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Load Flow, Load Loss and Short Circuit Analysis of The Third Thermal Power Plant's Electrical Supply System

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Abstract— The third thermal power plant is one of the largest in Mongolia, generating about 30% of Mongolia's electricity and more than 60% of Ulaanbaatar's thermal energy. Although Mongolia's electricity consumption has grown steadily, no new power plants have been built to meet this increased demand. This increase in load and the intermittent characteristic of renewable energy have adversely affected thermal power plants' sustainability. Therefore, to study how the static and dynamic transition process of the power plant is affecting the operation, the 110kV 35kV 10kV 6kV general circuit scheme was fully modelled on Powerfactory software to analyze the performance of the load flow, load loss, voltage level, determination of the loading condition, balanced and unbalanced short circuit calculation results are demonstrated.

Keywords— generator; transformer; section; line; busbar;

I. Introduction

Over the last few years, the Mongolian electrical system has been overloaded, but with new unstable renewable energy sources, even the smallest short-circuit could expand to become a more significant problem.

Because of these situations, each power plant needs to make a model for research and calculation to create the precise and most correct settings for the relay protection, excitation, and turbine system operation adjustment during the stable mode, short-circuit static and dynamic transition processes.

Since 2011 Powerfactory software of the company Digsilent of Germany has been mainly used in Mongolian Energy system calculation.

With this software, we can model each schematic separately and measure each equipment and machinery load, voltage, loss etc. Its advancements and innovations can be made through research by experimenting and testing the relay protection and excitation system operations.

II. Current Status of the Mongolian Energy System

Due to Mongolia's vast territory stretching from one end to the other, there is a need to transmit energy over long distances via a long transmission line from source to consumer. The energy system has a non-distributed centralised sources, and due to the low level of industrial development, most energy consumption is from domestic consumers. Therefore, energy consumption peak is from 5:00 pm to 9:00 pm. As of 2021, the peak load has reached 1387MW. In our country, the energy system is divided into five energy systems [1].

- Central energy system (CES) P_{max}=1370MW, P_{import}=222MW, $P_{thermal\ power\ plant}$=1118MW, $P_{wind\ power\ plant}$=30MW
- Western energy system (WES) P_{max}=43.1MW, P_{import}=33.4MW, $P_{hydro\ power\ plant}$= 12MW
- Altai-Uliastai energy system (AUES) P_{max}=21.7MW, $P_{hydro\ power\ plant}$=11MW
- East energy system (EES) P_{max}=37MW, $P_{therminal\ power\ plant}$=36MW
- Southern energy system (SES) P_{max}=223MW, $P_{thermal\ power\ plant}$=18MW, P_{import}=180MW

Figure 1-4 shows Mongolian energy system by zone, installed power, source structure and imports and it's integrated power grid scheme.

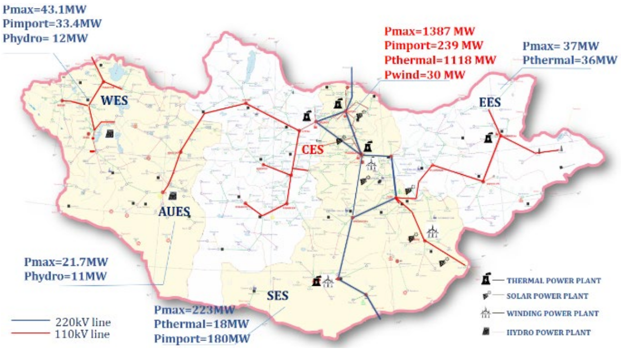

Figure 1. Mongolian energy system

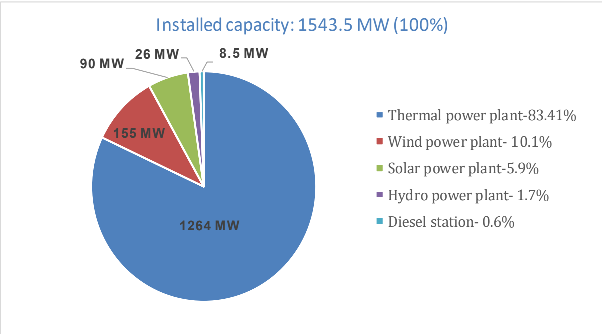

Figure 2. Installed power

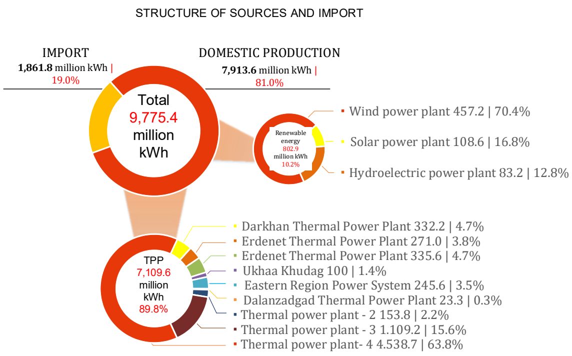

*Figure 3. Source structure and imports. *ERC's energy statistics [2]*

The Mongolian energy system is limited to importing up to 345MW from the Russian energy system.

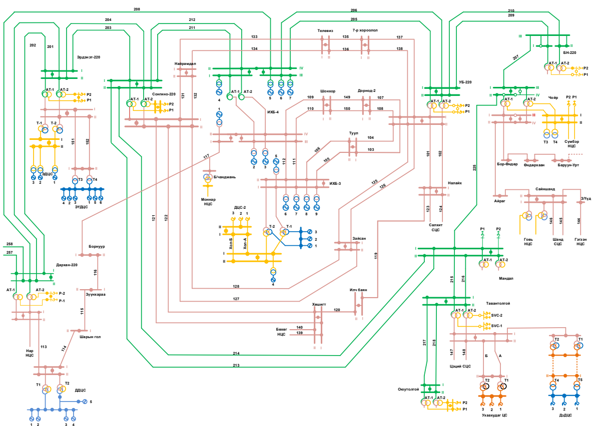

Figure 4. Integrated power grid scheme (green-220kV, red-110kV, yellow-35kV)

III. Modelling on Powerfactory

The third thermal power plant has its general circuit of 110kV, 35kV, 10kV, and 6kV in the Powerfactory-2015 program (this program is PTT#3 by license). In the case of future expansion and modernization of the plant, it is possible to use this model to calculate the actual and imaginary load flow, load losses, voltage levels, and short circuit current calculations.

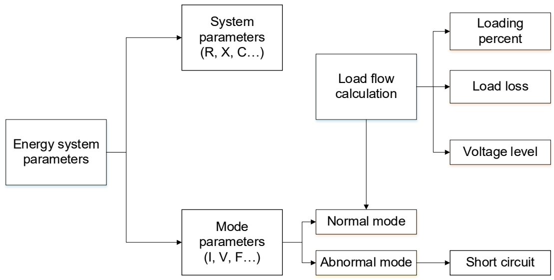

Figure 5. Energy system parameter

The calculation data of the main equipment and machines used for calculating the energy system mode are entered according to the required data of the "Powerfactory" calculation program. Generators, block transformers, power transformers, circuit breakers, switches and loads, cable lines, and short-circuit current limiting reactors are designed [5-11].

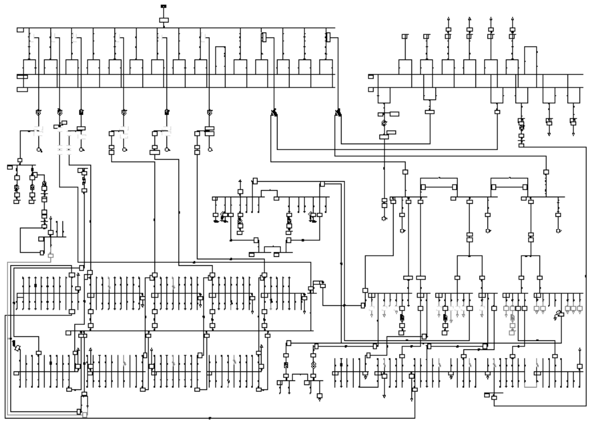

Figure 6. Modelling in Powerfactory software

Table 1. Generator Specification

Parameter name	Data				
	Parameter	***Unit***	***TG 1-4***	***TG 5-8***	***TG 9***
Apparent power	S	MVA	15	40	60
Nominal voltage	Un	kV	6.3	6.3	6.3
Power factor	cosφ	-	0.8	0.8	0.8
d-axis synchronous reactance	xd	p.u.	1.85	2.516	2.08
q axis synchronous reactance	xq	p.u.	1.85	2.516	2.08
Zero sequence reactance	x0	p.u.	0.0542	0.07	0.07
Zero sequence resistance	r0	p.u.	0	0	0.08
Negative sequence reactance	x2	p.u.	0.14	0.184	0.18
Negative sequence resistance	r2	p.u.	0	0	0.2

Parameter name	Data				
	Parameter	***Unit***	***TG 1-4***	***TG 5-8***	***TG 9***
Sub-transient d-axis reactance	xd"	p.u.	0.114	0.15	0.2
Inertia (related to apparent power)	H	s	2.6	5.4	4.5
Leakage reactance	xl	p.u.	0.05	0.05	0.05
Stator resistance	str	p.u.	0.004	0.001	0.001

Table 2. Transformer Specification

Parameter name	Data			
	Unit	***T1, T2***	***T4***	***10T***
Rated power	MVA	40	16	10
Rated voltage - HV side	kV	115	38.5	35
Rated voltage - MV side	kV	38.5	-	-
Rated voltage - LV side	kV	6.6	6.3	6.3
Vector group HV - side	Y/Δ	Y	Δ	Δ
Vector group MV - side	Y/Δ	Y	-	-
Vector group LV - side	Y/Δ	Δ	Y	Y
Neutral position of TAP	-	9	9	9
Maximum position of TAP	-	17	17	17
Minimum position of TAP	-	1	1	1
$\Delta P_{no-load\ losses}$	kW	30.17	15.3	15.3
$\Delta P_{\text{Copper losses}}$	%	194.98	91.2	91.2
$\Delta I_{\text{No-load current}}$	%	0.1	0.573	0.573
$\Delta U_{short\ circuit}$	kV	18.46	10.5	8.07

Table 3. Transformer Specification

Parameter name	Data			
	Unit	***T5, T6, T7, T8***	***T9***	***12T***
Rated power	MVA	40	75	25
Rated voltage - HV side	kV	110	110	110
Rated voltage - MV side	kV	-	-	-
Rated voltage - LV side	kV	6.3	10.5	6.3
Vector group HV - side	Y/Δ	Y	Y	Y
Vector group MV - side	Y/Δ	-	-	-
Vector group LV - side	Y/Δ	Δ	Δ	Y
Neutral position of TAP	-	10	9	3
Maximum position of TAP	-	19	18	5
Minimum position of TAP	-	1	1	1
$\Delta P_{no-load\ losses}$	kW	42.9	120	19.2
$\Delta P_{\text{Copper losses}}$	%	169.19	385.04	85
$\Delta I_{\text{No-load current}}$	%	0.65	0.55	0.7
$\Delta U_{short\ circuit}$	kV	10.72	11.33	10.38

It will be easier to enter data in the future if the equipment is expanded, upgraded or replaced. It means that a database of parameters of existing equipment (generator, transformer) has been created.

The Powerfactory Base Package has two major analytical functions and highly detailed modelling of the system's primary circuits, overhead transmission lines, and cable lines. It includes:

- Load flow analysis
- Short circuit current analysis (by complete method)

IV. Load Flow Analysis

Load flow analysis is performed using variables (AC), balanced calculations, and a range of control options for load flow calculations.

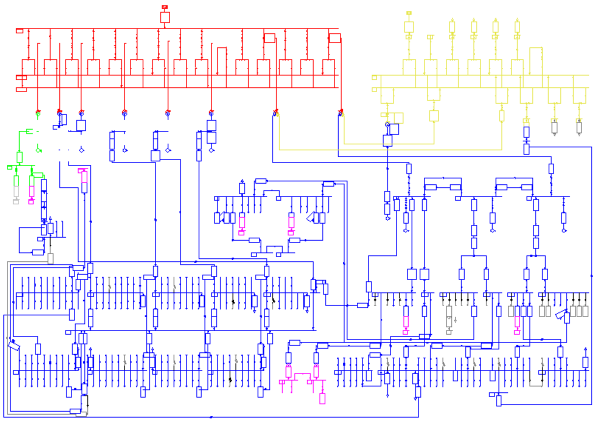

Figure 7. Load flow calculation

Following the guidelines issued by National Dispatching Center, based on the values of the 2021 winter peak load measurement, the busbar balance was calculated as a result of calculating the transformer losses in the Powerfactory software.

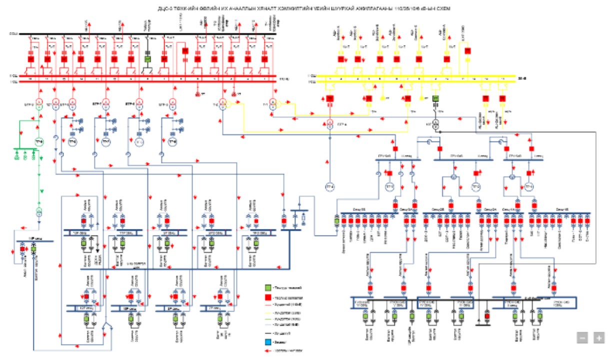

Figure 8. 110/35/10/6kV circuit for emergency operation during winter heavy load monitoring and measurement

1. Loading percent

The following tables show the loading percent of all transformers and generators at the third thermal power plant.

Table 4. Transformer Specification

Generator name	Parameter name		
	Active power [MW]	***Reactive power [MVAR]***	***Loading percent /%/***
TG-1	9.83	4.73	72.7
TG-2	10.56	4.07	75.4
TG-3	11.91	1.25	79.8
TG-4	10.30	3.28	72.1
TG-5	20.21	6.16	52.8
TG-6	21.60	2.55	54.4
TG-7	22.06	2.75	55.6
TG-8	20.69	3.75	52.6
TG-9	47.25	32.55	87.3
Total	174.41	61.09	

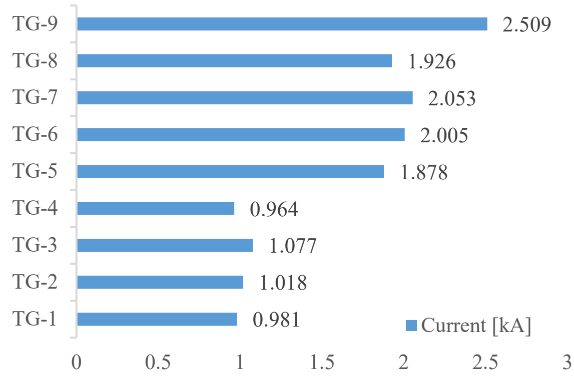

Figure 9. Generator stator winding current

Table 5. Transformer Specification

Transformer name	Parameter		
	Active power [MW]	*Reactive power [MVAR]*	*Loading percent [%]*
T-1	9.9	3.58	38.6
T-2	9.9	3.58	38.6
T-4	10.23	3.24	65.8
BTR-5	17.31	2.99	43.4
BTR-6	16.04	-1.62	40.4
BTR-7	18.38	-2.72	46.7
BTR-8	15.05	-0.67	37.7
BTR-9	46.82	22.01	66.6
10T	0.02	0.07	0.4
12T	-3.93	-2.28	29.4

Table 6. Transformer Specification

Internal use	Parameter		
	Section	*Active power [MW]*	*Reactive power [MVAR]*
High-pressure plant	1RO	0.72	1.01
	7R	2.16	2.16
	2RO	2.95	2.09
	8R	2.59	2.09
	9R	2.30	2.74
	10R	1.37	0.43
	11R	2.74	1.94
	12R	2.88	2.52
	14R	0.43	0.65
	12T	3.89	2.90
	Total	**22.03**	**18.53**
Middle-pressure plant	I	1.66	1.01
	II	1.80	1.08
	III	1.39	0.72
	IV	1.04	0.68
	V	1.22	1.01
	VI	1.01	0.86
	11T	0.07	0.02
	Panel-0.4	-	-
	Tungaakh II section	0.59	0.16
	Pump station-1	2.85	0.54
	Pump station-2	0.17	0.03
	Total	**11.8**	**6.11**

The plant's internal demand used 19.39% or 33.83 MW of the total generated power. If we can save and reduce domestic consumption as much as possible, the share of distributed energy will increase.

The technical losses of the third thermal power plant network have been determined using the Load flow function of the Digsilent Powerfactory. The results of the calculations are shown in the following table.

Table 7. Transformer Specification

Transformer name	Power	
	Active power[MW]	*Reactive power[MVAR]*
T-1	0.05	0.82
T-2	0.05	0.82
T-4	0.05	0.82
BTR-5	0.08	1.21
BTR-6	0.08	1.15
BTR-7	0.09	1.42
BTR-8	0.08	1.08
BTR-9	0.28	3.55
10T	0.02	0.09
12T	0.03	0.25
Total	0.81	11.21

2. Voltage level

The following table shows the voltage losses of 6 kV busbars high-pressure plant and middle-pressure plant of the third thermal power plant. The calculation shows that the voltage level is normal.

Table 8. Transformer Specification

Name	Parameter		
	Section	*Measurement value*	*Calculation value*
High-pressure plant	1RO	6.21	6.36
	7R	6.21	6.36
	2RO	6.3	6.36
	8R	6.3	6.36
	9R	6.12	6.34
	10R	6.02	6..34
	11R	6.02	6.36
	12R	6.3	6.36
	14R	6.25	6.34
	12T	6.02	6.11
Middle-pressure plant	I	6.19	6.19
	II	6.21	6.20
	III	6.23	6.20
	IV	6.22	6.20
	V	6.21	6.20
	VI	6.28	6.20

V. SHORT CIRCUIT ANALYSIS

The short circuit is when the phases are connected or the ground without load

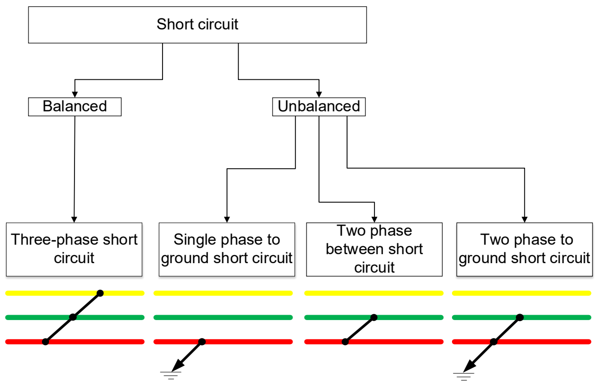

Figure 10. Type of short circuit

A balanced short circuit means that the three phases are connected without load, in which case the current-voltage vector diagram is symmetrical as in the normal phase but several times larger [3].

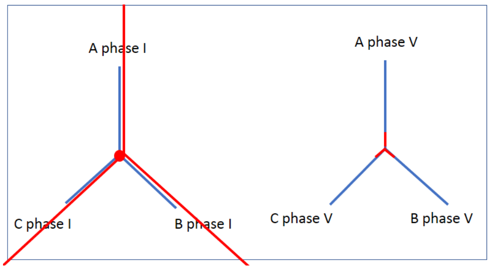

Figure 11. Three-phase short-circuit current-voltage vector diagram

$$I_{3ph} = \frac{V}{Z_1} \qquad (1)$$

Equation-1 represents the amount of current in a three-phase short circuit. V-line voltage, Z_1-direct sequence total resistance. Unbalanced short-circuits include single-phase ground, two-phase short-circuit, and two-phase short-circuits

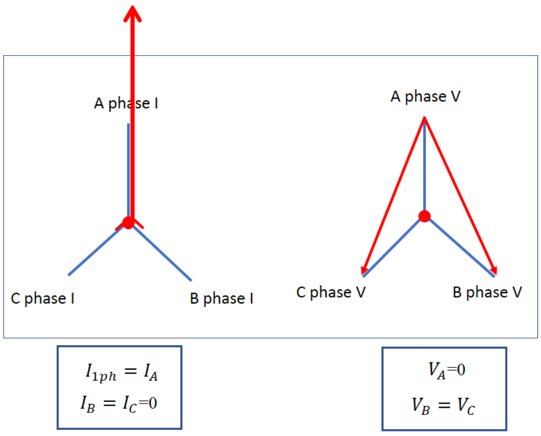

Figure 12. Current-voltage vector diagram of a short-circuits with a single-phase (A) ground.

$$I_{1ph} = \frac{3 * V}{Z_1 + Z_2 + Z_0} \qquad (2)$$

Equation-2 represents the amount of current that is short-circuited to a single-phase ground. V-line voltage, Z_1-direct sequence resistance, Z_2-reverse sequence total resistance, Z_0-zero-sequence total resistance.

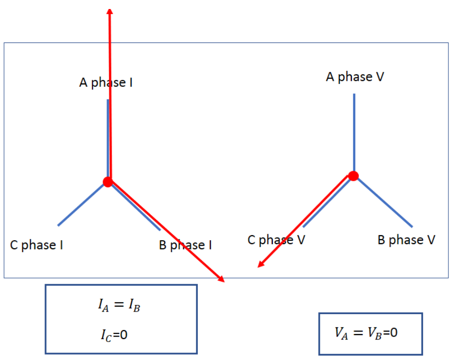

Figure 13. Current-voltage vector diagram of a short circuit between two phases (A, B)

$$I_{l-l} = \frac{V}{Z_1 + Z_2} \qquad (3)$$

Equation-3 represents the amount of current when two phases are short-circuited. V-line voltage, Z_1-direct sequence total resistance, Z_2-reverse sequence total resistance

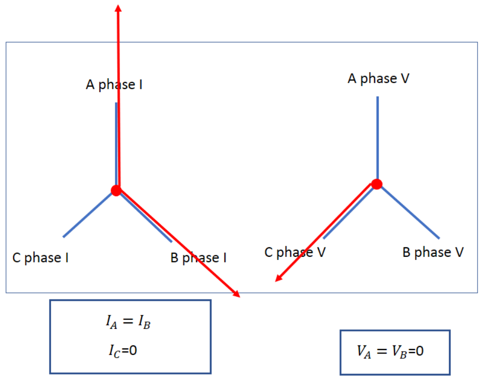

Figure-14. Current-voltage vector diagram of a short-circuit with two-phase (A, B) ground

$$I_{l-l-G} = \frac{V}{Z_1 + \frac{Z_2 * Z_o}{Z_2 + Z_o}} \qquad (4)$$

Equation-4 represents the amount of current when two phases are short-circuited to the ground. V-line voltage, Z_1-direct sequence total resistance, Z_2-reverse sequence total resistance, Z_0- zero sequence total resistance.

There are two types of short-circuit calculation modes: high-load and low-load. High-load mode is a mode of winter heavy-duty or multi-synchronous generator operation in parallel operation in the network. Low load mode refers to the low summer load mode. The equipment's load capacity is checked by means of calculations made in high load mode. However, the relay protection setting is selected based on the short circuit in low load mode [4].

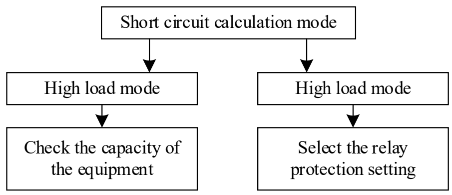

Figure 15. Condition of short circuit calculation

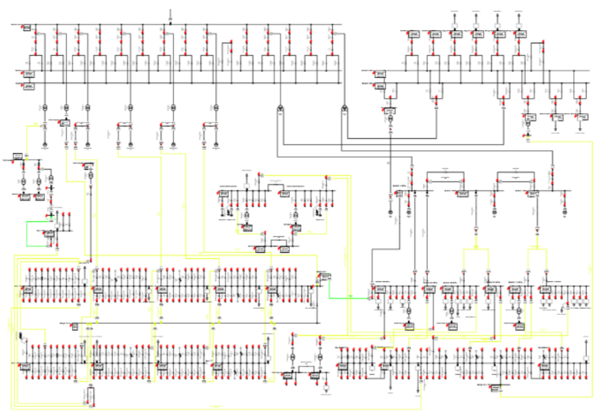

Figure-16. Calculation of short circuit in Powerfactory

The short circuit calculation was performed in accordance with the international standard complete method. The results of the analyses are shown in the following table.

Table 9. Result of Short Circuit Calculation

Busbar and cable name	Unbalanced			Balanced
	Single-phase to ground	***Two-phase short circuit***	***Two-phase to ground***	***Three-phase***
110 kV section busbar /kA/				
I	12.039	10.944	12.338	13.0
II	12.039	10.944	12.338	13.0
35 kV section busbar /kA/				
I	8.192	5.042	9.01	6.3
II	8.192	5.042	9.01	6.3
6 kV section /kA/				
1RO	0.003	26.406	26.405	31.3
7R	0.003	26.287	26.287	31.1
2RO	0.005	37.177	37.176	44.5
8R	0.005	36.960	36.961	44.3
9R	0.005	37.129	37.129	44.5
10R	0.005	36.912	36.912	44.2
11R	0.007	37.193	37.193	44.6
12R	0.007	36.976	36.976	44.3
13R	0.026	8.634	8.635	10
14R	0.010	10.724	10.725	12.6
I	0.006	25.522	25.520	31.9
II	0.006	25.523	25.519	31.9
III	0.006	25.444	25.025	31.6
IV	0.006	25.422	25.024	31.6
V	0.006	25.912	25.613	40.5
VI	0.006	25.913	25.612	40.6
GRU-1	0.006	33.682	34.05	43.4
GRU-2	0.006	33.682	34.05	43.4
GRU-3	0.006	33.682	34.05	43.4

On July 7, 2021, the 110 kV system was short-circuited between the two phases (B, C) on the "Dund Gol" overhead line connected to section busbar II, and the short-circuit current reached 13 kA and the system entered the emergency mode. Then the current mode, Short-Circuit Power Skmax = 1720 MVA; Skin = 1601 MVA; Short-Circuit Current Ikmax = 9.02765 kA; Ikmin = 8.40307 kA, when calculating the two-phase short circuit in the Powerfactory program, the short-circuit current is Speak = 12.895 kA.

VI. Conclusion

As a result of the load flow calculation on the Powerfactory software based on the measurement value of December 15, 2021, the loading, loss, and voltage level were determined, and the following conclusions were made as a result of the short circuit calculation. These includes:

1. In terms of generator load, TG-9 was the most loaded or 87.3%, TG-8 was the least loaded or 52.6%, and the average loading value of the 9 generators was 66.9%.
2. BTR-9 has the highest load or 66.6% and BTR-8 has the lowest load at 37.7%. 10T is connected to the preparation bus, but it is 0.4% because there are no consumers receiving the feed. Excluding 10T, the average load value of the other 9 transformers is 45.2%.
3. 19.39% or 33.83 MW of the total generated capacity was used for the internal needs of the plant.
4. The result of the loss calculation is only the purely technical loss of the transformer. In addition to technical losses, there are various unforeseen losses, such as measurement accuracy and human intervention.
5. According to the calculation results, the active power loss is 0.99 MW and the reactive power loss is 11.44 MW, or the majority of technical losses are transformer no-load losses.
6. The use of high-power transformers from load increases losses. Therefore, transformers should be loaded to the fullest extent possible and transformers of suitable capacity should be used.
7. Following the guidelines issued by NDC, based on the values of the 2021 winter peak load measurement, the busbar balance was calculated as a result of calculating the transformer losses in the Powerfactory software. It is estimated that the busbar balance is within ± 5%.
8. The voltage of the busbars is between 6.2-6.3 kV and there is no voltage drop, it is within the allowable range.
9. Balanced and unbalanced short-circuit calculations were performed on the Powerfactory software and the results were obtained. Balanced or three-phase short-circuit values are 13 kA on 110 kV section busbars I and II, 6.3 kA on 35 kV section busbars I and II, and 10-44.6 kA on 6 kV busbars.
10. The two-phase short circuit on the 110 kV "Dund Gol" overhead line on July 7, 2021, was calculated in the Powerfactory program using the current model, and the calculated value (12.895 kA) and the actual value (13 kA) had an approximate value.

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