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Research on Simulation of Automatic Reclosing Devices for Overhead Line Failures in Extreme Weather Conditions

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Abstract

In order to improve the reliability of the power system and provide uninterrupted power to the consumer, automatic reclosing (ARC) devices are often used in overhead power lines. On top of that, the condition of short-circuit elimination or removal during ARC recloser depends on many random factors. In this article, the number of outages of 110 kV overhead lines in the Khangai region of Mongolia was studied, and the statistics of ARC device operation were compared with international standards. Also, from the works produced by scientists from foreign countries, the development level and innovative trends of ARC devices were compared and studied, and the opportunity to introduce them to Mongolia's grid system was sought. Furthermore, the 110 kV transmission lines outage and the operation of the ARC devices installed in the Khangai region of Mongolia were studied. Hence, the average operation success rate of the ARC device in the last ten years was 76%. It was also found that the number of outages of 110 kV power lines is 8 per year on average, which is 2 - 3 times higher than the international norm. Eventually, the power grid scheme of the Khangai region, especially the Bulgan-Murun 110 kV distribution network, was modelled by Digsilent Powerfactory by including the features of Mongolia's power transmission network, and the operation of the model was checked by the load flow function of the software.

Keywords

Electrical System, Environmental Influences, Operation Algorithm, Outages of Line

1. Introduction

Calculating the operation success rate of the ARC device for each line and equipment used allows us to see the opportunities to improve the reliability of electricity reaching consumers and the efficiency of the electrical power grid. Recently, various research and academic works have been carried out in foreign countries to update and improve the structure, operation algorithm, and executive function of ARC and to study and make the modelling more sophisticated [1]-[7].

The percentage of successful operation of ARC devices in Mongolia is close to the international average, but due to the fact that the number of interruptions of overhead power lines is significantly higher than the international average and that most of the ARC devices are made of electromechanical relays, it is difficult to control ARC during a fault due to its features. Because line interruptions are significantly higher than the international average, it is necessary to make it "intelligent" by detecting the cause of the damage, using a more intelligent and sophisticated algorithm to operate the ARC in the event of damage, and improving the structure. Therefore, the purpose of this research is to conduct a study of the interruption of 110 kV overhead lines, clarify the operational status of the ARC device that will work during the interruption, and it will be aimed at creating a simulation and studying the possibility of intelligently managing the ARC operation of the too-long overhead line in accordance with the fault type.

2. Electrical Network of Mongolia

Depending on the vastness of the land, the low population density, and the development of the infrastructure, Mongolia's energy system consists of the Western Region Energy System (WRES), the Altai-Uliastai Energy System (AUES), the Central Energy System (CES), Eastern region energy system (ERES) and Southern region energy system (SRES) (**Figure 1**). Among these energy systems, CES covers about 70% of Mongolia's territory and supplies energy to about 80% of the total population. As of 2023, the installed capacity of CES is 1329 MW. Meanwhile, the power transmission network is divided into five regions: Ulaanbaatar region, Central region, Khangai region, East-South region, and Govi region.

Therefore, in this research, the electrical network in the Khangai region branch of the CES was studied, and the electrical networks included in the region are characterized as the main power lines that supply the central part of Mongolia with electricity **Figure 1**.

Mongolia's overhead line differs from other countries in that it is 2 - 3 times longer than the appropriate length, and the number of interruptions per year is many times higher than the standard. Due to its vast land and population density, the total length of the 220/110kV overhead line route belonging to the Khangai region branch of the Central Power System is 1518.14 km, which can be considered to be a long transmission line. Additionally, the route of the "Bulgan-Murun" 110 kV overhead line studied in this research is fed from the Bulgan

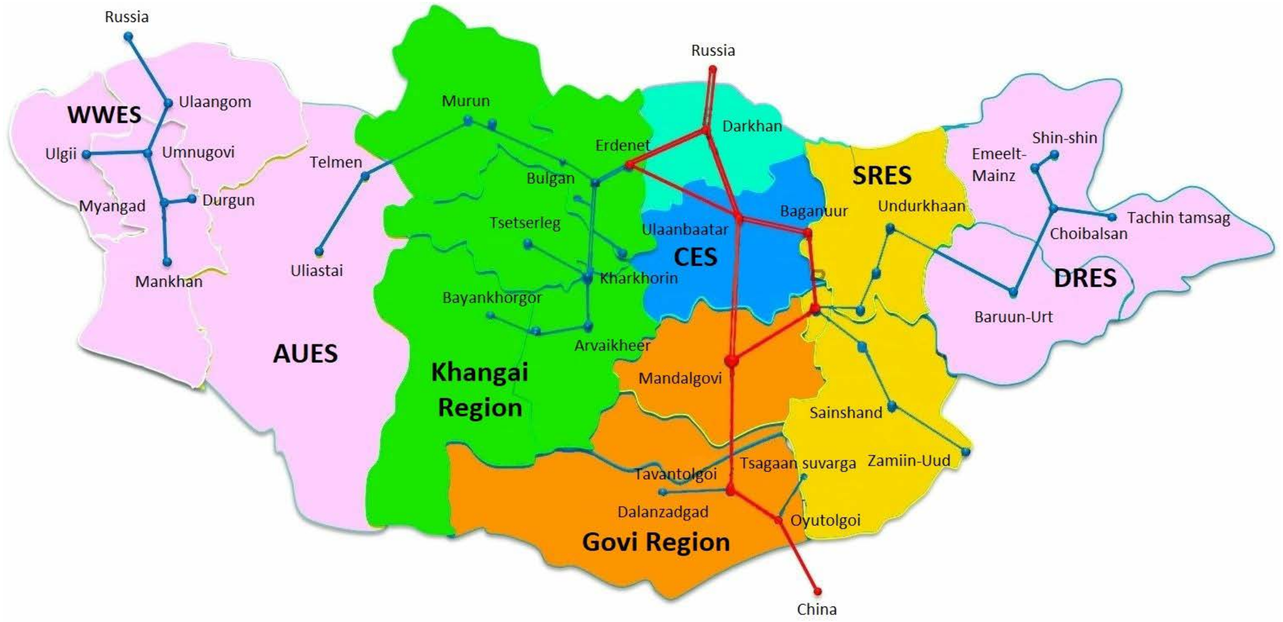


Figure 1. The general structure of Mongolia's electrical system [8].

substation and is 292.4 km long, and the estimated power flowing through the line is 70 MW.

3. The Outage Study of 110, 220 kV HV Line of the Electrical Network of the Khangai Region

The reliability of high-voltage overhead lines depends significantly 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. The main feature of this area is that the transmission line is located at an average height of 1400 m above sea level, so it is most affected by natural weather factors. Therefore, the factors affecting these line outages can be determined by the transmission line design and usage and their climatic conditions.

For instance:

- A variety of materials with different specifications are used in high-voltage power lines.
- Since the route of the line passes through different terrains, it is affected by the effects of external factors (air temperature, relative humidity, and changing composition of the soil structure).
- Lines are highly damaged due to mechanical loads, so the number of failures is high.
- Insulation contamination levels vary over the entire length of the line.

Also, transmissions are often interrupted by short circuits and among the types of short circuits, the single phase-to-ground short circuit is considered the most common.

The following conditions cause short circuits in electrical equipment:

- Damaging the conductor insulation
- Operator error in emergency situations
- Overloading of equipment conductors, etc

According to the statistics of the outages of the transmission lines, 50% - 60% of the rainfall in Mongolia occurs in June, July, and August, so the number of transmission line failures in these months is relatively high compared to the other times of the year (**Figure 2**). Since the amount of precipitation is relatively high in summer, and factors such as pollution, humidity, and lightning affect the outage, it partially proves the effectiveness of using ARC in Mongolia.

This research was conducted to determine the number of line breaks in 110 kV substations of the Khangai region from 2010 to April 2023, to clarify the factors and reasons affecting the outage of lines with high interruptions, and to determine the percentage of successful operation of automatic reconnection (ARC) devices of substations in the last ten years. For example, the outage of the 110 kV "Bulgan-Murun" overhead line, the route of the line, and the natural and climatic environment have been studied.

The 110 kV Bulgan-Murun substation starts northwest from the 110/35/6kV Bulgan substation, makes 48 turns, crosses two major rivers, crosses eight hills and covers 107.03 km of mountains, 175,582 km of plains, 3429 km of wetlands and 5.8 km through the forest to reach the town of Murun, Khuvsgul province. The 110 kV transmission line routes from east to west; geographically, it is in the southwestern part of the Khuvsgul province, Murun basin, Orkhon Selenge basin, middle mountainous region and Khangai Khentii mountain range.

Most of the line's route, about 70 per cent, will pass through hilly plains, intermountain valleys, lakes, and river basins, and the rest will pass through hills, mountains, passes, and ridges. The surface elevation of the line's route is 1095 m above sea level at the lowest point/crossing the Selenge River/, and the highest point is 1825 m above sea level /Khar Zalaat Hill/. Also, the height of the starting point of the 110/35/10kV Bulgan substation is 1600 m above sea level.

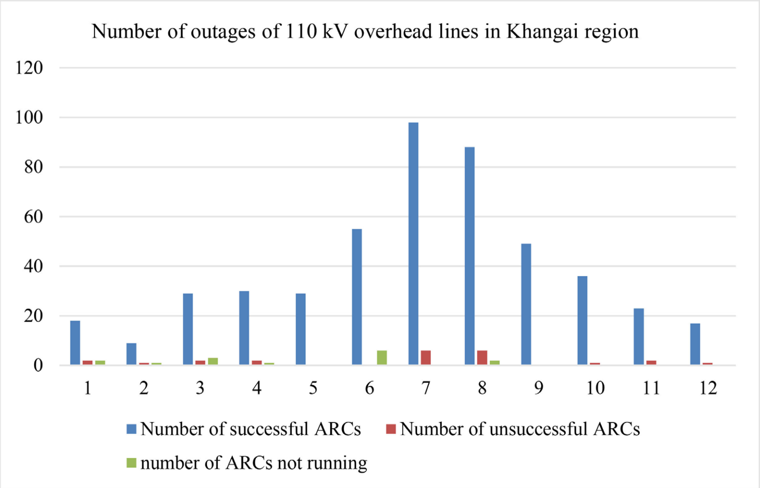


Figure 2. The annual average number of outages of the 110 kV power line in the Khangai region.

Environmental Influences on the Break in the Bulgan-Murun Transmission Line

Over half of the line outages occurred only in June, July, and August. Additionally, the majority of line breaks are observed to have occurred in the morning between 4 and 8 o'clock in the warm season. At this time, the relative humidity of the air will be the highest, and due to the sun's rise, the temperature of the environment will change dramatically, and the grass water will evaporate and settle on the surface of the insulation as dew. Therefore, the phenomenon of uniform wetting of the contaminated surface takes place strongly. The phenomenon of line breaks in the morning can be explained in advance by the fact that the contamination of the surface is taking place. This phenomenon is directly related to extreme continental climate.

Due to the fact that our country is far away from foreign seas, surrounded by high mountains on all sides in the centre of the Eurasian continent with an average elevation of more than 1500 m above sea level, it has a harsh continental climate. Also, one of the main characteristics of the climate is that there are large differences between the four seasons of the year, and due to this distinction, air temperature fluctuations are high, precipitation is low, and the climate differences between latitude and altitude zones are evident. Thus, Mongolia has short (from VI to mid-VIII), dry summers, very cold and long winters (from XI to IV), and the length of the spring and autumn seasons varies widely from year to year.

In terms of air temperature, the average temperature in the winter is −15˚C - −30˚C (6˚ - 22˚F), and in the summer, it is 10˚C - 26.7˚C (50˚ - 80˚F). The average annual air temperature is −4˚C cold in the mountainous areas of Altai, Khangai, Khentii and Khuvsgul, that is −6˚C - −8˚C cold in the intermountain depressions and large river valleys. On the other hand, 2˚C warm in the desert region, and 6˚C in the southern Gobi. The 0˚C line of average annual air temperature is along the 46˚ north latitudes on the northern border of Mongolia's steppe and Gobi region. In areas colder than the average annual air temperature of −2˚C, permafrost soils are widespread [9].

While studying the Murun 110 kV transmission line outages in terms of weather conditions, it has been observed that the 58% of all outages have occurred during tranquillity (**Figure 3**).

Whereas the reasons for the outages of the transmission lines were further studied, it can be seen that 43% of the reasons for the outages are unknown, 19% are due to equipment damage of the line itself, and 6% of the outages external factors (birds), 32% of the outages weather conditions (**Figure 4**).

4. Automatic Reclosing (ARC) Device

According to the study's results [4], the automatic reclosing devices used in the electric network of Mongolia were studied in detail in terms of their type, element base, and year of use. In 90% of the electric network of the "Khangai region," RPV-58 and RPV-358 electromechanical relays manufactured in Russia are used.

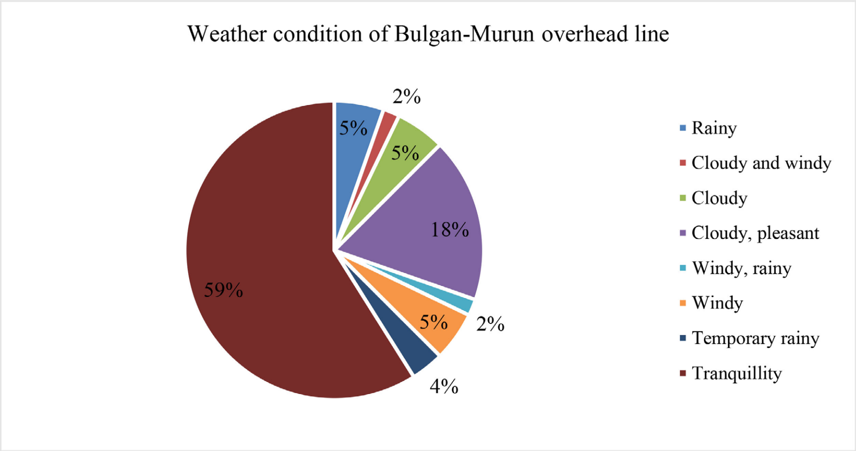


Figure 3. Annual weather conditions along the route of the Bulgan-Murun 110 kV overhead line.

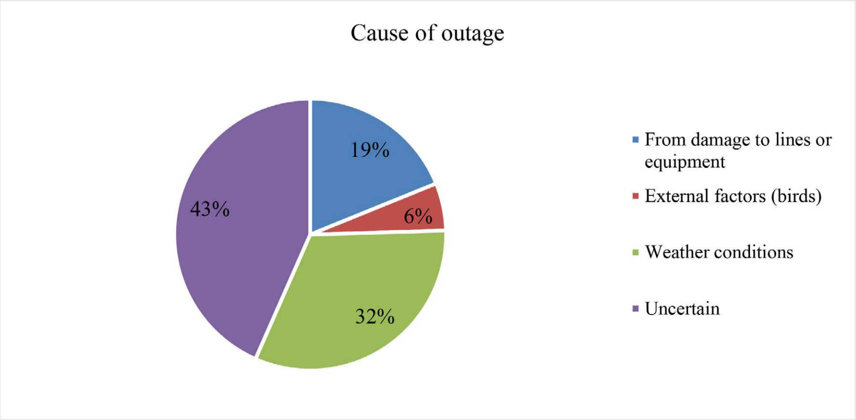


Figure 4. Reasons for the outage of the 110 kV power line in Bulgan-Murun.

Currently, depending on the state of the network, single-phase auto reclosing, three-phase auto reclosing (TARC), and synchronism-check auto reclosing (synchro-ARC) are the types of ARC used in the network. As for TARC equipment without synchronism control, it is used in rural lines with one-way supply, while single-phase reclosing and synchro-ARC are used in 110 and 220 kV system generating lines. Other types of ARC are currently not used in the electrical network of our country.

Theoretically, the success rate of ARC is 60% - 75% in the first cycle, 10% - 15% in the second cycle, and 1.5% - 3% in the third cycle [10]. As the voltage level of overhead power lines increases, the percentage of successful operation of ARC tends to decrease by 110 - 220 kV (75% - 80%), 330 kV (67% - 70%), and 500 - 750 kV (50%) [11]. In our country, the percentage of successful operation of ARC on overhead transmission lines is about 74% - 78% on average, based on the statistics of the last ten years [12] [13]. Therefore, there are technical conditions and needs for developing intelligent ARC algorithms suitable for the structure of our country's electrical network and overhead lines. If we can suitably develop ARC, it can improve the successful operation of ARC. However, it is necessary to modernize the algorithm, considering the conditions and requirements for the successful operation of ARC.

The successful operation of ARC means that when the overhead line and equipment are cut by relay protection, the overhead line and equipment remain at nominal voltage. In order to ensure the successful operation of the ARC, after a certain period of time after the protection has been cut off, the relay gives a command to open the circuit breaker, and during this period, the air must be deionized and find its insulating properties. This period is called the deionization period. The deionization time depends on the normal line voltage and many random factors, such as ambient conditions and climate. According to the research, the deionization time is 0.15 - 0.2 s for 110 kV overhead lines and 0.35 - 0.4 s for 500 kV overhead lines [10].

Therefore, when calculating the reconnection time of ARC, instead of taking the above factors into account and calculating the average, taking into account the normal voltage of the line, the natural and climatic conditions, the condition of the surface of the earth, and air pollution, if it is determined by the results of certain research and tests, the success rate of ARC will be improved, thus making it possible to fulfil the goal of providing consumers with continuous electricity. In some professional textbooks the success rate of 110 and 220 kV overhead lines is written as 75% - 80% (**Table 1**). Also, ARC's successful operation percentage for equipment other than overhead power lines is studied from textbooks (shown in **Table 2**).

The success rate of ARC used in our country is 78% for 220 kV overhead lines and 74% for 110 kV (**Figure 5**).

Table 1. Statistics on the successful operation of ARC for overhead power lines.

ARC types	Overhead line nominal voltage, кV				
	2 - 10	20 - 35	110 - 154	110 - 154	400 - 500
Single-shot TARC	53.5%	69.5%	75.0%	76.5%	67.0%
Multi-Shot TARC	56.2%	78.1%	80.5%	77.2%	-
Single-phase automatic reclosing	-	-	73.2%	80.7%	59.5%
All types	53.6%	70.5%	75.5%	77.0%	64.5%

Table 2. Data on the successful operation of ARC for devices other than overhead transmission lines.

Type of ARC device	Mixed line	Cable line	Bus	Transformer	Other objects
Single-shot TARC (Successful operation, %)	56.2	45.3	64.8	60	64.4
Multi-Shot TARC (Successful operation, %)	68.3	43	-	-	-
All types (Successful operation, %)	57	45	64.8	60	69.8
Single-shot TARC (Successful operation, %)	56.2	45.3	64.8	60	64.4

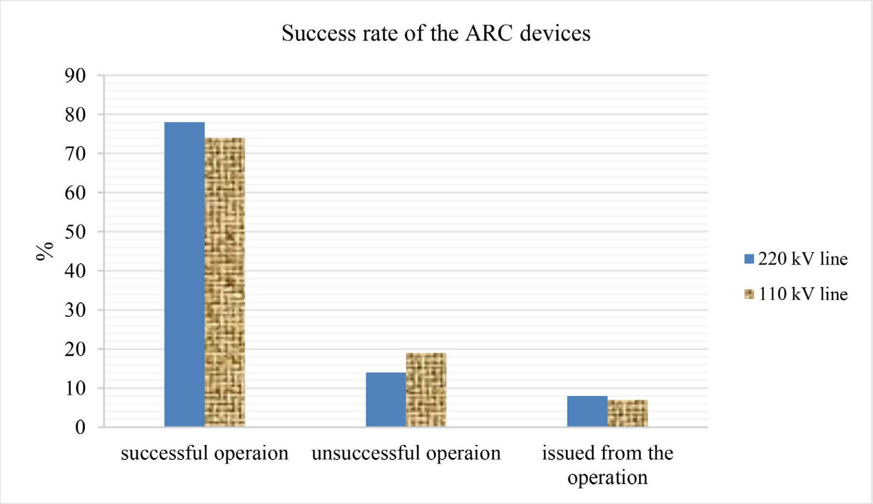


Figure 5. Success rate of the ARC devices in Mongolia (110, 220 kV overhead lines).

5. A Study of Automatic Reclosing (ARC) Device Operation in the Mongolia Electrical Network

Most of the faults in the power system in Mongolia are caused by overhead line faults. Since the majority of cases of faults on high-voltage lines are unstable, self-resolving, and temporary, there is a high probability that the fault will be removed and normal operation of that part of the system will be restored after reconnection by the ARC device [10].

If we calculate the average value of 10 years (2010-2023) of the study of the operation of the ARC of the overhead line, 76% were successful, 14% were put out of operation, and 10% were unsuccessful (**Figure 6**).

Also, according to the statistics of overhead line outages in each of the surveyed years, outages in months 6, 7, and 8 are relatively high compared to other months (**Figure 2**). This is due to relatively high rainfall in the summer as well as factors such as pollution, humidity, and lightning. From this, it can be seen that using ARC in overhead lines is effective for Mongolia. Also, in Mongolia, the number of overhead line outages is very high compared to other countries, and it can be seen that the success rate of ARC is high and effective.

The high success rate of ARC indicates that 80% - 85% of all line faults are caused by transient short circuits. Also, the following common factors were found to clarify the reasons why the ARC equipment on the lines failed to work. It includes:

Reasons why ARC did not activate:

- Circuit breaker failure protection tripped
- Bus differential protection tripped
- Cut off with automatic emergency response system
- The ARC being out of service

Reasons why ARC's operation was not successful:

- Reclosing made on a short circuit which was not cleared.
- The wires of the overhead line are downed; phases are connected.

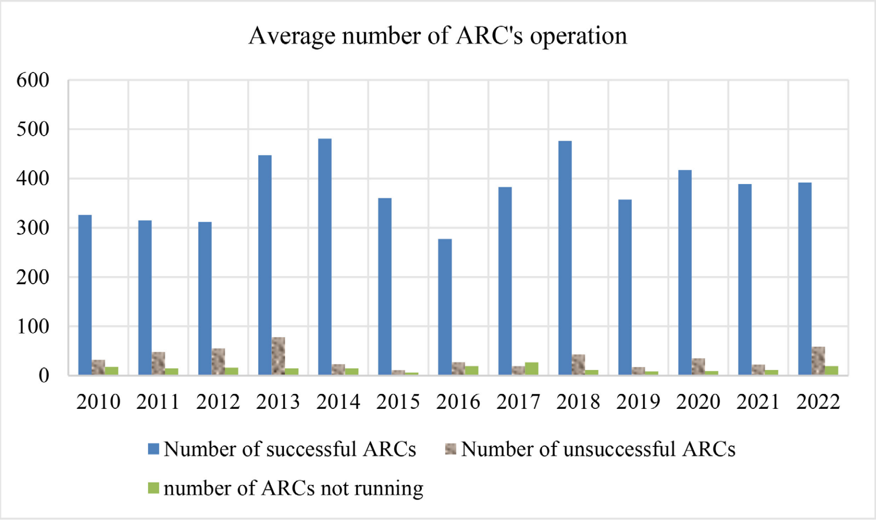


Figure 6. Average number of ARC device's operation in 2010-2022.

- The secondary winding of the measuring voltage transformer is damaged.
- Line insulation may be damaged.

Analyzing the Bulgan-Murun overhead line outage, the overcurrent protection operated was the highest, at 95% (**Figure 7**).

6. Results of Modelling of the ARC of the Too-Long Overhead Line by Digsilent Powerfactory

The electrical network of the "Khangai" region was modeled (**Figure 8**). In the Digsilent Powerfactory program [14], and the equipment data and system parameters necessary for the correct and error-free operation of the simulation were checked by calculating the load flow and short-circuit calculations. The modelling of ARC operation of too-long continuous lines represents the Bulgan-Murun 110 kV overhead line. In doing so, overcurrent and distance protection were entered by microprocessor-based devices, ARC settings were calculated, and operation was tested.

When testing the operation of ARC:

- Operations to lockout: 2
- Reset time: 30 s
- Reclosing interval 1: 0.5 s
- Reclosing interval 2: 1 s
- Closing command duration: 0.02 s
- Fast reclosing 1-phase: 1.6 s chose to be.

In this simulation, **Figure 9** sets the short-circuit fault on the studied line to the desired mode and value. It is possible to set the mode of operation of the ARC in the case of short-circuit types (3 phase, 1 phase to ground).

Furthermore, by replacing the existing ARC with a digital device-based ARC and improving the ARC algorithm, it is believed that there is an opportunity to operate the ARC intelligently depending on the type of fault and the distance of the fault (**Figure 10**).

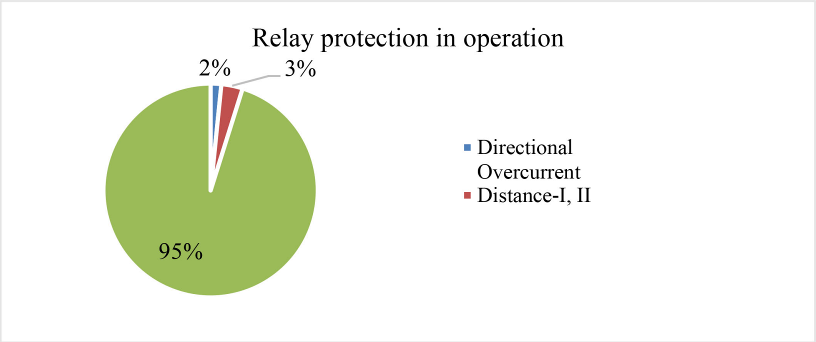


Figure 7. Working status of the Automatic Reclosing device in the Bulgan-Murun 110 kV overhead line.

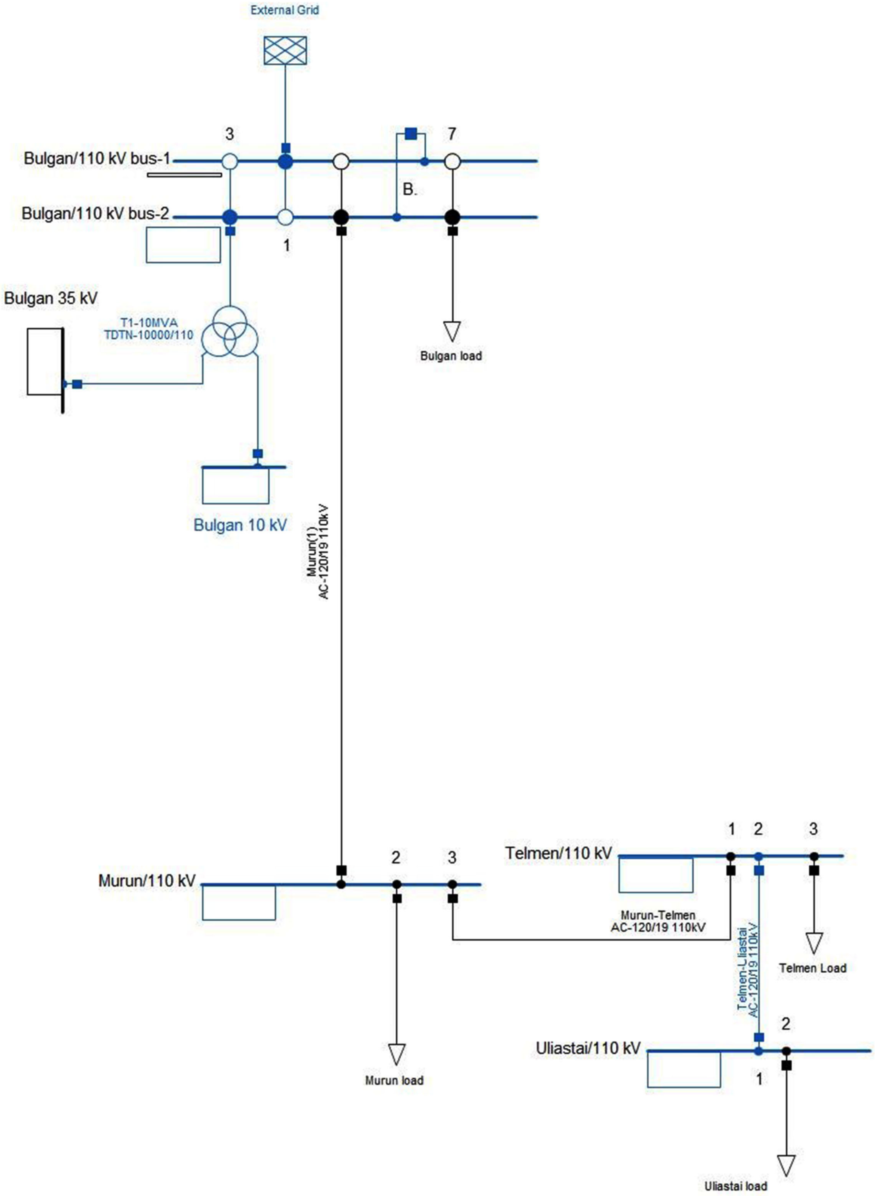
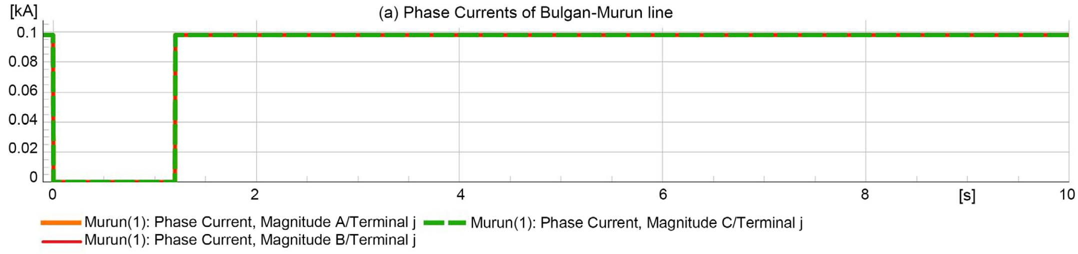
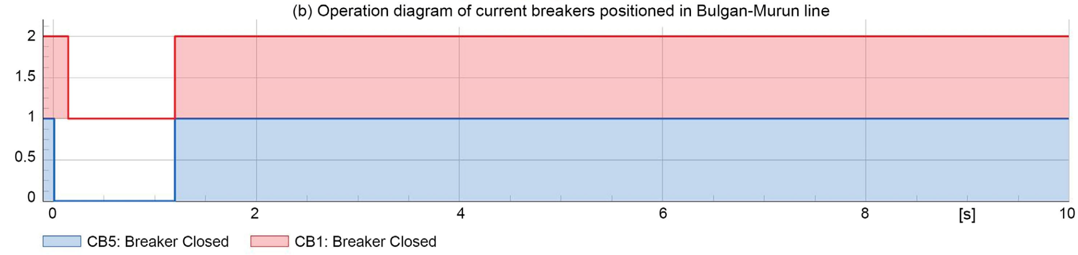


Figure 8. Modelling of electrical network in "Khangai" region in Digsilent Powerfactory software.


(a) Phase Currents of Bulgan-Murun line


(b) Operation diagram of current breakers positioned in Bulgan-Murun line

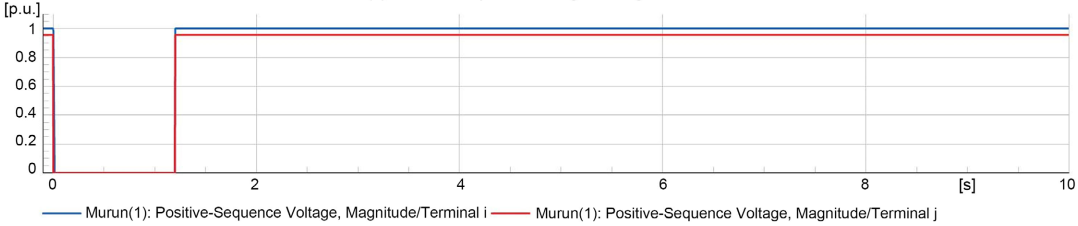

(c) Positive-Sequence Voltage of Bulgan-Murun line

Figure 9. Successful operation of ARC in the event of a 3-phase short circuit.

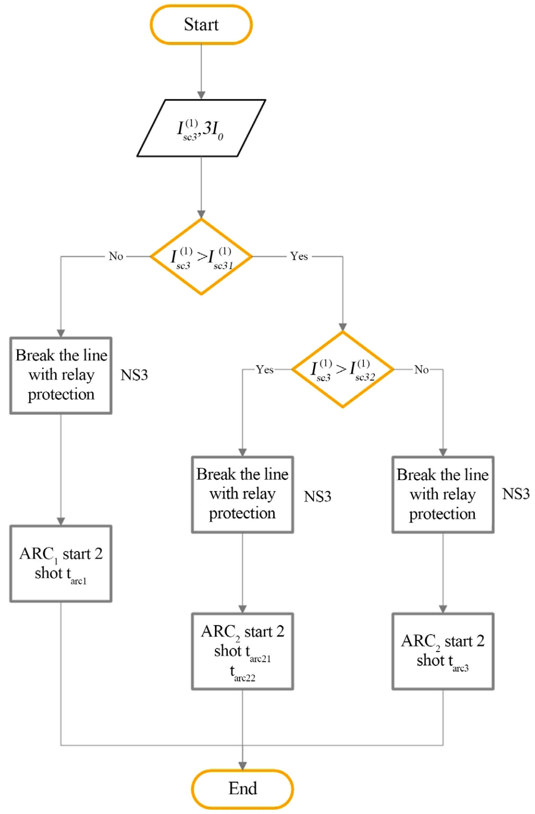


Figure 10. The proposed algorithm built to make the current ARC algorithm smarter and more flexible.

7. Conclusions

The number of outages of the 110 kV 1309.29 km long power line in the Khangai region of Mongolia, considered as a research object in this paper, and the state-of-art research of ARC use (element-based, types, and operation) were conducted and calculated based on the average values of the last 10 years. Also, the operation of the ARC of a too-long overhead line was simulated and tested.

1) Overhead power lines in Mongolia being longer than they should be can be considered as their particularity. For instance, the number of outages per year of the Bulgan-Murun 110 kV 292.4 km long transmission line considered in the study is 22, which is many times higher than the norm. However, ARC's success rate is relatively high, averaging 76%.

2) About 90% of the 110 kV overhead line ARC devices studied in this paper have an electromagnetic element-based RPV-358 relay.

3) According to the first results of simulating the ARC operation of the too-long overhead line on the Digsilent PowerFactory program, it is possible to test the prospect of changing and developing the operation of the ARC according to the nature of the line fault and climatic conditions and features of our country using the model.

4) Also, the currently used ARC algorithms can be enhanced with intelligent and flexible functions. For this reason, it is possible to increase the success rate of ARC devices by replacing the network relay protection device with a microprocessor device introducing an intelligent algorithm.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ivanov, N.G., *et al.* (2019) Fundamentals of Intelligent Automatic Reclosing of Long-Distance Transmission Lines with Shunt Reactors. *Russian Electrical Engineering*, **90**, 558-564. https://doi.org/10.3103/S1068371219080066

[2] Hussain, A., Choi, M.-S. and Lee, S.-J. (2014) A Novel Algorithm for Reducing Restoration Time in Smart Distribution Systems Utilizing Reclosing Dead Time. *Journal of Electrical Engineering and Technology*, **9**, 1805-1811. https://doi.org/10.5370/JEET.2014.9.6.1805

[3] Baayeh, A.G. and Bayati, N. (2020) Adaptive Overhead Transmission Lines Auto-Reclosing Based on Hilbert-Huang Transform. *Energies*, **13**, 5416. https://doi.org/10.3390/en13205416

[4] Sohn, S.-H., Cho, G.-J. and Kim, C.-H. (2020) A Study on Application of Recloser

Operation Algorithm for Mixed Transmission System Based on Travelling Wave Method. *Energies*, **13**, 2610. https://doi.org/10.3390/en13102610

[5] Korves, B.A. (2014) Modeling, Analysis, and Verification of a Weld-Breaking Mechanism for Automatic Circuit Recloser Applications. Diss. Marquette University. https://doi.org/10.1115/DETC2014-34371

[6] Shishlakov, V.F., *et al*. (2020) Modeling of the Operation Modes of the Electric Power System to Improve Its Sustainability of Functioning. *Journal of Physics*: *Conference Series*, Vol. 1515, IOP Publishing. https://doi.org/10.1088/1742-6596/1515/5/052083

[7] Khrushchev, Y.V., Zapodovnikov, K.I. and Yushkov, A.Y. (2012) Elektromekhanicheskieperekhodnyeprotsessy v elektroenergeticheskikhsistemakh (Electromechanical Transients in Electric Power Systems). Tomsk.

[8] National Electrical Transmission Network of Mongolia. https://www.transco.mn/

[9] Institute of Hydroclimatic Environment of Mongolia. https://irimhe.namem.gov.mn/

[10] Barzam, A.B. (1989) Sistemnaya Avtomatika (System Automatics). Energoatomizdat, Moscow.

[11] Bogorad, A.M. and Nazarov, Yu.G. (1969) Avtomaticheskoye Povtornoye Vklyucheniye v Energosistemakh (Automatic Reclosing in Power Systems). Energoatomizdat, Moscow.

[12] Doljinsuren, E. and Natsagdorj, Ch. (2019) Current Status and Analysis of Automation of the Power System in the Central Region. *Research Conference*, MUST, PES.

[13] Doljinsuren, E., Natsagdorj, Ch. and Munkhtuya, B. (2022) Statistics of Operation of the Automatic Reclosing Device of Electric Network of Mongolia. *Development of Information Technology in Energy and Mining Industry*-2022 *Scientific Conference*, Darkhan.

[14] Computing Software DIgSILENT Power Factory. http://www.digsilent.de