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Simulation results of an Automatic Reclosing Device Mode and Operation Modeling for Too Long Overhead Lines

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Abstract

Mongolia occupies a vast territory encompassing 1,564,116 square kilometers. However, due to its low population density, urban cities are mostly located far from one another, and electricity consumption can be relatively low. Also, 110 kV and 220 kV overhead power lines built in the urban areas of Mongolia tend to be longer than the standard. Therefore, Mongolia's power grid system differs from those of other countries due to these features. Furthermore, 110 and 220 kV overhead lines in Mongolia pass through high mountain regions and steppe regions at an average altitude of more than 1000 meters above sea level, providing electricity to consumers in adverse weather conditions. In addition, because it is not uncommon for electrical substations to be interconnected, the overhead lines are designed as a network that forms a system. In this case, the study of the operation, failure and outage of the overhead lines and electrical grid will play a significant role in improving the continuous reliability of the power supply. And the relay protection and automation equipment in the network should therefore be improved and made more flexible and smart. In our joint research, based on the results of the last ten years of data on overhead line outages, relay protection, and automatic reclosing device operation, we modelled a too-long-line automatic reclosing device that reflects the characteristics of Mongolia's electrical grids. As a final note, we have presented some of the results of the operation simulation of our model in this article.

Keywords: Outages of Overhead Line, Power Grid, Relay Protection

1. The structure and features of the 110, 220 kV power grid in Mongolia

Mongolia has a vast territory. However, due to its low population density, urban areas are stationed far from each other, so 110 kV and 220 kV overhead power lines can be longer with an average of 100-300 kilometres, and electricity consumption is relatively low.

The object of our research, the 110 kV Murun-Telmen overhead transmission line, was put into operation in December 2012 to supply the consumers of Khuvsgul, Zavkhan, and Govi-Altai provinces from the Central region power system. In the first part of this grid, there will be a single-circuit AC-120 transmission wire of 281 kilometers, which will continue through 2-3 low-power substations; the total length of this grid will be 534 kilometers (Figure 1).

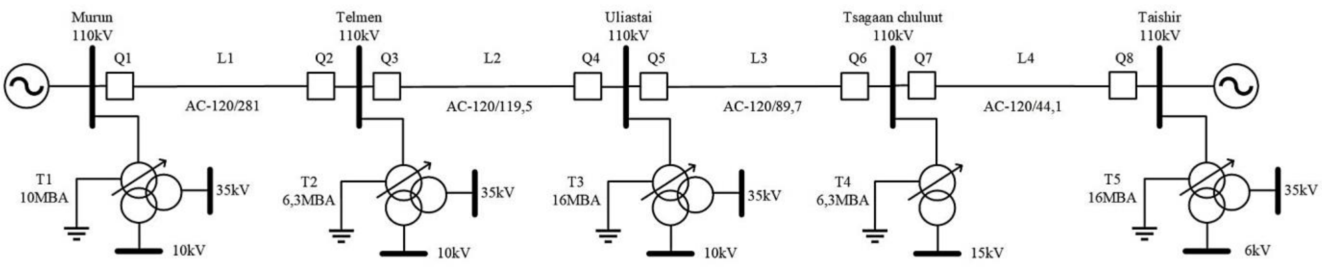

Figure 1. The study's main diagram

2. The data and regime of the equipment installed in the overhead transmission lines and substations used in the study

Table 1. Data from overhead power lines used in the study

№	Features	Murun/ Telmen	Telmen/ Uliastai	Uliastai/ Tsagaanchuluut	Tsagaanchuluut/Taishir
1	Line Voltage, U [kV]	110	110	110	110
2	Length, [km]	281	119,5	89,7	44,1
3	Span length [m]	270	270	270	270
4	Circuit type	Single /Three wires/	Single /Three wires/	Single /Three wires/	Single /Three wires/
5	Transmission line type	AC-120/19	AC-120/19	AC-120/19	AC-120/19
6	Overhead ground wire type	TK-50	TK-50	TK-50	TK-50
7	Pole type	U-110	U-110	U-110	U-110

Table 2. Data of transformers and reactors used in the study

№	Features	Telmen substation	Uliastai substation	Tsagaanchuluut substation	Taishir substation
Transformer					
1	Rated power [MVA]	10	6.3	6,3	6.3*2
2	Rated voltage, [kV]	110	110	110	110
		35	35	15	35
		10	10	-	6
3	Connection symbol	YnyD11	YnyD11	YnD11	YnyD11
4	Tap changer	OLTC-2, NLTC-3	OLTC-6/8, NLTC-3	-	OLTC-13, NLTC-4
5	HV grounding	grounded	grounded	grounded	grounded
Reactor					
6	Rated power [MVAR]	4,2	3,3	-	5

The main protection SEL-311C and backup protection SEL-421 devices are installed on the 1st part of the grid Murun-Telmen overhead line.

3. Natural and climatic conditions of the Murun-Telmen transmission lines

As an example, let us take a closer look at the features of nature and the climate in the area where the Muron-Telmen power transmission line is located. In an area of extreme weather conditions, this line is located at 49 degrees longitude and 97 degrees latitude at an altitude of 1650-2050 meters above sea level.

This region is known for its large annual and daily temperature fluctuations (+36.3^{0}C, -51.2^{0}C), annual average relative humidity of 50-60% [1], and frequent thunderstorms during the summer months. There is an average annual precipitation of 190-240 millimetres, with 85-91% of annual precipitation falling from the end of June to the end of August [1]. The coldest month of the year is January, with an average monthly temperature of -28^{0}C, while the warmest month is July with an average temperature of 25^{0}C. Especially, during the hot season, the relative humidity of the air changes strongly during the day. While the air humidity increases in the morning, evening, and nighttime, the humidity decreases significantly during the day.

4. Outage study of MURUN-TELMEN overhead line

The reliability of high-voltage overhead lines depends largely on the number, duration, and nature of outages. The main parameter that determines the reliability of high-voltage transmission lines according to international standards is the number of annual outages per 100 km [3].

The main feature of this Murun-Telmen overhead line is that the line is located at an altitude of 1650m above sea level, and it is mostly affected by natural weather factors. Therefore, the main factors affecting the line failures are determined by its design, operation, and climatic conditions. For example:

- A variety of materials with different specifications are used in high-voltage power lines.
- The lines mostly pass through various terrains and are therefore most affected by external factors such as air temperature, relative humidity, and soil composition.
- Due to mechanical loads, lines are likely to be damaged numerous times, resulting in a high number of outages.
- Insulation contamination levels vary over the entire length of the line.
- Fluctuation of line voltage during operation, temporary voltage increase during the transition process,
- Lightning and internal overvoltage action

In this research, the survey of outages of the Murun-Telmen overhead line since its first operation was conducted and summarized as results shown in Table 4.

Line outages numbers are defined as the amount of outages per 100 km, and the amount of outages in Mongolia's transmission overhead line was compared with that of other countries [5].

Table 3. Number of outages in Mongolia's transmission overhead line was compared with that of other countries

Country	*Line Nominal Voltage, kV*	*Amount of outages per 100 km per year*
Mongolia	110-220	2.83-28.1
Canadia	200	1.8
USA	138	0.3
Germany	110	0.5-3.2
Japan	11-154	0.52-1.64
Estonia	100-150	1.82
Latvia	100-150	2.35
Lithuania	100-150	1.77
Denmark	100-150	0.96
Finland	100-150	1.81
Island	100-150	0.88
Norway	100-150	0.74
Sweden	100-150	1.24

Table 4. Number of outages of the Muren-Telmen overhead lines

Year	**Month**												**Total**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
2013	4	6	17	3	6	12	7	12	7	3	2	2	**81**
2014	2	2	1	4	5	23	26	21	6	6	4	-	**100**
2015	-	1	-	-	20	31	44	22	7	2	-	-	**127**
2016	-	1	3	2	10	28	32	-	11	8	3	1	**99**
2017	1	2	3	3	7	18	35	12	8	5	2	1	**97**
2018	1	-	2	4	10	23	57	23	13	3	2	-	**138**
2019	-	1	2	3	8	14	25	16	6	5	4	1	**85**
2020	-	-	-	3	3	12	23	17	2	1	-	-	**61**
2021	1	1	1	1	3	7	10	10	4	3	1	-	**42**
2022	-	2	4	3	2	4	6	8	6	3	-	-	**38**
2023	-	-	4	4	10	24	10	5	14	30	-	-	**101**
Total	**9**	**16**	**37**	**30**	**84**	**196**	**275**	**146**	**84**	**69**	**18**	**5**	**969**

The number of line outages was studied using the quantitative analysis method along the length of the line to study the environmental and weather factors affecting the outage. According to the study of the annual outages of the Murun-Telmen line [4], most of the total outages were recorded in the summer season, from June to August. Thus, it can be seen that 64% of all outages occur during the warm season. Particularly, the most outages occur between 5 and 8 am, while the fewest occur between the hours of 1 to 3 pm and 0 to 1 am.

During the warm season, the period of maximum line breaks, which occurs from 6 am to 8 am, coincides exactly with the sunrise hours. Particularly in summer, air humidity increases at night and soil and air temperatures decrease. Meanwhile, when the sun rises in the morning, air and soil temperatures increase, causing condensation to form on the surfaces of insulators that have not yet been heated up by water vapour from the ground surface. This creates a conductive layer on the line, creating the ideal conditions for insulation breakdown to occur.

Furthermore, it should be noted that 40% of the total outages occurred between 113-168 kilometres of the line length, or between poles №432 to №644, which indicates that the damage occurred in the middle of the line (Figure 2). Thus, as further studies were done, it was observed that the salinity quality was significantly higher at the points where the line breaks the most.

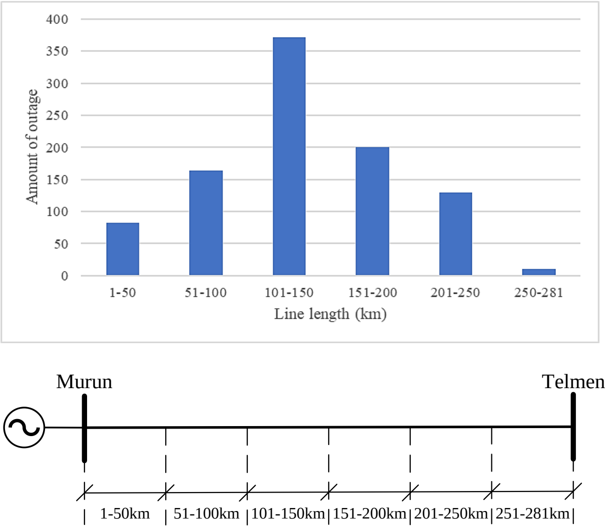

Figure 2. Comparison of the number of outages of the Murun-Telmen overhead line to the total length

The failure of the 110 kV Murun-Telmen power line occurring in the middle of the total length of the line could be related to the phenomenon of voltage increase in the middle of the extremely long line with low capacity.

5. The regime and operation modelling of automatic reclosing device for too-long lines

The initial scheme and the types of equipment of all existing substations must be included in the model along with its relevant data and should be simulated to create an automatic reclosing device (ARC) regime that is suitable for extremely long power lines based on the characteristics of the Mongolian Grid (Figure 3). In the following steps, the model performance must be tested for accuracy under several scenarios (winter high load mode, summer low load mode, etc.).

Static Var Compensator (SVC) installed in power systems is used for improving the system performance in several ways [6]. The SVCs are suitable to regulate system voltages, improve transient stability, increase transmission capacity, reduce temporary overvoltages, increase damping of power oscillations, and damp subsynchronous resonances and torsional oscillations [6]. The SVC as a tool to improve power quality is a consequence of the economic pressure on electrical energy systems throughout the world [7].

Modelling of ARC operation for too-long lines is included in the Telmen-Murun 110 kV overhead transmission line. This can be accomplished by entering the overcurrent and distance protection device data into the modelling software as a microprocessor-based digital device, calculating the ARC set points, and simulating the operation (Figure 4).

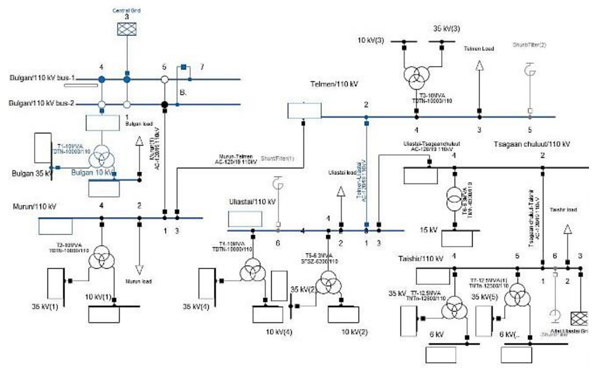

Figure 3. Research model

Table 3. Simulation result

Substation name	Bus Voltage, U [kV]	Load /P/, [MW]	Load /Q/, [MVar]	Scenario 1	Scenario 2 /SVS connected/
				Bus Voltage, U [kV]	Bus Voltage, U [kV]
Murun substation 110/35/10	109.8	9.826	3.801	107.4	109
Telmen substation 110/35/10	113.3	14.5	13.895	108.7	110
Uliastai substation 110/35/10	113.2	6.2	-3.75	110.1	109.9

Taishir substation 110/35/10	114.6	-1.29	-0.493	110	110

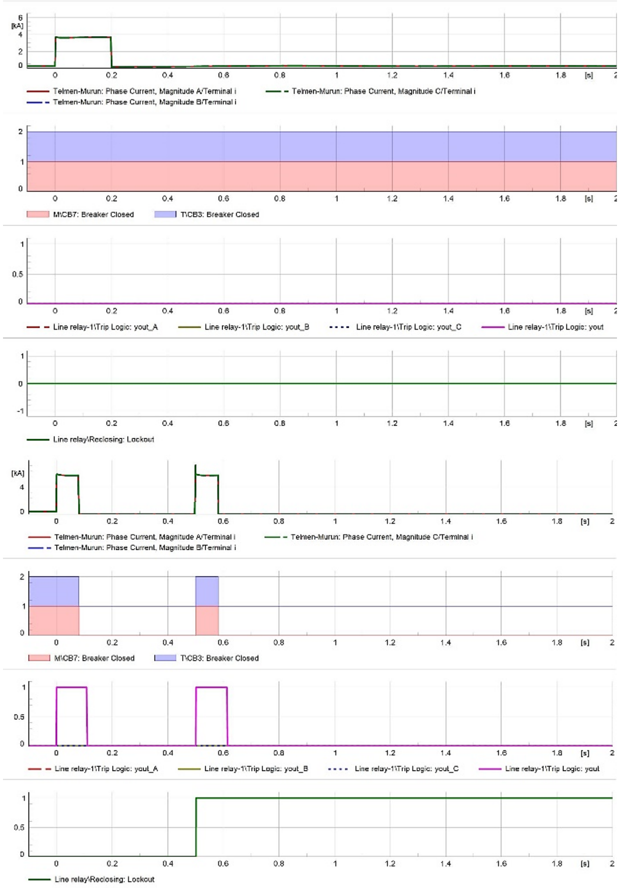

Figure 4. Model simulation result of ARC operation /3 phase short circiut successful and unsuccessful/

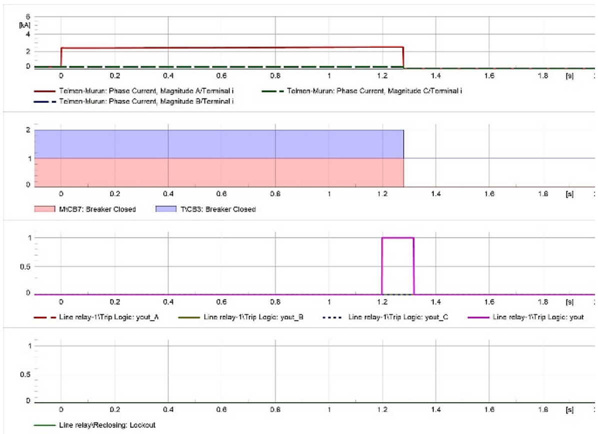

Figure 5. Model simulation result of ARC operation/1 phase short circiut unsuccessful/

This simulation can be used to adjust the regime and value of a short-circuit fault occurring on the research object (the Murun-Telmen overhead transmission line), which enables the ARC operation regime to be adjusted according to the short circuit types (3-phase, 1-phase to ground).

6. Conclusion

Since the first commissioning of the Murun-Telmen overhead line (2013-2023), there have been 969 outages. In Mongolia, during the warm season, the temperature difference between day and night reaches 20^0C, because the temperature changes sharply in the mornings and evenings due to the extreme climate of our country. The results of the research indicate that approximately 64% of all overhead line outages occur during the warm season, and more than 30% occur between the hours of 5 a.m. and 8 a.m.

The high number of outages during the sunrise in the warm season is explained by the dew falling on the surface of the insulation, and this may also be related to the occurrence of dust pollution from the soil in the conditions of Mongolia. In high-voltage devices, the lower part of the insulating element is heavily polluted, unlike the upper part, and it has been observed that, depending on the weather conditions in Mongolia, the pollutants weaken the bearing capacity of the high-voltage insulating equipment when morning and evening dew falls.

The development of the simulation of the too-long lines was done by including the initial scheme and equipment of the existing substations in the model with its relevant data, and the model was then simulated by putting it under several scenarios such as winter high load mode and summer low load mode. From the simulation of this model, it has been proved that it is possible to change and develop the operation of ARC devices depending on the natural and climatic conditions and features of the country.

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