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Load Shedding Scheme in Large Pulp Mill by Using Analytic Hierarchy Process and Fuzzy Analytic Hierarchy Process

H.H. GOH, S.W.LEE, B.C. KOK, K.C.GOH, T.W.SEOW & K.T.K.TEO

ABSTRACT

The advancement of technology had encouraged mankind to design and create useful equipments and devices. These equipments enable users to fully utilize them in various applications. Pulp mill is one of the heavy industries that consumes large amount of electricity in its production. Due to this, any malfunction of the equipment might cause mass losses to the company. In particular, the breakdown of the generator would cause other generators to be overloaded. Thus, load shedding scheme is the best way in handling such condition. Selected load will be shed under this scheme in order to protect the generators from being damaged. In the meantime, the subsequent loads will be shed until the generators are sufficient to provide the power to other loads. Once the fault had been fixed, the load shedding scheme can be deactivated. In order to determine the sequences of load shedding scheme, analytic hierarchy process (AHP) is introduced. Analytic Hierarchy Process is one of the multi-criteria decision making methods. It had been used in solving a lot of decision making problems since ages ago. AHP is widely used in comparing the options in order to achieve the goal. For the application of AHP in load shedding, the operating load and the area power are chosen to be the criteria. The options of each criterion will be the load of the electrical system in the pulp mill. On the other hand, fuzzy AHP is the advanced version of AHP which can solve the uncertainty of the pair-wise comparison and gives more accurate results in fuzzy situation. This paper presents the alternative methods to choose the load priority in load shedding scheme for a large pulp mill. The results of the AHP and fuzzy AHP analysis to the pulp mill are very promising.

Keywords: Analytic Hierarchy Process (AHP), fuzzy AHP, load shedding, pulp mill.

INTRODUCTION

China is one of the mass production countries around the world. The import activities and consumption of paper is in a huge amount. China's pulp mill industries grow by importing the pulp wood to 300% of the previous amount from 1997 to 2003. It covers 13% of the global market. According to the paper production and consumption statistic, pulp production in China amounted approximately 20 million metric tons in 2008. There are also 84 million tons of paper and board production in total. Besides, China also imported 10 million tons of pulp and 24 million tons of recycled fibre [1]. Many of the investors around the world had taken the opportunity to establish their industries in China. Asia Pulp & Paper (APP) which is maintained by Sinar Mas Group from Indonesia is one of the largest organizations among the competitors. The APP's production facilities implement newer and more efficient paper making technology and therefore the carbons

emissions are averagely lower than most of the paper makers. Besides, APP also supports more than 500,000 hectares of tropical forest as conservation area which acts as a massive carbon storage [2]. Due to APP as one of the mass production of paper and pulp, they have the responsibility to ensure the sustainability either in conservation of social or environment.

In pulp mill, there are quite a number of areas of land being used to allocate the equipment and devices [2]. The electrical system must be well managed in order to ensure that the operation in the mill is fully utilized. However, there might be breakdown in the electrical system due to the longer working period of the machines. The malfunction of the equipment or devices might cause huge losses to the company. Due to this, the load shedding scheme is needed in the pulp mill to prevent damage of the power generator.

In order to provide the manageable and controlled over the whole system in the pulp, an advance and relevant mill wide automation system and mill wide electrical load shedding system are placed in the centre of a control room which are operated by the well trained engineers or technicians. There are a lot of supervisory control and data acquisition (SCADA) system providers and SIEMENS is one of them [3]. SIEMENS provides the software which can communicate with SIEMENS PLCs using various communication devices in different protocol. Commonly, the protocol of the devices is object linking and embedding process control (OPC), Profibus and Modbus. By using SCADA, engineers or technicians can monitor the electrical system in the control room and take the fastest response towards any problems occurred. With the SCADA system, the remote switching of equipment or devices can also be done. This is effective in order to reduce the down time of the system.

Load shedding is defined as the action of switching off the electrical supply to parts of the electricity system [4]. H.H. Goh and B.C. Kok proposed the idea of AHP in load shedding scheme for the electrical power system [5]. As in the paper, the judgments of the importance of the criteria are based on the experiences gained. For instance, the frequency is 5 times more important than voltage whereas the important of frequency is also twice of the stability. In the study, they had also justified 5 criteria and 5 alternatives as the elements in determining which is the most prior to the load shedding scheme.

Load shedding might cause the loss of some information but it is possible to keep other equipments or devices which are more important to operate. The system will operate as normal once the system had been restored. Although the practice is rare, it is a core part of the emergency management of all the electricity networks. There are several ways in handling load shedding problems. For example, proportional or priority load shedding are commonly used to alleviate network violations [6]. The loads will be cut off if the power flow and voltage could not be alleviated. Another technique which is optimal power flow (OPL) method which is proposed by Dornellas *et al.* [7] in order to solve the over curtailed problems. Besides, Wang and Billinton [8] also proposed optimum load shedding techniques to minimize the interruption cost in the power system. No matter how, the main purpose of the load shedding is to prevent the damage of the whole system.

One of the most important elements in an industry is the electricity supplies. Each component that needs the electricity will consume the power provided by the generator. The blackout will cause losses to the industry. All operations that need electricity are forced to be halted. Due to this, most of the industries usually accommodate electric power generator for emergency use. Although the

generator might not provide the electric power sufficiently, the main operation of the industry still can be maintained. However, there must be some loads that need to be shut down or turned off in order to maintain the power provided by generator during black out. Due to this, the load shedding scheme had been introduced. The main objective of load shedding scheme is to solve the system voltage, load overloading, frequency and power balance problems. For examples, G.L. Cai *et al.* [9] use optimal multiplier power flow to do the corrective load shedding algorithm. The main purpose of the corrective action is to prevent the voltage collapse. Voltage collapse could be happen if the system does not satisfy the active power and reactive power demands. Besides, under voltage load shedding can also use the prior load selection in the load shedding scheme [10-12]. C.W. Taylor stated that there can be two extremes to be considered in analysis; a high proportion of motor load and a high proportion of resistive load [10]. The under voltage relays are fixed around the potential area and activate when necessary.

On the other hand, black out will also occur when the load increasing in a short time. At meanwhile, the generator will sense the speed change and it will increase the input power. Due to the disturbance, it might cause the frequency drop. Thus, under frequency load shedding should be activated at this time. V. Chuvychin *et al.* [13] proposed adaptive under frequency load shedding and under frequency load restoration system to make the automated load shedding system to be response faster. M.Karimi *et al.* used under frequency load shedding method on islanded distribution network in Malaysia [14]

For the application of load shedding for shipboard power systems, Z.P. Ding, S. Srivastava, and D. Cartes used AHP loads priority selection [15]. They used AHP to calculate the weight factor of each system criterion and it is effective. Generally, the load shedding of shipboard power system (SPS) is performed in several stages. The load shedding stage will trigger one by one until the load had been curtailed to the preset safe level. The triggering time for the power relay is preset by the technicians or engineers. If the stage 1 of the load shedding scheme did not reduce the electric plant load sufficiently, the stage 2 will shunt the breakers automatically [15]. Besides, there are researchers using neural network and differential evolution to execute optimum load shedding scheme for voltage stability [16-18].

For this paper, the priority of the criteria is initially unknown. The ratio among the criteria will be determined. From the result, the prior of the criteria will be obtained. The objectives of this paper are to study alternative ways to remove overloads situation of load shedding scheme in a large pulp mill by using Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (Fuzzy-AHP). In addition, the efficiency of both multi decision making methods is compared.

BACKGROUND OF STUDY

The application of analytic hierarchy process

The AHP approach is a powerful and flexible decision making process, and it was developed by Dr. Thomas Saaty, professor at the University of Pittsburgh [19]. It can be used either for the analysis or comparison among criteria. Christos Douligeris [20] had used AHP in analyzing and comparing the quality of several telecommunications companies. He also made the evaluation of alternate technologies in telecommunication [20].

On the other hand, Les Frair *et al.* had used Analytic Hierarchy Process in undergraduate curriculum evaluation. During the evaluation, the affected parties (students, faculty, employers, etc.) evaluate the curriculum alternatives through internet web site [21].

Besides, the AHP approach is also used in solving management problem. For example, Krystak Ramoutar and Chanan S. Syan analyzed the critical factors associated with successful implementation of WCM techniques in ISO 9001 certified firms based on AHP. They found that resistance to change is the most critical factor that leads to successful of ISO9001 implementation [22].

S. Yue, J. Yu, and B. Liang used the combination of data envelopment analysis (DEA) and AHP in their research on based assessment method of power system black-start effective schemes of ancillary services. By using the AHP approach, the best sequence of restoration path had obtained [23].

In the production of a company, the selection of machine tool must be done wisely. There are a lot of criteria need to be considered such as cost, profit, and period of modal returning. In order to make the best decision with given conditions, E. Cimren *et al.* used the AHP approach in machine tool selection. The priority of the alternatives can be changed from time to time. For example, one of the alternatives in machine tool named MX-50HB was ranked in the first place if cost analysis is the most prior for all the criteria. However, once the most prior criteria changed to reliability, machine tool named V-40 became the first among alternatives [24]. Thus, it is possible to make the final decision if the priority among cost and reliability could be identified clearly.

The application of fuzzy analytic hierarchy process

The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is the extension of AHP method that can solve the uncertainty of the fuzzy data. Due to the fuzzy situation, the data might be insufficient to make a comparison. The triangular fuzzy numbers are used for the preferences of one criterion over another in the fuzzy AHP approach. Then, the synthetic extent value of the pair wise comparison is calculated [25]. Fuzzy AHP is widely in used practically. For example, S. Mahmoodzadeh *et al.* [26] had proposed a new method which is a combination of fuzzy AHP and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to deal with project selection problems. On one hand, B. Serkan and K. Serdar also used the combination of fuzzy AHP and TOPSIS method to select the operating system [27]. On the other hand, H.H. Goh *et al.* used the combination of AHP and TOPSIS to analyse the load shedding for a pulp mill [28].

Meanwhile, M. Monitto *et al.* [29] used fuzzy AHP to make the decision in selection of the best Automated Manufacturing System. According to M. Monitto, the fuzzy AHP is able to manage the uncertainty and to consider productivity and flexibility issues. In particular, uncertainty due to unpredictable conditions has been analyzed by relationships among the fuzzy parameters related to the uncertain events. Furthermore, T.S. Li and H.H. Huang also used fuzzy AHP to develop innovative design for automated system [30]. They used the Russian Theory of Inventive Problem Solving (TRIZ) to propose the new automated design alternatives under innovative design consideration and then used the fuzzy AHP to support the evaluation of alternatives under vagueness and uncertainty situations.

In comprehensive survey, the AHP and fuzzy AHP have not been introduced in load shedding priority selection. Thus, the new method in determining the priority will be discussed in this

paper. Each of the method has its significant difference. The comparison between two methods will also be discussed in this paper.

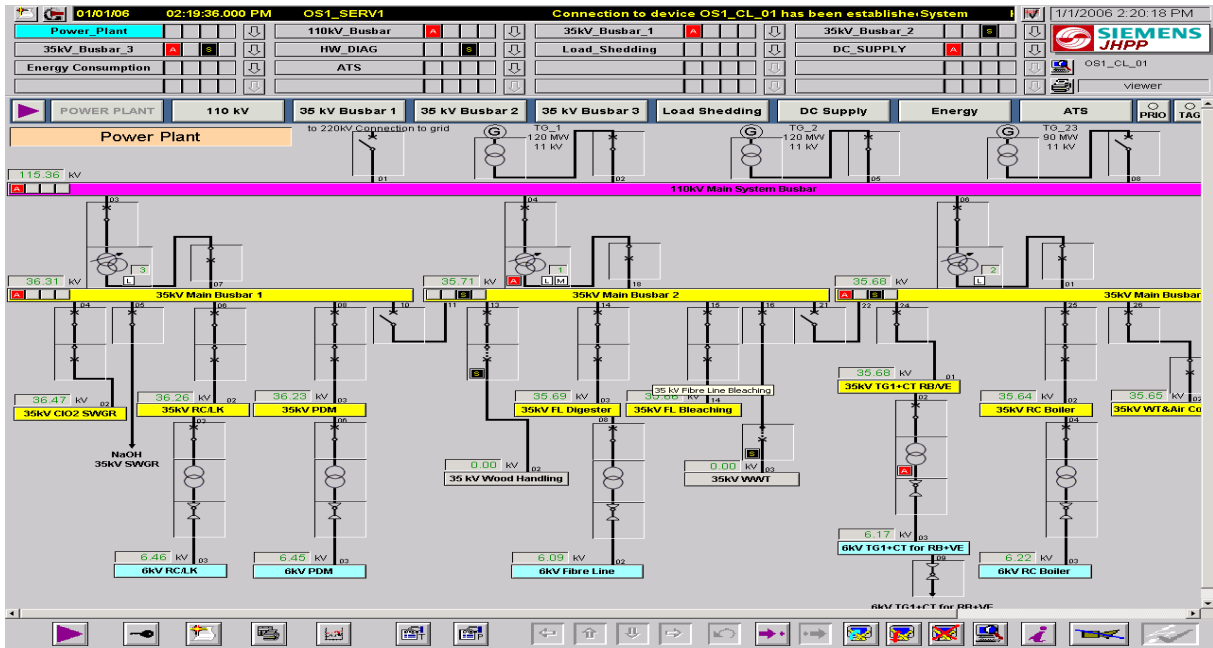


Figure 1: Pulp mill electrical system.

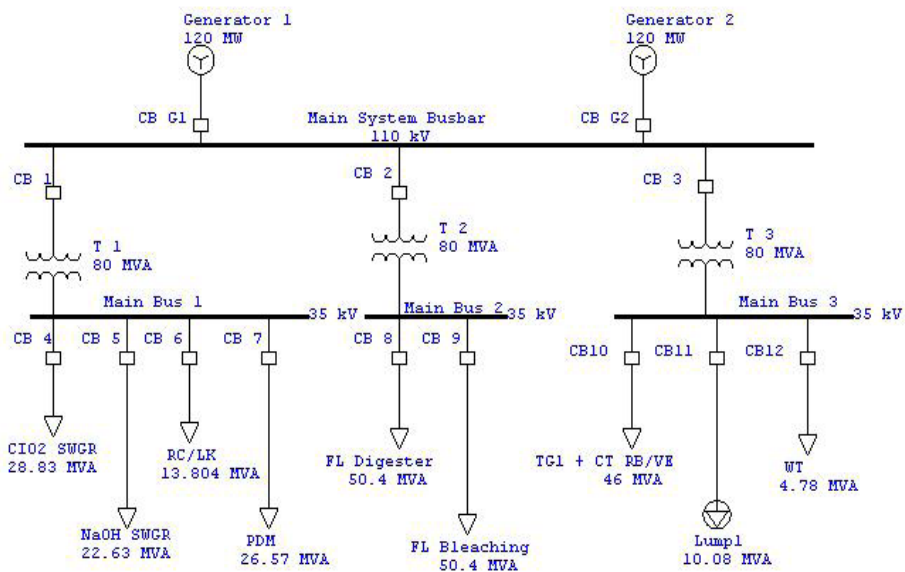


Figure 2: The one line diagram of the pulp mill electrical system using ETAP.

PULP MILL INFORMATION

For this paper, the load shedding scheme in a pulp mill is being studied. Figure 1 illustrates the electric power system of the pulp mill. Basically, the pulp mill electrical system can be divided into a few parts such as:

- 1 3-phase, 50Hz voltage level
 - High voltage : 110kVac
 - Medium voltage : 35kVac and 6kVac
 - Low voltage : 690Vac and 400Vac
- 2 3×Turbine generator: $2 \times 120\text{MW} + 90\text{MW} = 330\text{MW}$ and the connection to 220kV grid system.

The studies of application of AHP and fuzzy AHP will be conducted based on the information given as shown in Figure 1. The connection from the system to the grid had been tripped and the connection of the 90MW generator had been cut off. The generator is overloaded. In such circumstances, the load shedding scheme is activated. There are three main bus bars in the pulp mill electrical system. However, the bus bar 3 contains the RC boiler is having exception from the load shedding scheme. The boiler plays an important role in power recovery [31]. This is because the boiler will keep generating the steam for the steam turbo generator in order to make sure those operations of others equipments do not come to a halt.

In the analysis of the load effect, the circuit in Figure 1 can be designed by using electrical engineering power system analysis software, ETAP. The circuit in ETAP is shown in Figure 2. The information of the operating loads and estimation of power required for each area are shown in Table 1.

From Table 1, there are 25 areas in total. However, the analysis of the load shedding will only be done in those areas as in Figure 1. In addition, the operating load and estimation of area power will be filtered if both of the values are not significant. For an example, the load for RC/LK is 8MW in total and the estimation power of RC/LK is 13.8MW. Both values are less significant if compared with CIO2 REC, NaOH REC, PDM and FL. For the bus bar 3, it is important in power recovery process, thus it will not be included in the load shedding analysis. For those areas that are not in Figure 1 will not be considered in the load shedding scheme analysis.

RESULTS AND ANALYSIS

Analytic Hierarchy Process

From the Table 1, there are 7 information of the pulp mill listed. They are area, estimation of area power, Siemens load list, load factor, estimation of operating load power, LV motor and HV motor. For the area, it is essential for the analysis because it can clarify which part of the electrical system is facing problems. Estimation of area power is the information of power that delivered to the area. For the estimation of operating load power, it shows how much is the output power of that area. On the other hand, the Siemens load list will only work with Siemens software and hence, it does not included in the load shedding analysis. The same goes to load factor, most of the area has the same value. For the LV and HV motor, the availability of the motor will only affect the reactive power. Generally, name of the area, estimation of area power and estimation of operating load power are the key points in load shedding scheme.

Table 1: The pulp mill loading estimation.

Mill Wide Loading Estimation							
No	Area	MW	A	B	AxB	LV	HV
1	RC	10.08	11.24	0.55	6.2	135	0
2	LK	3.724	3.236	0.55	1.8	80	0
3	CIO ₂	1.088	1.088	0.55	0.6	45	0
4	CIO ₂ R	28.83	28.83	0.95	27.4	0	0
5	NaOH	2.328	2.328	0.55	1.3	102	0
6	NaOHR	22.63	22.638	0.95	21.5	0	0
7	CT	3.5	4.332	0.55	2.4	26	0
8	H ₂ SO ₄	0.61	0.893	0.55	0.5	49	0
9	PC	0.384	0.384	0.55	0.2	42	0
10	O ₂	5.253	8.831	0.55	4.9	28	0
11	WT	4.78	5.825	0.55	3.2	105	0
12	WWT	5	3.883	0.55	2.1	120	3
13	Comp	2.347	2.347	0.55	1.3	10	0
14	RB	30.5	22.88	0.55	12.6	303	9
15	VE	7.245	7.245	0.55	4.0	54	0
16	MB	13.139	13.08	0.55	7.2	123	6
17	TG1	0.8445	0.8445	0.55	0.5	35	0
18	TG2	0.4885	0.4885	0.55	0.3	21	0
19	TG3	0.246	0.246	0.55	0.1	17	0
20	COAL	3	3	0.55	1.7	40	0
21	CTVE	6.725	14.877	0.55	8.2	20	6
22	CTTG	8.249	15.161	0.55	8.3	25	4
23	WH	11.2	7.06	0.55	3.9	259	0
24	PDM	26.57	31.572	0.55	17.4	621	11
25	FL	50.4	37.45	0.55	20.6	290	6
TOTAL		249	249		158.0	2550	45

* MW = Area power in Megawatt (MW)

* A = Siemens load list

* B = Load factor

* AxB = Estimate operating load

* LV = Low voltage motor

* HV = High voltage motor

From the key points selected, estimation of area power and estimation of operating load will be the criteria for the load shedding analysis. In the meantime, the alternatives of the criteria can also be determined. As discussed in Section II, there 4 areas that more significant which are CIO2 REC, NaOH REC, PDM and FL. Hence, the criteria and alternatives of the system have fulfilled the conditions for AHP analysis. The relationship of the parameters can be illustrated as in Figure 3.

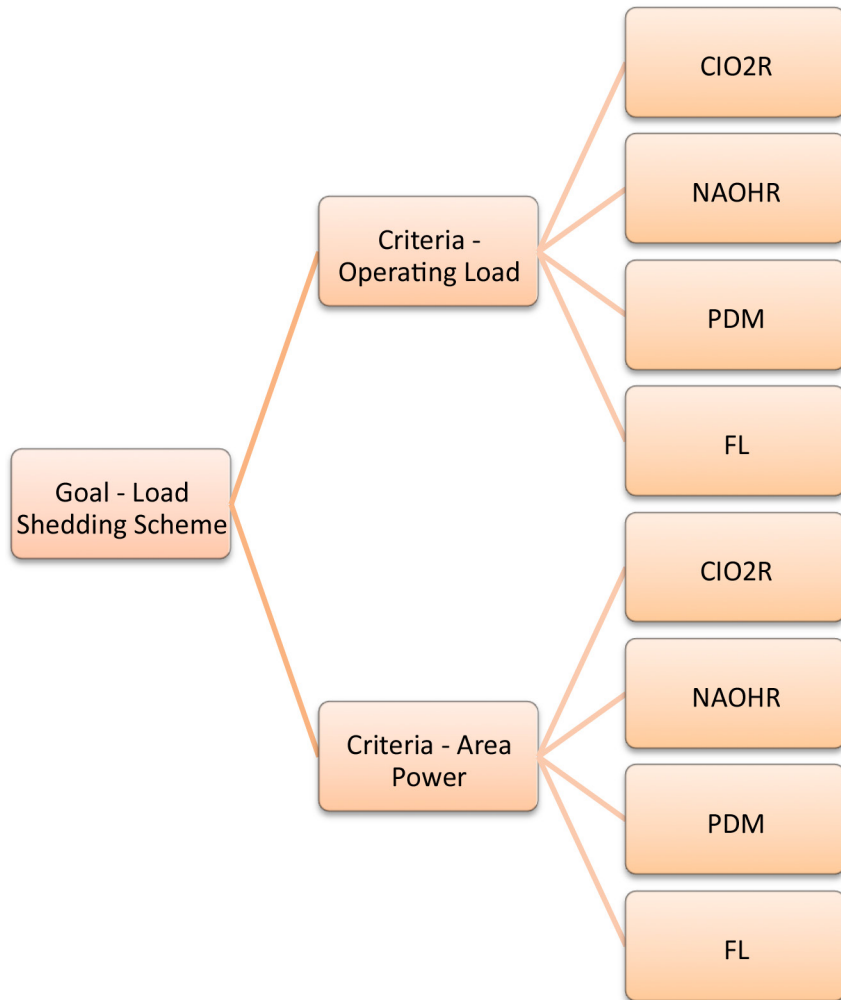


Figure 3: The hierarchy of load shedding scheme.

By using the calculation of the AHP, the importance of the criteria for operating load and area power are shown in Figure 4 and Figure 5 respectively.

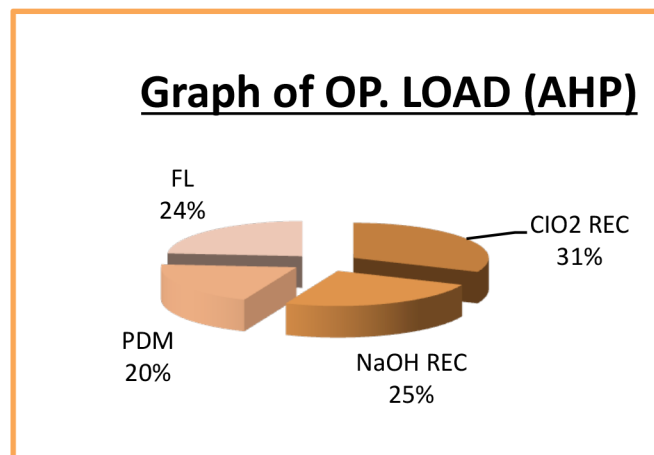


Figure 4: Percentage of alternatives in operating load.

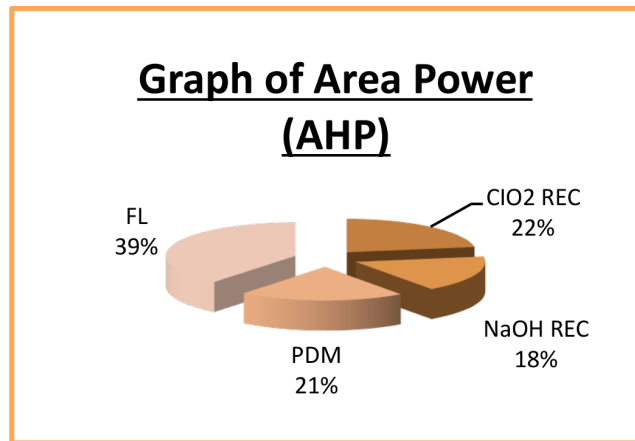


Figure 5: Percentage of alternatives in area power.

The calculation for the overall importance of the criteria can be illustrated in the flow chart as shown in Figure 6.

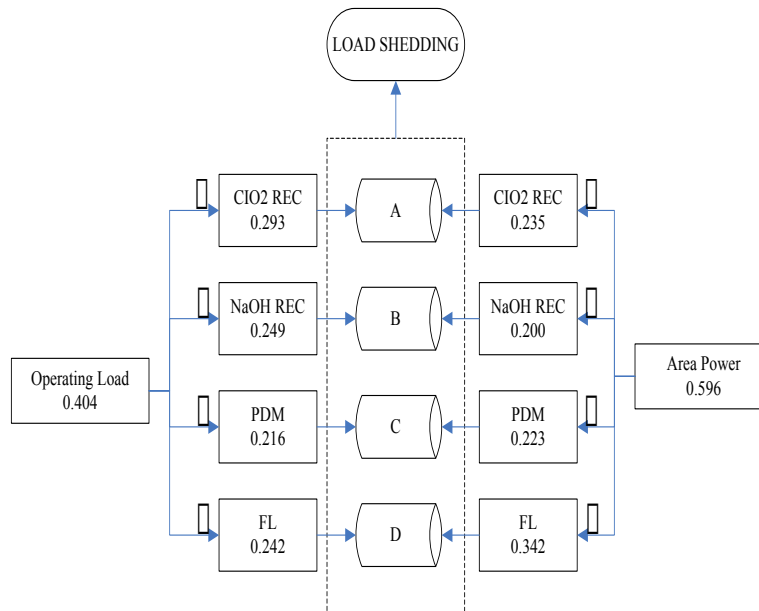


Figure 6: The overall results of the load shedding scheme by using AHP.

The load shedding scheme for the pulp mill will be triggered during the voltage unstable according to the load ranking determined by the AHP analysis. The sequence of the load to be shed can be tabulated in Table 2.

Table 2: The load ranking of the criteria using AHP.

Criterion	Load ranking	Weight
FL	1	30.1%
ClO2REC	2	25.8%
PDM	3	22.0%
NaOH REC	4	22.0%

The FL load with the highest percentage of load under overall consideration will be the first load to be shed. On the other hand, the ClO₂ REC with overall performance of 25.8% will be the second load to be shed. If the generator of the pulp mill still insufficient to supply the power, the third load should be shut down. Due to both PDM load and NaOH REC load have the same percentage of load, either one of the loads can be shed as the third load. For this case, let the PDM as the third load to be shed.

Fuzzy Analytic Hierarchy Process

Fuzzy AHP is the extended analysis in order to analyze the data in vague situation. Sometimes, the data obtained might be fuzzy and is hard to determine the importance of the criteria or alternatives. Thus, the fuzzy AHP is specially derived to calculate the priority of the data according to the fuzziness of data. For this paper, let the α -cut or also known as value of fuzziness, $\alpha = 0.5$. The value of α is ranging from 0 to 1 which means very uncertain and certain, respectively. $\alpha = 0.5$ is chosen in this paper because the performance of fuzzy AHP under vague condition need to be studied. So, for the most secure analysis, 0.5 is the most suitable value for α -cut. The normalized weight for each criterion is tabulated in Table 3.

Table 3: The normalised weight of criteria.

Normalised weight of	Weight
Operating load	0.42
Area Power	0.58

After a series of calculation by using fuzzy AHP method, the weights of alternatives under operating load and area power are shown in Figure 7 and Figure 8.

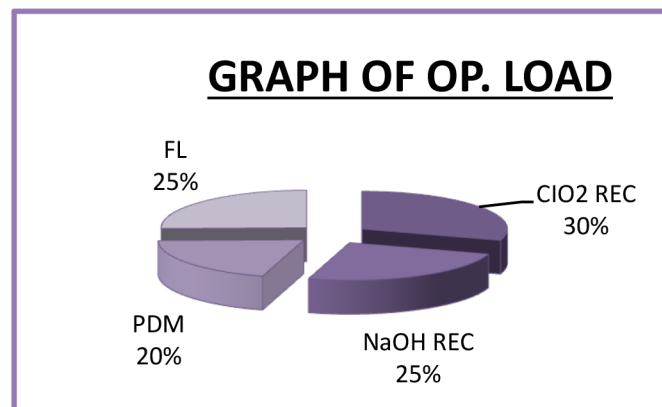


Figure 7: The weight of alternatives under operating load.

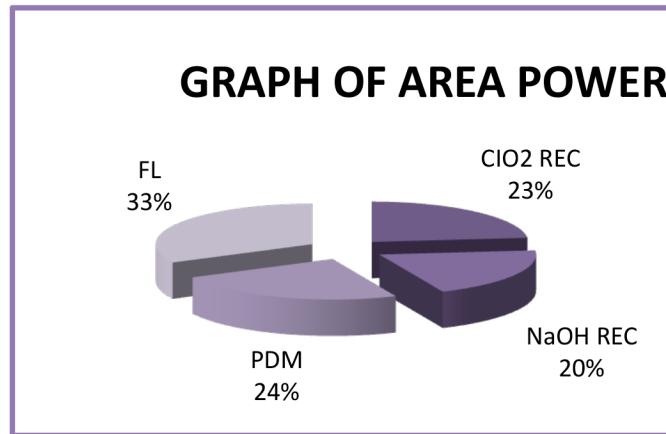


Figure 8: The weight of alternatives under area power.

In the load ranking to be applied in the load shedding scheme, the overall hierarchy diagram can be done by using the mathematic arithmetic operation. The arithmetic operation for fuzzy AHP can be shown in Figure 9 and the priority of the load can be tabulated in Table 3.

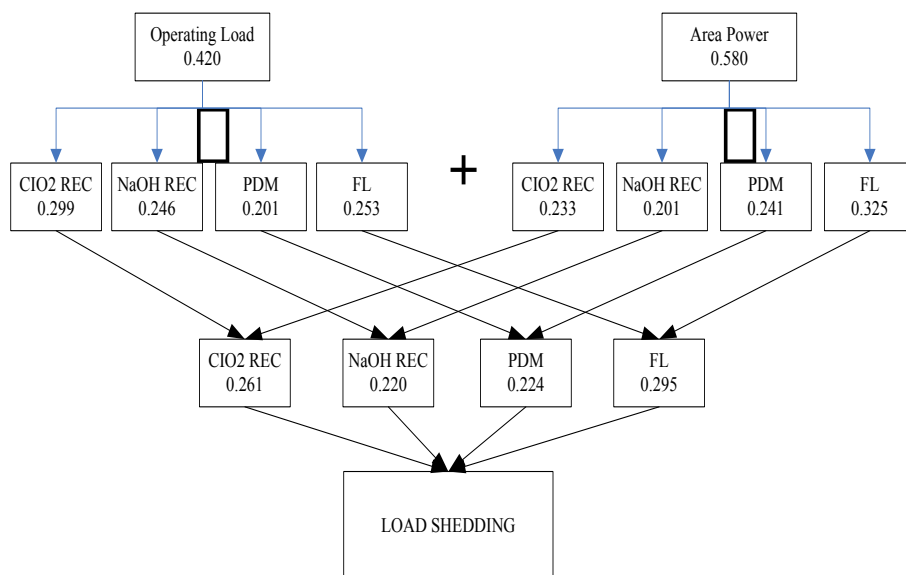


Figure 9: The overall hierarchy diagram for fuzzy AHP analysis.

Table 3: The load ranking of the criteria using fuzzy AHP.

Criterion	Load ranking	Weight
FL	1	29.5%
CIO2REC	2	26.1%
PDM	3	22.4%
NaOH REC	4	22.0%

As the result, the FL load obtained the highest priority of order in load shedding scheme. The FL load covered 29.5% of power if compared with other loads. Besides, the CIO2 REC load still remains the second priority as in AHP analysis. The remaining loads have similar percentage of priority which are NaOH REC and PDM.

DISCUSSION

From the AHP analysis, FL load is consumed the most electric power. Although the operating load of the FL load is not the highest, it contributes to the most power consumption in such area. It needs 30.1% of electric power. Even though CIO2 REC takes the highest percentage of operating power; it only consumes 25.8% of the overall power. In the meantime, PDM and NaOH REC are having the same percentage in overall power consumption which is 22%.

On the other hand, FL load had 29.5% of power consumption under fuzzy AHP analysis. CIO2 REC had 26.1% from the overall power consumption whereas PDM and NaOH REC had 22.4% and 22.0% respectively. In such circumstances, FL load has the most priority in load shedding scheme since both methods have the same result. If the load shedding action performance is not enough to overcome the overloading, CIO2 REC can be the next curtailment. According to the analysis had been done, PDM and NaOH REC are having an almost the same percentage. It is possible that either one of the loads can be chosen in order to alleviate the overloading of generator.

Generally, AHP analysis is faster and more convenient when compared with fuzzy AHP analysis. The calculations in AHP are simpler than in fuzzy AHP. In addition, the consistency ratio can be determined in order to obtain the result accurately. However, fuzzy AHP can determine the performance of criteria even when there is a vague condition. The fuzziness of the evaluation can be taken into consideration by using α -cut. This is useful for such evaluation which has limited data and condition.

CONCLUSIONS

In conclusion, the loads priority in load shedding scheme is successfully selected by using AHP and fuzzy AHP. Even though the formulas of calculation are different; both of the analysis methods are related one with another. AHP is a good multi decision making method and can be apply in any field of study whereas fuzzy AHP can determine the priority under vagueness condition. Load shedding scheme providers might use these approaches to determine the preceding load to be shed. Data of each branch or area will be collected by using software and the operators or engineers can take the proper action in handling the problems.

The whole AHP and fuzzy AHP processes apply basic calculations in selecting the load based on a few criteria and alternatives. Both methods help to capture subjective and objective evaluation measurements. There are a lot of factors that will affect the load shedding scheme. Thus, AHP and fuzzy AHP introduced to the load shedding scheme for electrical system in a pulp mill is beneficial to either consumers or developers.

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