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An Improved Load Shedding Scheduling Strategy for Solving Power Supply Defisit

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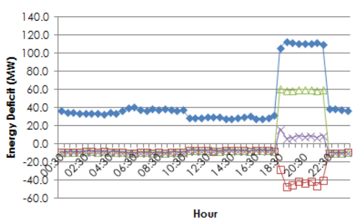
Husna Syadli[a,b,c], Md Pauzi Abdullah[a,b*], Iqbal Faridiansyah[a,b,c], Mohammad Yusri Hassan[a,b], Faridah Hussin[a,b]

[a]Centre of Electrical Energy Systems (CEES), Institute of Future Energy, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia
[b]Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia
[c]Electrical Department, Faculty of Engineering, Universitas Malikussaleh, 24351 Aceh, Indonesia

*Corresponding author
mpauzi@ utm.my

Graphical abstract



Abstract

When high electricity demand growth not matched by the growth in generating capacity, energy deficit problem cannot be avoided. Power outages of up to 6 hours per day are part of the power crisis experienced by electricity consumers in Sumatra. The utility has applied load shedding approach to tackle the problem, however, there are weaknesses on the current load shedding program. It is discovered that most of the power outage occurs randomly without any prior notice and sometime lasted for many hours. Load shedding program is not properly scheduled and not fairly distributed among all consumers. A proper scheduling program must have a clear periodic schedule, fixed outage hours, fairly distributed and alternated among consumers and most importantly solve energy deficit problem. This paper presented an improved load shedding scheduling strategy based on Round Robin method. The method is then illustrated and applied on actual daily load profile of Sumatra electrical system.

Keywords: Load shedding, scheduling, round robin, energy deficit

1.0 INTRODUCTION

High energy deficit has been a problem for Sumatra Indonesia because their production of electricity cannot meet the significant increase in electricity demand caused by population growth. Hence, power outages among electricity consumers are inevitable and caused discomfort among them. These energy deficit problems have led to rolling blackouts that are carried out for 2 to 3 hours, and maybe 6 hours a day on each consumer. It becomes even uncomfortable when blackouts can occur at any time and at any duration. Domestic consumers faced difficulties to plan their daily activities due to random blackouts. For industrial users, this will interrupt their daily production causing them to put up their own generating sets, hence increasing their operating costs. Work in [1], has proposed to use DSM approach as one of the many options to solve the problem of energy deficit in Sumatra. Although some DSM methods are cheap, their effectiveness is limited. There are more effective methods such as the use of renewable energy technology, but it requires high investment and requires a longer time before getting their impact.

The immediate and effective solution to resolve the energy deficit problem is by using load shedding scheduling or rolling blackouts as what is currently being used by the electricity utility in Sumatra. This method will shed the supply of electricity to consumers in rotation to reduce electricity demand. This method is effective to reduce the deficit because it reduces the demand for electricity. However, it must be properly schedule so that the blackout rotation is made in fair manner. For a power system like Sumatra, this is a great challenge due to significant energy deficit for 24 hours especially at peak hours (7pm-10pm), complicated system requirements and the electrical load is keep changing all the times. As a result, the blackouts are sometimes made irregular, not on schedule, the period is too long and so much more.

This paper proposes an improved load shedding scheduling strategy based on the concept of Round Robin Scheduling theory to gain fair and systematic rolling blackouts. Details of the proposed strategy and its illustrative example will be presented in later section. The next section presents the background of the electric system in Sumatra and energy deficit problems being faced by them

2.0 LOAD SHEDDING

Load shedding is the last step to prevent the collapse of the country's entire power system. When there is not enough power station capacity to supply demand (load) of all consumer, electrical system becomes unbalanced, which can cause it to travel out of the country-wide (a blackout), and that can take days to recover. When the power is not enough, the electricity utility company may either increase supply or reduce demand to bring the system back into balance. The utility usually takes a sequence of steps to ensure a stable system and to avoid the burden of shedding the demand/load. The first step includes asking for large consumers to reduce their demand/electricity consumption on voluntary basis. However, if the deficit is sudden, the utility may go directly to load shedding to prevent the system from becoming unstable.

Methods to solve the problem of inadequate supply have been raised in previous studies [3-6]. Many methods introduced are for solving temporary shortage of supply caused by unplanned cuts. Total energy deficit is not large, so the load reduction can be made in various ways such as frequency control, voltage control using a variety of computing intelligence techniques. However their impact is limited and cannot be used in cases where energy deficit is significant. In such cases, the direct and effective way is to delete the load in rotational basis. In other words, the consumer is taken out of service, and then reinstated, by way of rotation. The main challenge is to develop a method of outage schedule that is fair and efficient. A good schedule should make sure the user experience minimum electricity outage period, blackout divided evenly on each user, different time every day and so on. The schedule should also be prepared in advance with a supply outage notice to enable users to plan ahead. From a survey conducted in South Korea, due to a serious imbalance in the supply and demand, causing a blackout in 2011, researchers estimated the cost of the difficulty of a sudden rolling blackout is 3,900.67 KRW (3.56 USD) per month for each household, while a rolling blackout with early notice to be at 3,102.95 KRW (2.83 USD). The study shows that the cost can be reduced nationwide by providing advance notice of planned rolling blackouts (Load Shedding Schedule) to consumers [3]. Thus, it is important for the schedule to be published in advance so that consumers can know the day and time when they would be compromised if load shedding became necessary. Furthermore, the schedule must be simplified to make the schedule easier to understand and remember, improve the utility ability to comply with the planned schedule and improve the consistency and predictability of schedule.

3.0 THE CONCEPT OF SCHEDULING

In literature, scheduling methods is widely used for solving computer processing problem. Some of the methods that commonly used are Priority Based, Shortest Job First (SJF) and Round Robin Scheduling [7,8]. In Priority Based Scheduling, each process will be given priority to be decided by any needs. The process with the highest priority will be executed first and so on. Shortest Job First (SJF) is a set of strategies to implement the process with the least processing time first. Round Robin (RR) was one of the oldest scheduling algorithms, the simplest and most equitable and the most widely used. Each process is allocated with processing time so-called quantum. Each process will be executed one-by-one on rotational basis.

For load shedding scheduling problem, the process to be executed in computer processing problem is substituted by the load/consumer to be shed. Therefore, based on the Priority Based Scheduling, load with the highest priority will be deleted first. In the case of power system, the loads which are critical such as hospital may be given lowest priority whereas loads which are not so critical such as residential homes may be given the highest priority in shedding. For Shortest Job First (SJF) scheduling, load with the lowest demand will be shed first followed by the next load with next lowest demand until the energy deficit problem at that particular hour is solved. While effectively solve the problem of energy deficit, both Priority Based and Shortest Job First Scheduling cannot provide a fair schedule to all consumers since the same consumers may be repeatedly being shed as compared to others. In Round Robin scheduling, every consumers/load will be shed one-by-one on rotational basis. As all loads will be affected and participated in the shedding, the method is fair and more favorable. Round Robin method requires the quantum size of each hour to be the same. The quantum size in this problem is the electricity demand size of each load that must be the same. Every load is unique and it is changing all the time thus it is impossible to get similar load demand at each hour. To overcome this, the load/consumers must be grouped in such a way that the electricity demand of each grouped load is the same/almost the same at the same hour. Also, the demand-quantum size needs to be appropriate. If the size is too large, the amount of shedding may be more than required hence causing loss to the utility. If the size is too small, the shedding of load for certain times may not solve the energy deficit problem.

This paper proposes a strategy for load shedding scheduling based on Round Robin scheduling theory. The concept of sub-schedules in the schedules was introduced to overcome the problem of demand-quantum size. Each grouped consumer will be arranged into the load shedding schedule one by one in sequence (Round Robin). If there are still unsolved energy deficit problem at any particular hour/s, sub-schedule will be introduced in the original schedule at that particular time and the grouped consumers will be arranged once again in this sub-schedule. This step continues until the energy deficit problem is solved. The proposed method will be presented in details in the next section.

4.0 THE PROPOSED LOAD SHEDDING SCHEDULING

The proposed scheduling for load shedding is described as follows.

4.1 The steps

Step 1: Grouping the loads/consumers

In order to apply Round Robin method for load shedding, the load-quantum size of all grouped consumers of a particular hour must be approximately the same. The quantum size can be different at different hour. This ensures that the amount of electricity demand that being shed at any particular hour remain approximately the same even though demand from different group is shed. Once the consumers have been grouped, the number of grouped consumers N_{groups} can be obtained.

Step 2: Determining number of daily time slots

The number of time slots in one day depends on the total duration for load shedding in one day and the duration of each shedding for each grouped consumers. The number of daily time slots can be calculated as follows:

$$\mathrm{N_{slots}} = \frac{\mathrm{T_{affectedhours}}}{\mathrm{T_{shedding}}} \quad (1)$$

where$T_{affectedhours}$ is the total affected hours in one day while $T_{shedding}$ is the duration of each load shedding. For example, if the affected hours is 24 hours and the duration of each shedding is 2 hours, then there will be 12 slots. To avoid the same consumer being shed at the same time slot every day, then the following rule is applied: $N_{slots} \neq N_{groups}$

Step 3: Develop Round Robin Scheduling

Distribute the grouped consumers in the time slots base on Round Robin. For example, if there are grouped consumers A, B, C, D, E and 4 time slots in one day, the consumers will be distributed as illustrated in Table 1.

Table 1 Development of round robin scheduling

Time Slots	Day				
	D_1	D_2	D_3	D_4	D_5
t_1	**A**	**E**	**D**	**C**	**B**
t_2	**B**	**A**	**E**	**D**	**C**
t_3	**C**	**B**	**A**	**E**	**D**
t_4	**D**	**C**	**B**	**A**	**E**

Step 4: Develop Round Robin Sub-Scheduling

If the energy deficit is not solved in particular/some time slot/s, sub-scheduling inside the scheduling in previous step is developed. In this sub-schedule, the grouped consumers are distributed again using Round Robin approach. The allocated grouped consumer at each time slot must not the same as the grouped consumer in the earlier schedule (from previous step). For example, if the energy deficit is not solved at time slots t_3 and t_4, a new sub-schedule will be introduced at t_3 and t_4 as follows:

Table 2 Development of round robin scheduling with sub-scheduling

Time Slots	Day				
	D_1	D_2	D_3	D_4	D_5
t_1	**A**	**E**	**D**	**C**	**B**
t_2	**B**	**A**	**E**	**D**	**C**
t_3	**C,B**	**B,A**	**A,E**	**E,D**	**D,C**
t_4	**D,C**	**C,B**	**B,A**	**A,E**	**E,D**

This step is repeated until all energy deficits are solved.

4.2 Illustrative Example

To illustrate the proposed method, a simple example is used. Consider a power system with 10 consumers (L1-L10). It is assumed that the electricity demand of each consumer at 5 hours (load profile) has been forecasted and is given in Table 3. The total demand, generation availability and the resulting energy deficit at each hour are given in Table 4.

Table 3 Load profile of each consumer

Consumers	$hour_1$	$hour_2$	$hour_3$	$hour_4$	$hour_5$
L1	5	5	7.5	10	5
L2	3	3	3.5	4	3
L3	2	2	4	6	2
L4	5	5	7.5	10	5
L5	4	3	4	5	3
L6	1	2	3.5	5	2
L7	8	8	5	5	8
L8	2	2	10	15	2
L9	5	5	7	8	5
L10	5	5	8	12	5

Table 4 Data of the system

	$hour_1$	$hour_2$	$hour_3$	$hour_4$	$hour_5$
Total Demand	40	40	60	80	40
Generation Availability	30	30	32	40	32
Deficit	10	10	28	40	8

Step 1: Grouping the loads/consumers

The consumers are grouped together to gain same demand quantum size at each time slot, as given in Table 5.

Table 5 Consumers that have been grouped and their demand data

Group	Consumers	$hour_1$	$hour_2$	$hour_3$	$hour_4$	$hour_5$
G1	L1+L2+L3	10	10	15	20	10
G2	L4+L5+L6	10	10	15	20	10
G3	L7+L8	10	10	15	20	10
G4	L9+L10	10	10	15	20	10

Step 2: Determining number of daily time slots

It is assumed that the affected hours is 5 hours and the duration of each time slot is 1 hour. Thus the number of time slots in one day is

$$N_{slots} = {}^{5}/_{1} = 5 \text{time slots}$$

Step 3: Develop Round Robin Scheduling

The grouped consumers are distributed in the schedule one-by-one on rotational basis as given in Table 6. The resulting demand and energy deficit with the load shedding schedule are given in Table 7.

Table 6 Round Robin Scheduling of the grouped consumers

Time slots	D_1	D_2	D_3	D_4	D_5
t_1	G1	G2	G3	G4	G1
t_2	G2	G3	G4	G1	G2
t_3	G3	G4	G1	G2	G3
t_4	G4	G1	G2	G3	G4
t_5	G1	G2	G3	G4	G1

Step 4: Develop Round Robin Sub-Scheduling

From Table 7, the energy deficit is not solved in hour 3 and hour 4. Sub-scheduling for time slot 3 and 4 (for hour 3 and hour 4) is developed as illustrated in Table 8. It can be seen from Table 9 that energy deficit is solved.

Table 7 Data of the system with load shedding schedules

	$hour_1$	$hour_2$	$hour_3$	$hour_4$	$hour_5$
Total Demand	30	30	45	60	30
Generation	30	30	32	40	32
Deficit	0	0	13	20	-2

Table 8 Round robin schedule with sub-scheduling

Time slots	D_1	D_2	D_3	D_4	D_5
t_1	G1	G2	G3	G4	G1
t_2	G2	G3	G4	G1	G2
t_3	G3,G2	G4,G3	G1,G4	G2,G1	G3,G2
t_4	G4,G3	G1,G4	G2,G1	G3,G2	G4,G3
t_5	G1	G2	G3	G4	G1

Table 9 Data of the system with sub-scheduling

	hour 1	hour 2	hour 3	hour 4	hour 5
Total Demand	30	30	45	60	30
Generation	30	30	32	40	32
Deficit	0	0	-2	0	-2

5.0 CASE STUDY: SUMATRA POWER SYSTEM

5.1 Background of The System

The electrical power system in Sumatra consists of Northern Sumatra, Middle Sumatra and southern Sumatra electrical systems. Power outages in northern Sumatra are still continued to occur due to the high electricity demand growth is not matched by sufficient generation capacity. Among the contributing factor to the problem is the delay in several power plant projects such as steam power plant Nagan Raya in Aceh, PangkalanSusu in North Sumatra, and TelukSirih in West Sumatra. Also there are delays in geothermal power plants in Tapanuli Utara and hydropower power plants in Lampung. Another contributing factor is due to shut down of some generation plants to aging machines and damage.

Figure 1 show the yearly peak load recorded in Sumatra from year 2000 until 2012. The highest peak load is recorded in March 2012 at 1528.2 MW. The highest numbers of blackout events is recorded in the year 2012 in December as many as 33 times with duration between 2 to 3 hours for each blackout and some cases reaching up to 6 hours. Figure 2 shows the hourly load demand and hourly supply ability on March 26, 2012 with an installed power capacity of 2280.6MW. The highest peak load was 1528.16 MW with deficit of -431.4MW at 19:30 pm and supply power ability at 1096.8MW. Outside peak load, the highest load was 1128.28 MW with a deficit of 231.3 MW at 06:00 am and supply power ability of 897.0MW [1,9,10]

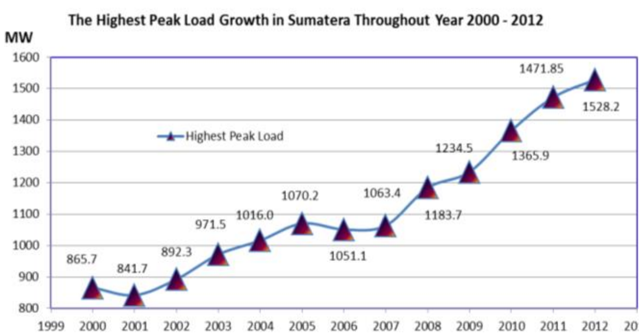


Figure 1 Peak Load Growth in Sumatra (2000 -2012)

5.2 Application of the Proposed Load Shedding Scheduling On Sumatra

Figure 2 shows the total system demand profile for Sumatra and its generation capacity for 24 hours on Monday, 1 February 2010. It can be seen that the generation capacity unable to meet the demand at every hours. The energy deficit is highly significant from time 1800 until 2200. To simplify the analysis, it is assumed that similar demand quantum size at each hour has been achieved by properly grouping the consumers in Sumatra. Also, t is assumed that the consumers have been grouped into 20 big groups (named here as G1, G2…. G20). The affected hours are 24 hours while each time slot lasted for 2 hours. Thus, there will be 12 time slots in one day. Applying the proposed load scheduling method will result in schedule (for 3 days) presented in Table 10. Note that sub-scheduling is applied twice at time slot t_{10} and t_{11} to solve the significant deficit problem from 1800 until 2200. Also, it can be seen from the table that the grouped consumers are distributed fairly in the schedule. Figure 3 shows the deficit comparison of the system between no load shedding, load shedding without sub-scheduling, with sub-scheduling 1 and sub-scheduling 2. It can be seen from the figure that energy deficit problem at most hours can be solved without using sub-scheduling. 2 times sub-scheduling is needed to solve energy deficit problem from 1800 until 2200. Due to demand quantum size, the amount of demand that being shed during these hours is above the required amount. This however can be solved by using smaller demand quantum size. Doing this may increase the number of sub-scheduling.

The problem has been simplified to demonstrate the application of the proposed method. The daily load profile of another day may be slightly different from the one used in the study. This can be solved by using average or slightly above average daily load profile as a reference for the scheduling. Also, different schedule for weekends or public holidays may be recommended since and their demand profiles significantly different for weekdays.

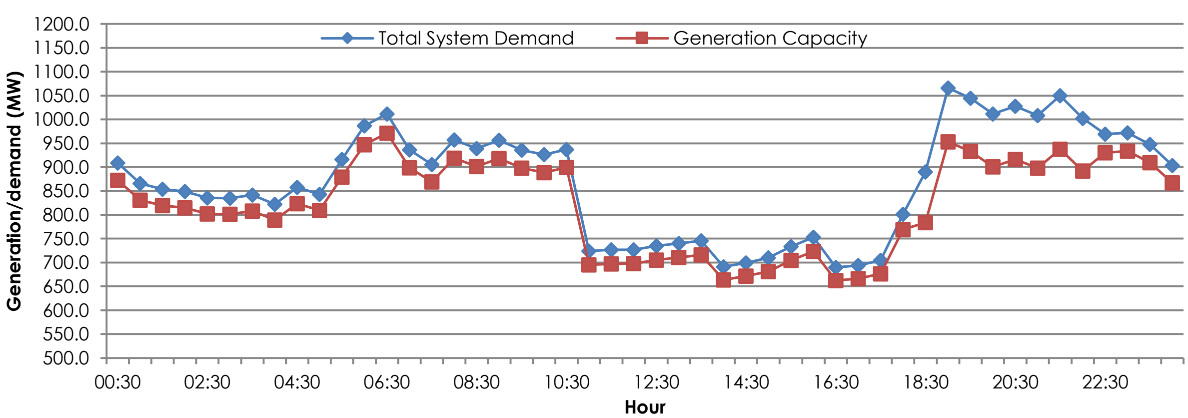


Figure 2 Total system demand and generation capacity profile for one day of Sumatra (Monday, 1 February 2010)

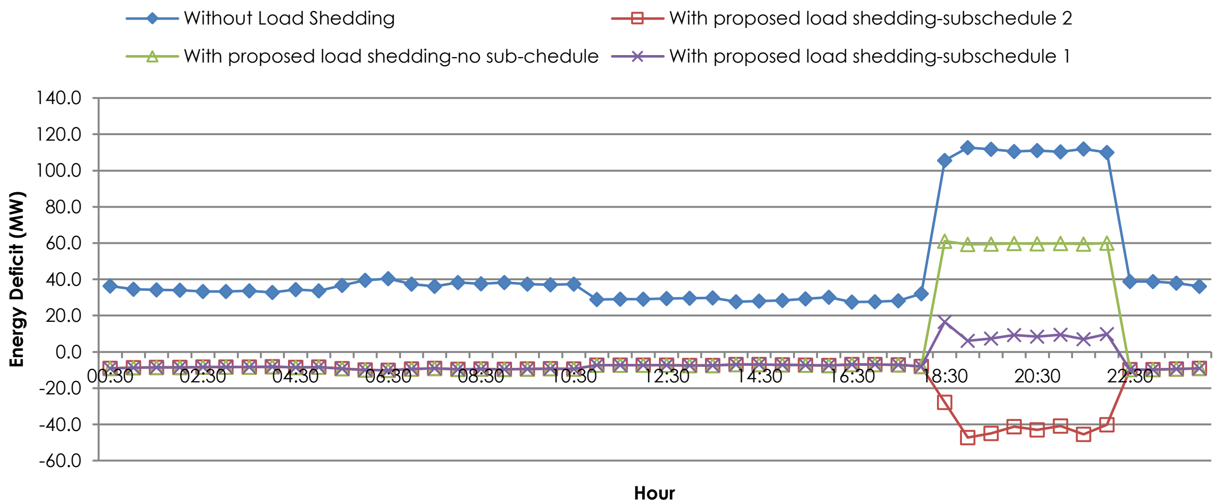


Figure 3 Energy deficits without load shedding and with load shedding scheduling

6.0 CONCLUSION

This paper has presented an improved Load Shedding Scheduling base on round robin approach to solve energy deficit problem especially in cases where generation capacity of a power system unable to meet the demand at all time. The proposed method has been illustrated and tested on actual load profile data from Sumatra electrical system. The results showed that the method is fair, systematic and importantly is able to solve the energy deficit problem.

Table 10 Load shedding scheduling by using proposed method

Time slots	D_1	D_2	D_3
t_1	G1	G13	G5
t_2	G2	G14	G6
t_3	G3	G15	G7
t_4	G4	G16	G8
t_5	G5	G17	G9
t_6	G6	G18	G10
t_7	G7	G19	G11
t_8	G8	G20	G12
t_9	G9	G1	G13
t_{10}	G10,G9,G8	G2,G1,G20	G14,G13,G12
t_{11}	G11,G10,G9	G3,G2,G1	G15,G14,G13
t_{12}	G12	G4	G16

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