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Analysis of the Magnitude of Load Shedding on Frequency Reduction at the UP3 Cotton Plantation Diesel Power Plant (PLTD)

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Load shedding due to frequency reduction in the Fakfak Regency electric power system occurred due to the overload of the KORMAN-01 engine with an installed power of 400 kW, operating power 200 kW, DOSSAN-02 engine, with installed power 500 Kw, operating power 500 kW, and KOMATSU-04 engine with installed power 800 Kw, operating power 600 at PLTD Kebun Kapas, PT. PLN (Persero) ULP FAKFAK, there was an overload on generating machines that were still operating due to a lack of power being generated where the power generated was less than the load on the system which decreased resulting in a black out. The aim is to determine the amount of load shedding when the frequency decreases by calculating. The results obtained by overloading the KORMAN-01, DOSSAN-02, KOMATSU-04 engines resulted in a decrease in frequency to 49,765 Hz, 48,883 Hz, 48,170 Hz approaching the normal frequency of 50 Hz and the calculated load shedding results were 198,108 kW, 23,092 kW, and 153,565 kW.

Keywords: Black out, frequency drop, Load Shedding, Overload.

1. INTRODUCTION

Electrical energy is secondary energy which is widely used in various sectors, both for household and industrial purposes. To meet electricity needs in this rapidly growing economic era requires a lot of electrical energy. Therefore, the quality of electrical energy needs to be improved [1]. In an ideal electric power system, electrical energy is transmitted constantly both in frequency and current. Because increasing power loads are more complex, especially non-linear loads, will change the waveform and current spectrum to become distorted [2]. In general, the stability of an electric power system can be defined as the ability of an electric power system to maintain its synchronous state during and after a disturbance occurs [3]. In electric power system operations, the supply of electric power to consumers is said to be good if the voltage and frequency received are in accordance with those specified and are still within tolerance limits. [4]. Frequency is a measure of the quality of a generating system. Therefore, the frequency must be kept stable in order to provide good quality electrical energy. The problem that often occurs is that when there is a change in load it takes a relatively long time to return to the standard frequency, namely 50 Hz. [5]. In an electric power system, a sudden change in load will result in a change in the stability of the system. One of the causes of sudden changes in load is due to the disconnection of the operating generator. This change in load can reduce the working frequency if it exceeds the generator capacity [6]. In an electric power system that serves loads continuously, the voltage and frequency should remain constant, but if there is a disturbance in one of the generators or on the rails, it cannot be denied that there will be disturbances in the power distribution. [7]. Disturbances and sudden changes in load, whether due to load transfer or additional load, cause rapid changes in parameters in the Electric Power System. This has an impact on the generating machine connected to the system because it must maintain stability of rotation and voltage [8]. One of the effects of interference is electromagnetic oscillations, which if not properly dampened, the system will be disturbed and can leave its stability area, resulting in worse effects such as a total (blackout). [9]. A sudden change in load will result in a change in the stability of the system. One of them is a change in the stability of the system frequency. The frequency will increase if the generator produces more power than the load demand and conversely the frequency will decrease if the generator produces less power than the load demand. If the decrease in frequency is not immediately addressed, it will cause the system to experience a total (blackout) [10]. The power balance between load requirements and generator generation capacity is one of the parameters of the stability of the operation of an electric power system. However, in the operation of an electric power system there will always be changes in load so the generator needs to adjust its output power through governors and excitation settings [11]. This is not effective and efficient, the power generated is less than the load on the system, resulting in frequency instability, experiencing a decrease in frequency [12]. Frequency system settings are carried out based on Standard Operational Procedures (SOP) for handling emergency systems as follows :

• System normal frequency at 50.10 HZ (normal)
• System lowest frequency at 49.30 HZ (warning)
• System highest frequency at 52.00 HZ (warning)
• The feeder UFR works at a frequency of 49.00 HZ (trip)
• If the trip from the generation side will occur Under Frequency
• If the trip from the feeder side will occur Over Frequency [13]

Frequency regulation can be done by adjusting the amount of power serving the load through energy storage. The setting is carried out by receiving input in the form of the difference between the measured frequency and the nominal frequency, then providing a power response to the microgrid via energy storage [14]. Frequency stability is one of the parameters in good electric power system operation. One way to reduce frequency reduction is by shedding the load [15]. Load shedding is carried out as an effort to improve system stability which is disturbed due to overload. Load shedding is expected to restore frequency quickly. There are stages that can be determined in load shedding. To prove the effectiveness of the load shedding scheme [16]. Therefore, to carry out a simulation based on the description above, it is necessary to analyze the amount of load shedding against frequency reduction at the UP3 Kebun Kapas mobile power plant (PLTD) to find out the stages in carrying out load shedding when a frequency decrease occurs and to know the calculations in determining the amount of load shedding when a frequency decrease occurs. so that it can be a reference for PLTD Fakfak to be able to increase the stability of the protection system and anticipate frequency instability if disturbances occur.

2. METHOD

As for the research and time allocation used in this research, it was carried out at the PLTD Kebun Kapas, Fakfak. The analytical method in this research uses two (techniques) solving techniques with mathematical equations, namely mathematical equations to calculate the stages in determining load shedding when a frequency decrease occurs, namely the calculation rate of the frequency decrease rate and the calculation of load shedding when the frequency decreases. Diesel Power Plant (PLTD) is a power plant that uses a diesel engine as a prime mover. A prime mover is equipment that has the function of producing the necessary mechanical energy that rotates the generator rotor to produce electrical energy. The generating machines used at PLTD Kebun Kapas, PT. PLN (Persero) ULP Fakfak, namely KOMATSU engines, MAN engines, KORMAN engines, DOSSAN engines and Cummins engines.. However, in this research the author only examined several machines that experienced load shedding due to frequency reduction, namely the KORMAN-01, DOSSAN-02, KOMATSU-04 machines. The data on the generating machines used at PLTD Kebun Kapas, PT. PLN (Persero) ULP FAKFAK, which can be seen in table 1 below:

Table 1. PLTD Fakfak Generating Engine Specifications

Ulp fakfak	Location	No. Units	Brand	Type	Dt(kw)	Operation (kw)	Status
Up3	PLTD Kebun Kapas	1	Korman-01		400	200	Operation
		2	Dossan-02		500	500	Operation
		4	Komatsu-04	Saa 12v 140-p1150	800	600	Operation
Total p3					1,620	1,420	

Table 1 shows the specifications of the PLTD Fakfak engine, Brand KORMAN-01, with an installed power of 400 kW and a capacity of 200 kW. DOSSAN-02 brand, with installed power of 500 kW, and capacity of 500 Kw. KOMATSU-04 Brand, with SAA 12V 140-P1150 Brand, Installed Power 800 kW, and Capable Power 600 kW.

Table 2. Fakfak Regency Electric Power System Defense Scheme.

Over Frequency	**52,0 Hz**	
Frequency Upper Limit	50,5 Hz	
Normal Frequency	50,0 Hz	
Lower Frequency Limit	49,8 Hz	
UFR Phase 1	49,2 Hz	Taking Off the Load 588 kW
UFR Phase 2	49,0 Hz	Taking Off the Load 667 kW

From table 2 above you can see the defense scheme for the Fakfak Regency electric power system. According to PLN standards, the electric power system frequency value is 50 Hz, valid for all of Indonesia. According to

Table 1, the electric power system in the generator in this study is: Installed power of 1,620 kW with a capacity of 1,420 kW. This data is used as a reference for this research:

1. Observation Method (Directly)
   Retrieval of data in the form of physical files and overall rough data directly on the spot or location.
2. Literature Study (Indirectly)
   Collect data from reference books and journals that are relevant to the research topic.

The types of research data collected are as follows:

1. Generator Plant Data at PLTD Fakfak
2. Data on the electric power system defense scheme
3. Data on the amount of limit load on PLTD Fakfak
4. Under Frequency Relay (UFR) Data

The research was carried out using quantitative research methods and interviews/discussions, where this research focused more on collecting data directly and conducting interviews/discussions with parties involved in PLTD Kebun Kapas, PT. PLN (Persero) ULP Fakfak. The research to be carried out is divided into several stages, including starting with the preparation stage for several references, collecting technical data at PLTD Kebun Kapas, PT. PLN ULP Fakfak, data processing, results and conclusions are included in the report. There are several data needed in the analysis of this research, such as comparative data on generator data at PLTD Fakfak, defense scheme data, load size data, and under frequency relay.

Decreased Frequency Due to Overload, The frequency reduction rate depends on the size of the overload that occurs, the nominal frequency, the MW rating of the generator in ideal conditions

$$\frac{df}{dt} = -\frac{f_0}{2H}\, x\, \frac{Pso}{Pgot - Psot} \quad \textbf{(1)}$$

$$f_1 = f_0 + \left(\frac{df}{dt}\right) x\, (t_1 - t_0) \quad \textbf{(2)}$$

F1 = Beginning of frequency reduction (Hz)
F0 = Nominal frequency (Hz)
$\frac{df}{dt}$ = Interval (Hz/sec)
H = Inertia constant
t0 = Normal frequency time (sec)
t1 = Initial time of frequency drop (sec)
Pso = The power generated by the unit is interrupted (kW)
Pgot = The installed power of the operating units (kW)
Psot = The installed power of the unit is interrupted (kW) [17]

Calculation of the Frequency Released
To obtain the value of the load that must be removed, there are parameters that must be determined taking into account the reliability of the system, namely:

a. Expected frequency after load shedding.
b. Recovery time. The two parameters above are used to calculate the value of the frequency increase rate that should occur.

$$f_n = f_0 + \frac{df}{dt} \quad \textbf{(3)}[15].$$

Calculation of released load
The calculation of the amount of load released when the frequency decreases can be found using the following equation:

$$S_1 = S_{g1}\, x\, \frac{f_0^2}{f_1^2} \quad \textbf{(4)}$$

$$\Delta S1 = S0 - S1 \quad \textbf{(5)}$$

S_1 = Generator residual power at expected frequency (kW)
S_{g1} = Generator residual power (kW)
f_1 = Load shedding reference frequency (Hz)
$\Delta S1$ = The amount of load released (kW)
$S0$ = Total generator power (kW). [15].

3. RESULTS AND DISCUSSION

In determining the frequency reduction rate, a calculation will be carried out which will be described as follows:

1. KORMAN-01 engine

The following is a calculation of the frequency reduction rate on the KORMAN-01 machine:

Is known:

fo = 50 Hz, $pgot$ = 1620 kW, pso = 200 kW, $psot$ = 400 kW, h = 2 $detik$, $t0$ = 0 $detik$

$t1$ = 0,1 $detik$

Asked:

$\frac{df}{dt}$ = ?

f_1 = ?

Solution:

$$\frac{df}{dt} = -\frac{f_0}{2H}\, x\, \frac{Pso}{Pgot - Psot}$$

$$\frac{df}{dt} = -\frac{50}{2.2}\, x\, \frac{200}{1620-400}$$

= -12,5 x 0,163934426

$\frac{df}{dt}$ = -2,049180325 $\frac{Hz}{dt}$

$$\boldsymbol{f_1 = f_0 + \left(\frac{df}{dt}\right) x\,(t_1 - t_0)}$$

$f_1 = 50 + (-2{,}049180325\; x\; 0{,}1)$

f_1 = 49,76508 Hz

From the results of the calculations above, it is known that the frequency reduction rate is equal to $\frac{df}{dt}$ = -2,049180325 Hz/ second, so that the frequency drops to reach 49,76508 Hz. The calculation results obtained are presented in table form below:

Table 3. Frequency Decrease Rate Results on the KORMAN-01 Machine

Stage	Delay (sec)	$\frac{df}{dt}$	Frequency (Hz)
1	0	0	50
2	0,1	-2,049180325	49,76
3	0,2	-2,049180323	49,56016
4	0,3	-2,049180320	49,38524
5	0,4	-2,049180316	49,18032
6	0.5	-2,049180311	48,97540
7	0.6	-2,049180305	48,77049
8	0.7	-2,049180298	48,56557
9	0,8	-2,049180290	48,36065
10	0.9	-2,049180281	48,15573
11	1	-2,049180271	47,95081

From table 3 above you can see the results of calculating the frequency reduction on the KORMAN-01 machine so that the system frequency has decreased from the normal frequency of 50 Hz to reaching a frequency of 47.95 Hz within 1 second. So the researcher made a graph or bar diagram from the results of the frequency reduction calculation so that the frequency reduction from the normal frequency to the initial load shedding frequency could be clearly seen.

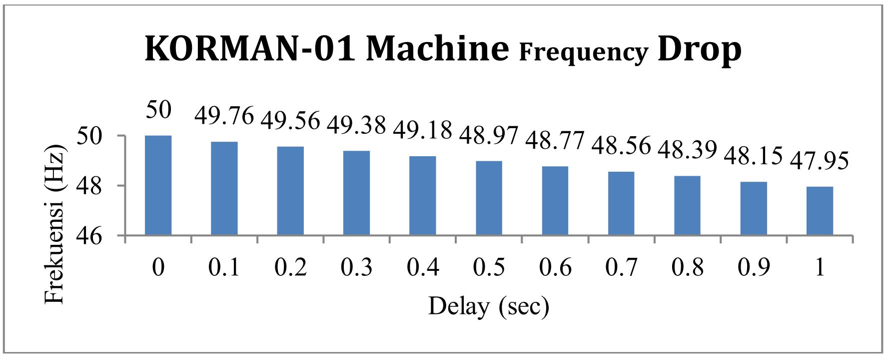

Figure 1. Graph of frequency reduction for the KORMAN-01 engine

In Figure 1, the graph above can be seen the results of calculating the frequency reduction on the KORMAN-01 machine so that the system frequency has decreased from the normal frequency of 50 Hz to reaching an abnormal frequency of 47.95 Hz in a period of 1 second. When the frequency drops beyond the lower limit, namely 47.5 Hz, it can result in a total blackout if left untreated and not treated. (PLTD Fakfak, 2023). So what must be done to return the frequency to its normal position is by shedding the load. Load shedding is carried out so that the power generated by the load on the system is balanced so that the system frequency returns to normal.

2. DOSSAN-02 engine

Table 4. Frequency Decrease Rate Results on the DOSSAN-02 Machine

Stage	Delay (sec)	$\frac{df}{dt}$	Frequency (Hz)
1	0	0	50
2	0,1	-11,160714275	48,8839285725
3	0,2	-11,160714274	47,767857145
4	0,3	-11,160714273	46,6517857175
5	0,4	-11,160714272	45,53571429
6	0.5	-11,160714271	44,4196428625
7	0.6	-11,160714270	43,303571435
8	0.7	-11,160714269	42,1875000075
9	0,8	-11,160714268	41,07142858
10	0.9	-11,160714267	39,9553571525
11	1	-11,160714266	38,839285725

From table 4 above, you can see the results of calculating the frequency reduction on the DOSSAN-02 machine so that the system frequency has decreased from the normal frequency of 50 Hz to reaching a frequency of 38.83 Hz in a period of 1 second. So the researcher made a graph or bar diagram from the results of the frequency reduction calculation so that the frequency reduction from the normal frequency to the initial load shedding frequency could be clearly seen.

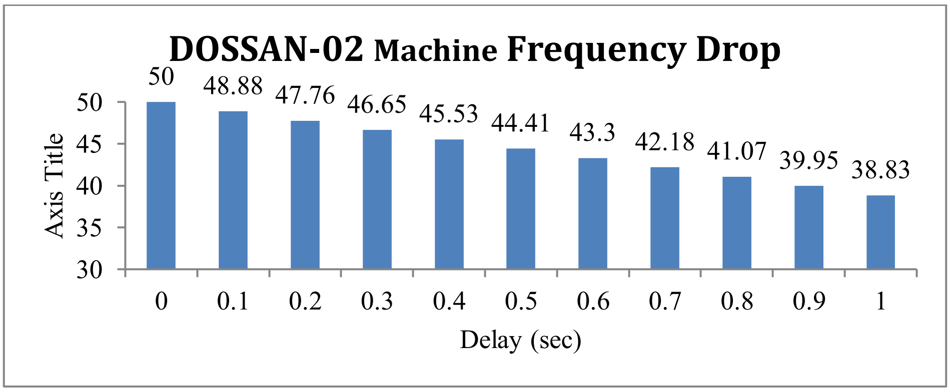

Figure 2. DOSSAN-02 Machine Frequency Decrease Graph

In Figure 2, the graph above can be seen the results of calculating the frequency reduction on the DOSSAN-02 machine so that the system frequency has decreased from the normal frequency of 50 Hz to reaching an abnormal frequency of 38.83 Hz in a period of 1 second. When the frequency drops beyond the lower limit, namely 42.5 Hz, it can result in a total blackout if left untreated and not treated (PLTD Fakfak, 2023). So what must be done to return the frequency to its normal position is by shedding the load. Load shedding is carried out so that the power generated by the load on the system is balanced so that the system frequency returns to normal.

3. KOMATSU-04 engine

The following is a calculation of the rate of frequency reduction on the KOMATSU-04 machine:

Table 5. Frequency Decrease Rate Results on the KOMATSU-04 Machine

Stage	**Delay (sec)**	$\frac{df}{dt}$	**Frequency (Hz)**
1	0	0	50
2	0,1	-18,29268275	48,170731725
3	0,2	-18,29268274	46,34146345
4	0,3	-18,29268273	44,512195175
5	0,4	-18,29268272	42,6829269
6	0.5	-18,29268271	40,853658625
7	0.6	-18,29268270	39,02439035
8	0.7	-18,29268269	37,195122075
9	0,8	-18,29268268	35,3658538
10	0.9	-18,29268267	33,536585525
11	1	-18,29268266	31,70731725

From table 5 above you can see the results of calculating the frequency reduction on the KOMATSU-04 machine so that the system frequency has decreased from the normal frequency of 50 Hz to reaching a frequency of 31.70 Hz within 1 second. So the researcher made a graph or bar diagram from the results of the frequency reduction calculation so that the frequency reduction from the normal frequency to the initial load shedding frequency could be clearly seen.

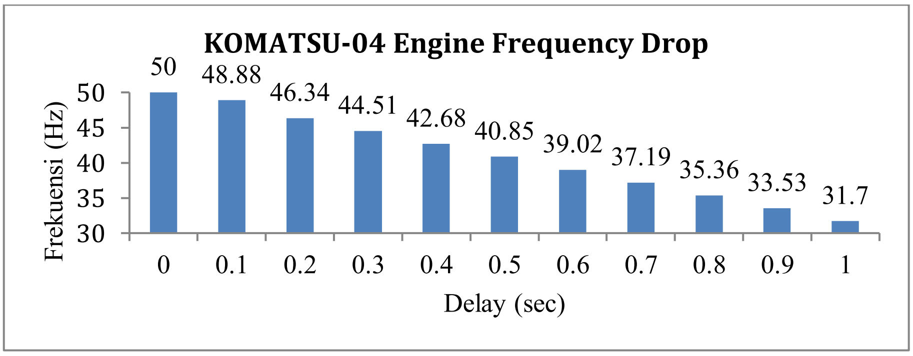

Figure 3. KOMATSU-04 Engine Frequency Reduction Graph

In Figure 3, the graph above can be seen the results of calculating the frequency reduction on the KOMATSU-04 machine so that the system frequency has decreased from the normal frequency of 50 Hz to reaching an abnormal frequency of 31.70 Hz in a period of 1 second. When the frequency drops beyond the lower limit, namely 42.00 Hz, it can result in a total blackout if left untreated and not treated. (PLTD Fakfak, 2023). So what must be done to return the frequency to its normal position is by shedding the load. Load shedding is carried out so that the power generated by the load on the system is balanced so that the system frequency returns to normal.

Calculating the frequency reduction rate, load shedding can then be calculated when the frequency decreases which will be described as follows:

1. KORMAN-01 engine

The following is the calculation of load shedding on the KORMAN-01 engine:

Is known ;

S_{g1} = 200 Kw, f_1 = 49,7650 Hz, f_0 = 50 Hz, S0 = 400 kW

Asked :

$\Delta S1$ = ?

Solution :

$S1 = S_{g1}\, x\, \frac{f_0{}^2}{f_1{}^2}$

$S1 = 200\, x\, \frac{50^2}{49{,}7650^2}$

$= 201{,}892$ kW

$\Delta S1 = S0 - S1$

$\Delta S1 = 400 - 201.892$

$= 198{,}108$ kW

On the KORMAN-01 engine, the load that must be released to restore the frequency reduction is 198,108 kW. With this load shedding, it is hoped that the frequency on the KORMAN-01 engine can increase to the normal point of 50 Hz.

From the calculation results obtained in table 6, they can be presented in the form of the table below:

Table 6. Results of load shedding on the KORMAN-01 engine

Stage	**Frequency Drop (Hz)**	**ΔS (kW)**
1	49,76	198,108
2	49,56016	203,567
3	49,38524	205,012
4	49,18032	206,724
5	48,97540	208,459
6	48,77049	210,215
7	48,56557	211,993
8	48,36065	213,794
9	48,15573	215,619
10	47,95081	217,457

From table 6 above, it can be seen that the load shedding is proportional to the decrease in frequency, where the smallest load released is 198.108 Kw at a frequency of 49.76 Hz. Begitu juga pada beban terbesar yang dilepaskan sebesar 217,457 kW pada frekuensi sebesar 47,950 Hz. Likewise, the largest load released was 217,457 kW at a frequency of 47,950 Hz. So the researcher made a graph or bar diagram from the results of the load shedding calculations so that the magnitude of the load shedding relative to the frequency reduction could be seen clearly.

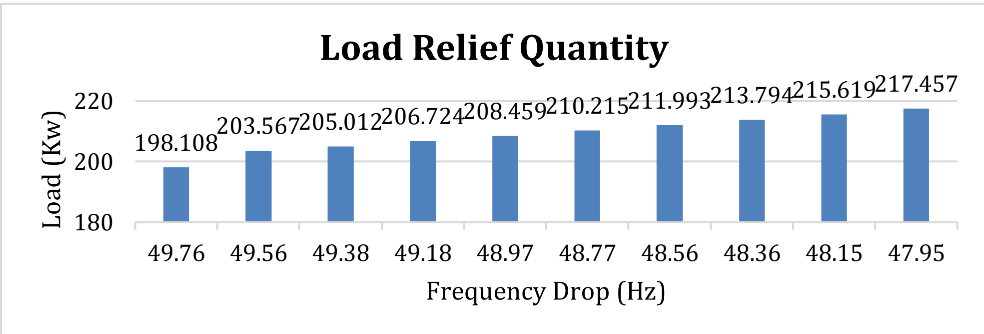

Figure 4. Graph of load shedding against decreasing frequency of the KOMATSU-01 engine.

In Figure 4, the graph above can be seen that the load that must be released will be greater if the frequency decreases, where the frequency at the point 49.76 - 47.95 Hz must release a load of 198.108 - 217.457 Kw. With this load shedding, it is hoped that the frequency will return to normal at the 50 Hz point.

2. DOSSAN-02 engine

The following is the load shedding calculation on the DOSSAN-02 machine, On the DOSSAN-02 engine, the load that must be removed to restore the frequency reduction is 23,092 kW. With this load shedding, it is hoped that the frequency on the DOSSAN-02 machine can increase to the normal point of 50 Hz.
From the calculation results obtained in table 7, they can be presented in the form of the table below:

Table 7. Results of load shedding on the DOSSAN-02 machine

Stage	Frequency Drop (Hz)	ΔS (Kw)
1	48,8839285725	23,092
2	47,767857145	47,84
3	46,6517857175	74,365
4	45,53571429	102,863
5	44,4196428625	133,537
6	43,303571435	166,613
7	42,1875000075	202,348
8	41,07142858	241,036
9	39,9553571525	283,01
10	38,839285725	325,655

From table 7 above, it can be seen that the load shedding is proportional to the decrease in frequency, where the smallest load released is 23,092 Kw at a frequency of 48,883 Hz.. Likewise, the largest load released was 325,655 Kw at a frequency of 38,839 Hz. So the researchers made graphs or bar charts from the results of load shedding calculations so that they could be seen clearly.

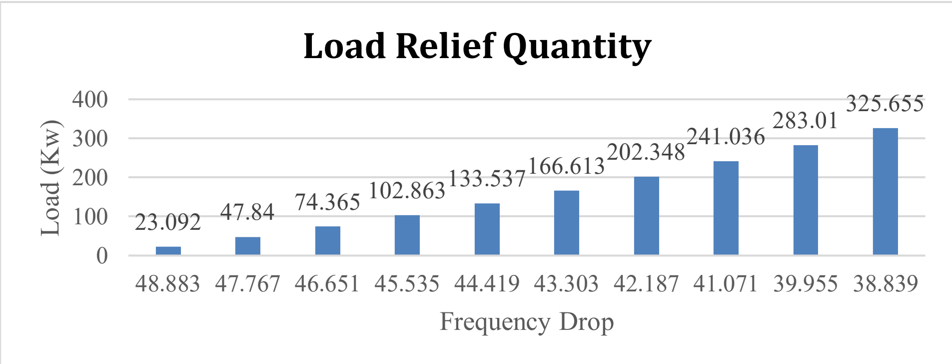

Figure 5. Graph of load shedding against frequency reduction for the DOSSAN-02 machine.

In Figure 5, the graph above can be seen that the load that must be released will be greater if the frequency decreases, where the frequency at the point 48,883 – 38,839 Hz must release a load of 23,092 – 325,655 kW. With this load shedding, it is hoped that the frequency will return to normal at the 50 Hz point.

3. KOMATSU-04 Engine.

On the KOMATSU-04 engine, the load that must be released to restore the frequency reduction is 27,733 kW. With this load shedding, it is hoped that the frequency on the KOMATSU-04 engine can increase to the normal point of 50 Hz. From the calculation results obtained in table 8, they can be presented in the form of the table below:

Table 8 Results of load shedding on the KOMATSU-04 engine.

Stage	Frequency Drop (Hz)	ΔS (Kw)
1	48.8839285725	27,733
2	46.34146345	98,49
3	44.512195175	157,071
4	42.6829269	223,382
5	40.853658625	298,759
6	39.02439035	384,98
7	37.195122075	484,23
8	35.3658538	599,34
9	33.536585525	733,73
10	31.70731725	892,04

From table 8 above, it can be seen that the load shedding is proportional to the decrease in frequency, where the smallest load released is 27.733 kW at a frequency of 48.8839 Hz. Begitu juga pada beban terbesar yang dilepaskan sebesar 892,04 kW pada frekuensi sebesar 31,707 Hz. So the researcher made a graph or bar diagram from the results of the load shedding calculations so that the magnitude of the load shedding relative to the frequency reduction could be seen clearly.

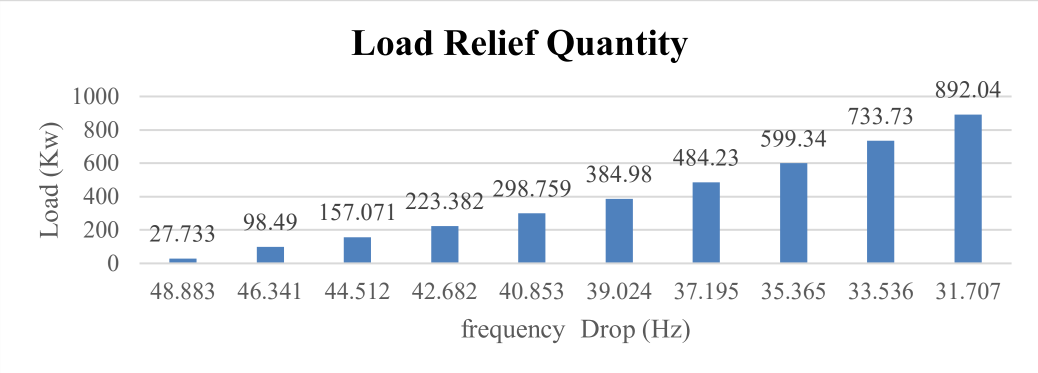

Figure 8. Graph of load shedding against decreasing frequency of the KOMATSU-04 engine

In Figure 8, the graph above can be seen that the load that must be removed will be greater if the frequency decreases, where the frequency is greater point 48,883 – 31,707 Hz must release a load of 27,733 – 892.04 Kw. With this load shedding, it is hoped that the frequency will return to normal at the 50 Hz point.

4. CONCLUSION

Based on the data and calculation analysis results, it can be concluded, the cause of load shedding at the Fakfak Regency power plant was due to an overload on the KORMAN-01, DOSSAN-01, and KOMATSU-04 engines at the Kebun Kapas PLTD, resulting in an overload which caused the system frequency to decrease due to the power produced by the plant. smaller than the load on the system, resulting in disruption to the Fakfak district electrical power system. The load that must be released on the KORMAN-01 engine will be greater if the frequency decreases, where the frequency at the point 49.76 – 47.95 Hz must release a load of 198,108 – 217,457 Kw. With this load shedding, it is hoped that the frequency will return to normal at the 50 Hz point. The load that must be released on the DOSSAN-02 machine will be greater if the frequency decreases, where the frequency at the point 48,883 – 38,839 Hz must release a load of 23,092 – 325,655 Kw. With this load shedding, it is hoped that the frequency will return to normal at the 50 Hz point. The load that must be released on the KOMATSU-04 engine will be greater if the frequency decreases, where the frequency at the point 48,883 – 31,707 Hz must release a load of 27,733 – 892.04 Kw. With this load shedding, it is hoped that the frequency will return to normal at the 50 Hz point.

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