the best possible load shedding solution that is computed by the application of GA for the given load shedding requirement at 7:00 am is shown in Table V and Table VI respectively . The binary bit '1' represents all the loads that are disconnected from the supply.

Table V. 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 VI. Load shedding solution for 500kW at 7:00 am

LT1	LT2A1			LT2A2		LT2B	LT3		LT4	LT5	LT6	LT7	HT1	HT2	HT3
1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0
1	0	1	1	0	0	1	0	0	1	0	0		0	1	0
	1	1	0	0	0	0	0	0		0	1			0	
	1	0	0	0	0	1	0	1		0	0				
	1	0	0	0	0	0	0	1		0	0				
	0	0	0	0	1	0	0			1					
	0	0	0	0	0	0	1			0					
	0	1	0	0	0	0	1			0					
	1	0	0	0	0		1			1					
	0	0	0	0	1		1			1					

It is found that the load shedding error at 7:00 am is around 0.65kW which is a good result. The sum of the grade points of all the loads shed is 1200. We know that during early morning hours more power is required by the residential customers. The results obtained show that the algorithm takes care in providing maximum power to the residential customers with the help of grading scheme. Thus power is provided to the right customer at the right time.

Again the program is executed for the same load shedding requirement at 4:00 pm. The solution obtained in this case is given in Table VII .

Table VII. Load shedding solution for 500 kW at 4:00pm

LT1	LT2A1			LT2A2		LT2B	LT3		LT4	LT5	LT6	LT7	HT1	HT2	HT3
1	1	0	1	0	0	0	1	1	0	0	0	0	0	1	0
1	1	1	0	0	1	1	0	0	0	0	0		0	0	0
	0	0	0	1	1	0	1	0		1	1			0	
	1	0	0	0	0	0	1	0		1	0				
	1	1	0	0	1	0	0	1		1	0				
	1	1	0	0	1	0	0			1					
	0	1	0	0	0	1	1			0					
	0	1	0	1	0	0	0			1					
	0	0	1	1	1		0			0					
	0	0	0	0	1		0			0					

The solution obtained conveys that with the deployment of this algorithm loads which are of high priority at a given time are kept in operation whereas less important loads were shed. The algorithm provides an optimal load shedding solution and is successful in selective shedding of loads based on their importance and social impact .

Case (ii) Different load shedding requirements at the same time of the day

The program is run by entering different load shedding requirements at 8:00 am. The results are summarised in table VIII .

Table VIII. Load shedding errors for different load shedding requirements at 8:00am

Load shedding Requirement(kW)	Load shedding Error(kW)	Percentage error in load shedding (%)
100	0.14	0.14
200	0.43	0.215
300	0.68	0.226
400	0.98	0.245
500	0.56	0.112
600	0.81	0.135
700	1.31	0.187
800	0.23	0.025
900	1.39	0.154
1000	1.01	0.001

From the results we can see that the percentage error in load shedding error is well within 0.5% of the amount of load to be shed. This is an exceptionally good result when comparing with the conventional load shedding schemes which result in excessive shedding of loads. The graph showing the minimization of load shedding error is given in Fig. 2.

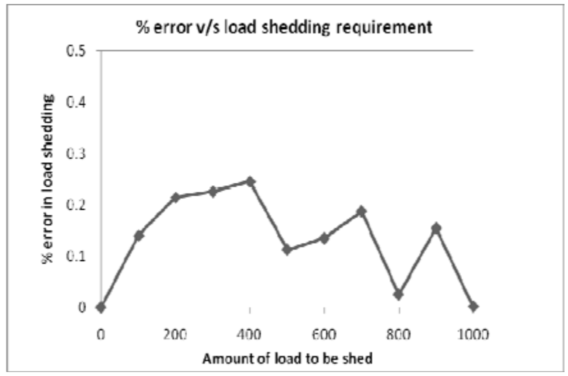

Fig. 2. Minimization of load shedding error

Case(iii) Load shedding requirement and time of day remaining the same

The load shedding requirement and the time of day are kept fixed and the program is executed for a repeated number of times. The solution obtained for a load shedding requirement of 500kW at 7:00 am is shown in Table IX. This is then compared with the solution given in Table V.

Table IX. Solution for 500 kW at 7:00 am

LT1	LT2A1			LT2A2		LT2B	LT3		LT4	LT5	LT6	LT7	HT1	HT2	HT3
0	0	0	0	0	1	0	0	1	0	0	1	1	1	1	1
0	0	0	0	0	0	0	1	0	0	0	0		0	0	0
	1	0	0	0	0	0	0	1		0	0			0	
	0	0	0	0	0	0	1	1		0	0				
	0	0	0	0	0	1	1	0		0	0				
	1	0	1	0	0	1	0			0					
	1	1	0	1	0	1	0			0					
	0	0	0	0	0	0	0			0					
	0	0	0	1	1		0			1					
	0	0	0	0	0		1			1					

The error in load shedding is 1.43kW. We find that on comparing both the tables the solutions obtained are not unique. Loads which were shed earlier are excluded from shedding in the second case. The algorithm helps in minimising the inconvenience caused to the customers when load shedding duration is high. This is one of the advantage of using GA for load shedding application since load shedding takes place in a probabilistic manner. The solutions obtained is based on the initial chromosome pool. Since the objective function is an inequality more than one solution satisfying the problem is possible.

VIII. CONCLUSION

An algorithm for selective load shedding in a smart grid environment is developed with the help of artificial intelligent technique of Genetic algorithm. The algorithm can efficiently control the loads based on their priority. It is successful in minimising the load shedding error and also reducing the impact of load shedding. The algorithm improves customer satisfaction by providing them power during their priority time of usage. With the help of this algorithm the critical loads such as hospitals, data centres etc can be exempted from load shedding. This method can be further extended to enable partial load shedding of a consumer which ensures a certain amount of consumer load be supplied even when load shedding becomes inevitable.

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