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Partial Outage and Load Shifting Based Cost Optimization For Consumers In Developing Countries

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***Abstract*—For In Developing Countries like India, it is filled with a lot of basic essential issues that first needs to be solved such as continuous access for drinking water to all, food for all and most importantly electricity for all. Due to the lack of these essentials it is hard to build an infrastructure that will solve the problem, hence this paper talks about the problems related to electricity shortage and also a new algorithm that gives a smart pathway for electricity distribution. The algorithm results in a partial outage state than the complete blackout condition this is achieved by giving weightage to sanctioned loads, load curve, revenue generated by the consumers with respect to the utility etc., The second part of the paper discusses about the load shifting techniques which further optimizes the cost for the consumer.**

Keyword- Load Shifting, Partial Outage, Power Shortage, DSM, Power Management.

I. Introduction

The residential building sector is one of the largest consumers of electricity in India. Continuous urbanization and the growth of population result in increasing power consumption in buildings. Thus, while experts express the huge potential for energy conservations in this sector, the belief still predominates among stakeholders that energy-efficient buildings are more expensive than conventional buildings, which adversely affects the "greening" of the building sector. Government of India is now encouraging installation of small scale solar panels (1kW) on roof tops to make electricity consumption at least partially self-sufficient. Due to these periodic power cuts, invariably every establishment will have 4 sources of power grid, diesel generator, solar, battery. In this paper the model of partial outage is introduced. Assume there is a shortage of 'X' KW during 9am to 12pm for a particular city. Thus instead of shedding the loads in 1 or 2 areas completely and creating a blackout, parameters such as sanctioned load, load curve and revenue generated for the utility are considered and the power is proportionately distributed amongst the consumers. This leads to a partial outage and eliminates the inconvenience caused to the consumers. The remaining shortage of power can be backed up by the other sources available. Several studies have focused on the impact of unreliable grids as seen in the following: An in-depth investigation into the impact of power outages for consumers and businesses in Africa is performed in [4]. This study also assesses the economic consequences of the unreliable grids. A report on real power cost in India [5] reveals that the overall intent of providing cheap and affordable power to the consumers in the country is noble, but if the supplies are inadequate or unreliable, the consumers could actually end up paying a much higher price. A report from United Nations [6] provides directions to expand access of modern energy services at the household level. An application of combined model of extrapolation and correlation techniques for short term load forecasting of an Indian substation is presented in [7]. Specific opportunities for DSM in the Indian scenario are presented in [8]. Low-cost energy generation using bio- mechanical energy is presented in [9] and this provides technology options for both off-grid users as well as on-grid users who have unreliable power. Emerging markets are plagued by rampant electricity outages or blackouts [1-3] often ranging from 2 hours to more than 10 hours a day . Typically, major blackouts occur when the grid transitions way from its stable operating region into unstable domains caused by disturbances and load-supply gap widening. In effect, small disturbances triggered lead to large cascading failures across the entire grid or large sections of the grid. Demand-side-management (DSM) policies are being formulated by various stakeholders in India and other developing countries. These policies are specifically targeted to overcome large energy demand-supply gaps, to provide inclusive and reliable power for entire populations [9]. For example, in India, load scheduling has recently been implemented successfully for the agricultural sector. As in developed countries, load scheduling is driven by the utility for peak clipping of demand, load shifting for energy conservation and/or supporting load growth. In this work, our aim is to highlight the urgent need for demand-side-management policies to address one of the major unaddressed challenges for a consumer in a developing country which is the problem of frequent power outages. DSM solutions and policies need to be developed, validated and framed to enable the consumer get reliable power and reduce his dependence on expensive diesel back-up systems.

II. METHODOLOGY

In a typical Indian scenario one substation supplies power to different areas. Each of these areas supply power to a bunch of houses. Every house has an upper limit of utilization of power called commonly as the sanctioned power or sanctioned load. This sanctioned power is issued by the local electricity board during the time of occupation of the establishment and can be increased if not sufficient. Thus summing up all the individual sanctioned power of each establishment in a area the total sanctioned power for a particular area can be obtained.

In the present scenario especially in India if there is a shortage of power during a day the supply is cut completely for certain areas depending on the sanctioned power and also through previous experience, this cutting of power is either greater or equal to the shortage of power at that time of the day. This still a very primitive method of power distribution, this leads to a lot of inconvenience to the consumers, even though there is a method its not a fare method. The following algorithm explains the new method of fare distribution of the limited power available during a shortage.Figure 1 gives a random data for 5 different areas (white) connected to a particular substation. As explained above the table also shows the sanctioned power of each area (green) and also the average power being utilized for each hour (yellow). The last row of the table shows the total average power being utilized for a particular hour for all the 5 areas (blue).

TABLE 1: Table containing the load profile's of all areas

LOAD		**Total Sanctioned Load (kW)**	**Avg Power Consumption at time t (kW)**																							
SL NO	**AREAS**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
1	**AREA 1**	200	97.33	97.69	56.1	96.39	109.2	91.06	64.1	68.4	119.4	127.4	93.37	104.1	103	85.94	116.1	58.16	127.7	122.2	79.81	77.77	93.68	80.65	122.5	102.5
2	**AREA 2**	122	48.81	65.12	61.95	49.88	60.3	77.85	52.53	63.7	51.29	61.46	58.49	82.52	46.56	78.14	39.47	46	52.2	43.79	61.23	67.25	54.47	62.11	72.79	64.26
3	**AREA 3**	135	64.88	49.98	69.67	91.25	64.4	96.99	75.2	63.96	46.38	59.87	87.2	86.84	87.95	44.91	96.73	50.38	51.67	75.74	58.38	72.49	66.14	70.15	75.96	38.77
4	**AREA 4**	140	77.26	69.72	81.23	56.12	65.8	56.4	83.32	62.97	94.8	56.25	54.3	49.69	78.22	51.94	53.5	63.57	87.67	55.99	59.37	54.8	80.63	57.53	67.38	50.23
5	**AREA 5**	200	110.4	116.1	87.08	119.7	78.25	102.5	101.8	98.1	100	123.5	78.97	117.5	89.34	113.5	111.3	132.8	87.89	97.66	80.48	113.8	116.2	101.9	96.92	114.3
	Total energy consumption at time 't'		398.7	398.6	356	413.3	378	424.8	376.9	357.1	411.9	428.5	372.3	440.6	405.1	374.4	417.1	350.9	407.1	395.4	339.3	386.2	411.1	372.4	435.6	370.1

A solved example with general equations is explained below.

'n' is the number of areas in a given region.

't' denote the hourly time variable in a day, i.e., between 0-24 hours.

The power supply available to area 'n' at time 't' be P_n^t.

Let the sanctioned load of each area is S_n

Assume the cost of energy from the grid set by the electricity board is G_n= 5

The total cost of power consumption to be paid by the user for a day (or 24 hours) be 'C'

This algorithm has 2 steps before we have a fare distribution of power.

Step 1

Considering table 1 area 1 at an hour 9,

t=9,

P_1^9=119.4

total power supply required at time 't' by all the areas put together or by a substation is A^t

From the table 1

A^9 = 411.9Kw

Considering a shortage of power supply by 20% i.e. around 82.38 Kw, the net supply available during shortage is a^t

a^9= (411.9-82.38) = 329.52Kw

This new availibility of power supply is further divided or redistributed based on the sanctioned power S_n instead of cutting an individual area's power supply completely the algorithm uses brood force method to tabulate the new power supply available to each area this is represented as p_n^t.

p_n^t =(a^t/A^t)* P_n^t.

p_1^9= (329.52/411.9)* 119.4= 95.52

Step 2

The step 1 is the redistribution based purely on P_n^t and the shortage of power, but if there areas having the same S_n , the P_n^t might be higher or lower to each other, in such cases the step 2 is initiated which takes into accout the total revenue generated R_n^t by each of the areas at the particular time, who has the same S_n.

For example revenue generated by area n= 1 at time t=9

R_n^t = P_n^t*G_n

R_1^9= 119.4*5 = Rs 597

revenue generated by area n= 5 at time t=9

R_5^9= 100*5 = Rs 500.

Hence area 1 generates more revenue for the utility at hour 9 compared to area 5. In such cases the p_n^t of these 2 areas are added and are redistributed based on revenue for fare distribution of power.

Net = p_1^9+ p_5^9 = 95.52+80 = 175.52Kw

Total revenue generated by an area for one day is

R_n

in this case R_1= 2294.55*5 = Rs 11472.75

R_5 = 2489.99*5 = Rs 12449.95

Area 1 even though has a higher requirement of power during time t=9 compared to area 5 at time t=9 is generating less revenue for one complete day compared to area 5.

New power availability for area 1 are as follows

NP_n^t = NP_1^9= (R_1/R_1+R_5)*Net =(11472.75/23922.7)*175.52 =84.175

New power availability for area 1 are as follows

NP_5^9= (R_5/R_1+R_5)*Net =(12449.95/23922.7)*175.52 =91.34.

Each area is assumed to have 10 establishments, now the new supply availability of each area has to be further fairly distributed amongst these 10 establishments, for this that same above mentioned algorithm is further broken down and the new supply availability is generated for each establishments.

The MATLAB methodology to model the demand side management optimization and scheduling are described in this section. The MATLAB code is structured in such a manner that it fetches all the input data from various excel files, these excel files can be edited for demand, for the individual load power characteristics, for the load start time, the load run time, for forecasted outage start time & outage duration etc., Once these inputs are ready we can go to the MATLAB GUI to run the code. Once the code is run for a forecasted outage it results in a new load schedule for the following day depending on the outage. Due to the unreliable grid, we have assumed an error in the outage scenario of maximum of 1 hour on either sides of the forecasted outage. Thus to simulate this unreliable grid we do a real time fuzzy logic based DSM on the loads by creating an error in the outage either in the outage start time or outage end time or even both. Thus depending on the actual outage the fuzzy logic rule base is referred for a further correction in the load schedule to reach to the best optimal cost. The baseline costs assumed for the grid is 5c/KWhr (residential) and the baseline diesel costs assumed in the simulation are 20 c/KWhr. As the power characteristics of the loads are not constant we have divided the day into multiple of a 5 minutes chunk, so 24 hours is considered as 288 chunks, by doing this we can be very accurate in calculating the effective cost, for a better and simple understanding we have assumed all the heavy loads considered in the paper i.e. 3 Geysers, 1 washing machine, 1 dishwasher & a dryer to have flat power characteristics curves.

III. OPTIMIZATION EQUATION

The cost minimization equation is as follows: Input parameters

LPASSIVE(t) - Passive Load at time t

LSHIFT,i(t) - Shiftable Load i at time t

Total Load ∑(L(t)) = ∑LPASSIVE(t) + ∑LSHIFT,i(t) for i=1,n tG Grid available time for a day

tB Diesel usage time in a day

CG(tG) Cost per unit with grid

CB(tB) Diesel cost per unit

Total cost per unit at time t C(t) = CG(tG) + CB(tB)

Total Cost CTOTAL = ∑C(t)L(t) for t = 0,24

COPT = Min (CTOTAL)

Algorithm: - Finding optimal load schedule is done by following the below mentioned flowchart in Figure 2.

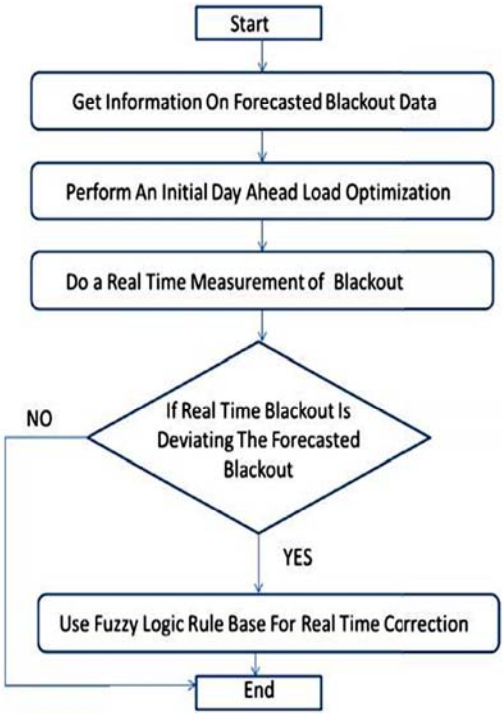

Figure 2: Basic algorithm flow chart

$L1_{NrsT}$ - Normal Start Time Of Load (1)

$L1_{NST}$ - Earliest Start Time Of Load (1)

$L1_{LST}$ - Latest Start Time Of Load (1)

$L1_{RT}$ - Run Time Of Load (1)

$L1_{NrET}$ - Normal End Time Of Load (1)

$L1_{NrET} = L1_{NrsT} + L1_{RT}$

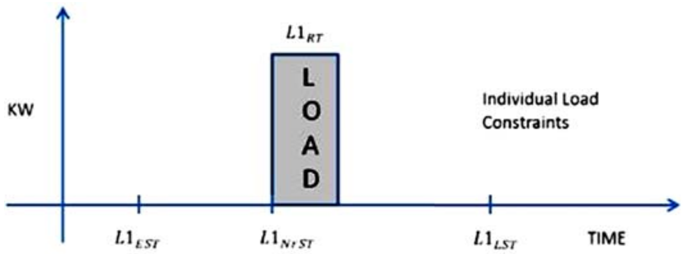

Figure 3. Load schedule constraint

Figure 3 speaks about how every shiftable load is normally scheduled & also what are its constraints i.e. the load cannot be shifted randomly during the day but has an earliest start limit & also a latest start limit. Hence any shifting of these loads has to be done between this time frame.

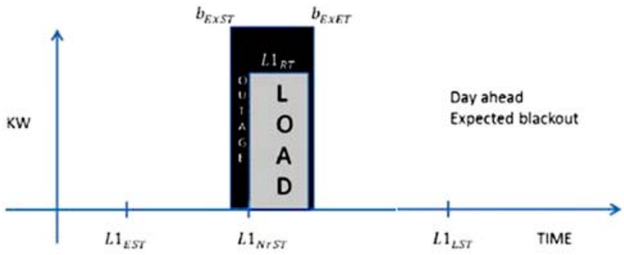

Figure 4. Expected outage for the following day

b_{ExST} - Expected Outage Start Time

b_{ExST} - Expected Outage End Time

In **Figure 4** we can clearly observe that the outage is expected to affect the load, thus this load has to be shifted, Thus the load is scheduled to a new start time either before the outage or after the outage, this completely depends on the load constraints & also the runtime of the load, if the gap is available on both sides of outage, the algorithm chooses to shift the load before the outage as it is safer to execute the load beforehand, rather to risk the execution of the load with the unreliable grid supply. This is seen in **Figure 5**.

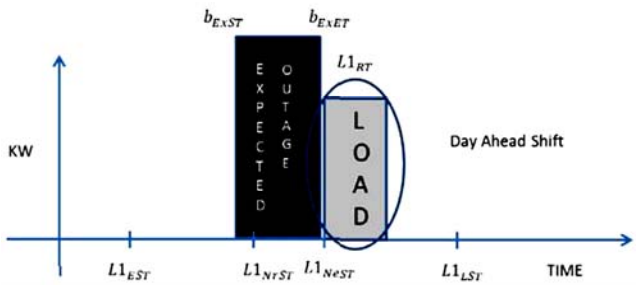

Figure 5 Day ahead Load Shift Schedule

$L1_{NeST}$ - New Expected Load Start Time

$L1_{NeET}$ - New Expected Load End Time

$L1_{NeET} = L1_{NeST} + L1_{RT}$

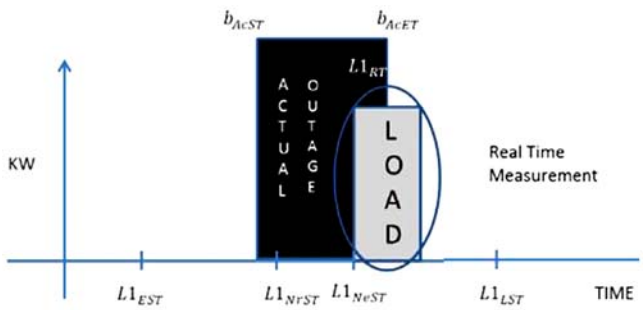

Figure 6. Actual Outage

b_{AcST} - Actual Outage Start Time

b_{AcET} - Actual Outage End Time

In **Figure 6** we can observe that the actual outage is overlapping the new scheduled start time of the load, this data is obtained from the real time supply sensors. Now the real time Fuzzy Logic Rule base for this kind of a scenario where a second shift of the load is required comes into action. The rule mentioned below comes into action & the load is shifted at the b_{AcET} as shown in figure 7.

If $b_{AcST} \leq L1_{NeST}$ & $L1_{NeST} \leq b_{AcET} \leq L1_{NeET}$ =>2[nd] Shift

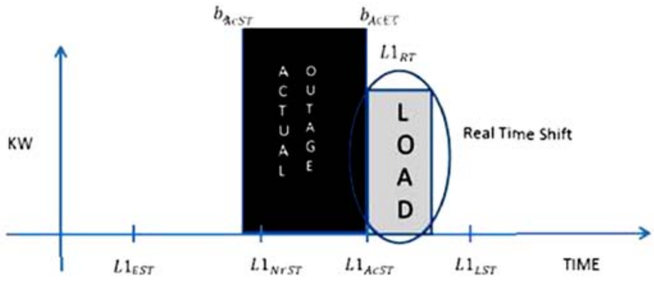

Figure 7. Actual Load Schedule.

$L1_{AcST}$ - Actual Load Start Time

Thus the $L1_{AcST} = b_{AcET}$

All the shiftable loads undergo this exercise to get the best possible optimal solution to attain the least cost, by finally reaching COPT = Min (CTOTAL)

IV. RESULTS

In this section, the key results and benefits from the MATLAB program for the creation of a partial outage state for both residential and non-residential areas are discussed. For each hour, different cases for load shortage are taken by varying the shortage, based on the shortage percentage (i.e., 20%, 40%, 60% and 80%).

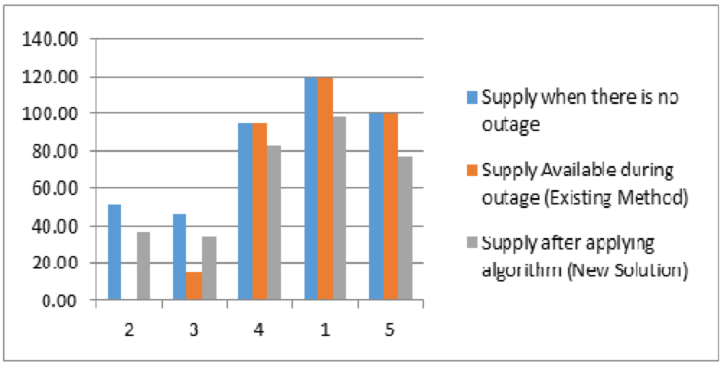

Figure 8: Shows Different Supply patterns for a 20% shortage of power

TABLE 2: Shows supply distribution for each establishment in an area for 20% shortage of power

Buildings	Total Sanctioned Load	Actual Supply when there is no outage	Supply available during an Outage	Supply Available after applying algorithm	Supply Deducted after applying algorithm
House 1	6	5.75	0.00	3.92	1.82
House 3	10	3.52	0.00	2.31	1.21
House 4	10	9.03	0.00	8.03	1.00
Shop 3	14	9.02	6.26	8.24	0.78
House 2	20	5.54	5.54	4.74	0.80
Hospital 1	20	3.31	3.31	2.55	0.76
Shop 1	30	28.79	28.79	24.80	3.99
Shop 2	30	7.80	7.80	3.99	3.80
School 1	30	19.47	19.47	15.89	3.58
Hospital 2	30	27.15	27.15	23.85	3.29

Observing Table 1, Figure 1 and Table 2, area 1 has been considered for this case. The actual load requirement at 9am is 120KW for area 1 observe the blue line in figure 1, where as from Figure 1 we observe that there has been 20% shortage of supply at 9am for area 1. In the existing scenario we can observe that area 2 is completely cut off and area 3 is partially cut off observe brown line in Figure 1. After applying the algorithm the green line in Figure 1 shows the redistributed supply finally creating an equilibrium state by not shutting off any areas completely. Now observe Table 2 this explains another step further into the algorithm. Here once the algorithm calculates how much amount of load has to be cut, it has to further cut that load from houses or other establishments, hence referring to Table 2 instead of cutting the supplying to house 1, 3 & 4 completely, all the establishments in that area get a partial outage.

Results of Load Shifting: Considering the load at hour 9 for house 1 from table 2, it is observed that the supply required is 5.75Kwp. Out of the 5.75Kw observe the below table after applying partial outage and load shifting algorithm, we can observe upto 90% savings at 20% shortage of supply.

TABLE 3: Cost Analysis

Supply Shortage in %	Supply Required (Watts)	Partial Supply (Watts)	Shiftable Load (Watts)
20	5745	3920	3500
40	5745	2100	3500
60	5745	280	3500
80	5745	1690	3500
Supply Shortage in %	Cost (Rs) Without Partial Outage and Loadshifting, Using Diesel Generator	Cost (Rs) After Partial Outage/ % Savings	Cost (Rs) After Partial Outage and Load Shifting
20	114.9	56.1/51.17	11.225/90.23
40	114.9	83.4/27.415	13.4/88.33
60	114.9	110.7/3.655	40.7/64.57
80	114.9	89.55/22.06	19.55/82.98

V. CONCLUSION

Every establishment is different and has its own unique constraints, but the energy supplies are limited, hence it is very important to choose the right combination of energy sources at right time of the day to achieve the best possible cost optimization possible. The case studies highlight the ease of use of the GUI developed, where the customers need not provide any technical details. The GUI can have wide applications in the domestic sector, to help consumers take a decision on installation of solar PV and also for the auxiliary supply in substations. Majority of substations in India use battery backup for their auxiliary supply. Solar plants can serve as a smarter alternative to these fuel based systems in terms of cost saving over a longer term and serving green energy, reducing the carbon footprint on our planet.

Use of multi-layer load-shifting techniques to mitigate power outages in developing countries shows significant cost savings potential by massive reduction in diesel consumption by load-scheduling. The maximum diesel reduction for the consumer due to load shifting during power outages can be approximately 45% to 75% for a flat- tariff grid. The study also showed that the actual savings potential depends on the timing of power outage, duration and the specific load characteristics. As diesel prices increase, the economic benefits of load-shifting are also increase correspondingly. For blackouts of lesser duration (e.g. 2 hrs) the benefits in saving diesel can be as much as 75%. For longer blackouts (e.g. 8 hours), the diesel savings is in the range of 20%-60%. DSM policies for developing countries should consider specific approaches to mitigate power outages and provide relief to customers. Clearly, challenges exist in implementation of DSM policies since most consumers in India and frugal markets have outdated appliances that are unintelligent with a severe need to develop low-cost smart network-controllable solutions as a retrofit.

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