Embedded Selforganizing Systems

Utilizing WAMS Technology for Voltage Stability Analysis in the Mongolian Power System

Zagdkhorol Bayasgalan
Power Engineering School
Mongolian University of Science and Technology
Ulaanbaatar, Mongolia
zagdkhorol@must.edu.mn

Munkh-Erdene Oyundelger
National Dispatching Center
Mongolian University of Science and Technology
Ulaanbaatar, Mongolia
o.munkheredene1215@gmail.com

Zoljargal Enkhsumiya
Power Engineering School
Mongolian University of Science and Technology
Ulaanbaatar, Mongolia
B201050631@must.edu.mn

Nomin Lkhagvasuren
I&C supervisor of MCS International
Mongolian University of Science and Technology
Ulaanbaatar, Mongolia
nomin.l@mcsi.mn

***Abstract*— Voltage stability is a critical factor in maintaining the reliability and efficiency of power systems, especially in regions with growing electricity demand and expanding infrastructure, such as Mongolia. This paper explores the application of Wide-Area Monitoring Systems (WAMS) technology for voltage stability analysis in the Mongolian power system. WAMS utilizes real-time data from Phasor Measurement Units (PMUs) to provide system operators with improved situational awareness and more precise control over grid stability. Following significant disruptions to Mongolia's integrated energy system in years such as 2004, 2006, 2015, and 2018, which resulted in instability and resource loss, the Relay Protection and Automation Department of the National Dispatching Center initiated the deployment of the WAMS in 2019 to improve reliability in the energy infrastructure. Through the simulation, and analysis, we demonstrated that WAMS technology significantly enhances the ability to monitor, predict, and respond to voltage instability events, contributing to the overall robustness of the Mongolian power system.**

Keywords*— *Phasor measurement unit, WAProtector software, Power system automation, Real-time monitoring, voltage fluctuation

I. Introduction

The energy sector plays a critical role in ensuring national security and promoting sustainable development. To keep up with these demands, it is essential to quickly integrate proven techniques and technologies, along with modern software applications into Electric Power Systems (hereafter EPS). A key tool in this effort is the Wide Area Monitoring System (hereafter WAMS), which is recognized worldwide for its ability to monitor and analyze the dynamics of power systems during both electromechanical changes and steady operations.

In Mongolia, WAMS was successfully introduced within the electricity system under the name Transition Mode Control and Information System on December 23, 2019. This system marks a significant upgrade in the country's energy management capabilities. With a steady increase in electricity consumption—averaging about 228 million kWh, or 6.3% annually—Mongolia faces challenges in meeting consumer demands entirely with current energy sources [2]. Therefore, enhancing the reliability of electricity supply and ensuring system stability through automation has become critical.

The WAMS implemented in Mongolia comprises of several core components. The core of the system is the Phasor Measurement Unit (PMU), also known as a vector measurement device, is central to the system. It works alongside the Phasor Data Concentrator (PDC), which handles data storage and transmission from the PMUs, and dedicated software for visualizing and processing this information [3]. Together, these components allow for continuous monitoring of the system's performance.

The PMU is an advanced device that uses microprocessors to deliver highly accurate data transmission and is widely used across various sectors. Its main applications include analyzing faults, studying power quality, and overseeing the management of substations and power networks.

The PMU can report the following information [4]:

- Voltage Magnitude & Angle (Phasor)
- Current Magnitude & Angle (Phasor)
- Frequency (measured in mHz deviation from the nominal value)
- Rate of Change of Frequency (ROCOF, in Hz/s)

With these capabilities, WAMS significantly enhances the efficiency and reliability of the energy system in Mongolia.

This paper is organized as follows: Section 2 examines the WAMS in Mongolia, highlighting its features and benefits for improving electricity supply and system stability. Section 3 explores the WAProtector software, detailing its capabilities and uses in the energy sector. The final section provides an analysis performed in PowerFactory, illustrating how

WAProtector contributes to effective power system management.

II. Implementation of WAMS Technology in the Mongolian Energy System

Following a major incident in the integrated energy system on September 15, 2018, the Relay Protection and Automation Department at the National Dispatcher Center of Mongolia recognized the urgent need for a more robust monitoring system. As a result, they embarked on the provision of the Wide Area Monitoring System (WAMS) in the network. The primary goals of this initiative were to accurately assess system stability, improve the monitoring of relay protection automation, and enhance dispatcher control. This led to the development of another project that unveiled WAMS through the monitoring of the Electric Power Systems through the Transition Mode Monitoring and Information System [1].

Amongst the benefits WAMS has delivered was the ability to create a unified automation system for stabilization referred to as Load Shedding Active Power (LSAP) that was unattainable through conventional SCADA systems [1]. Furthermore, it was observed that during a power failure, the system is of great help. It is called WAProtector software, which employs GPS technology to track outages' locations in a real-time system, reducing response time. This software provides details of reasons for outages, and other elaborate analyses and computations. The integrated system has effectively stopped seven potential emergency outages, as illustrated in Fig. 1.

Fig. 1. Points where PMUs are installed in Mongolia's power system

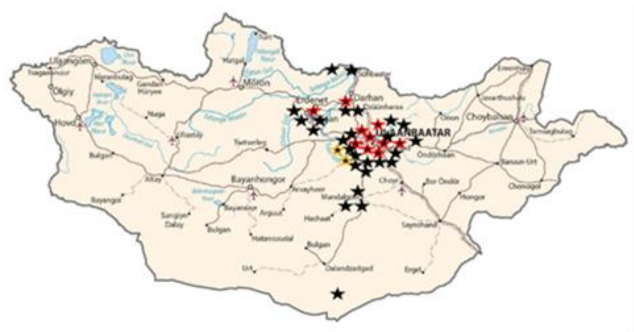


Fig. 2. Measurement of rotor angle during parallel operation of generators

III. Usage of WAProtector software for WAMS

The system currently in use in Mongolia is the WAProtector software from ELPROS which is a general power control, management, and automation system that is in more than 40 nations.

Thector software is a critical component of Mongolia's WAMS and was created by the Slovenian company ELPROS. This software offers a full suite of energy control, management, and automation functions [5]. Founded in 2001, ELPROS has created software that enables real-time data analysis for efficient energy system assessment and management, compliant with the international IEEE C37.118 standard [11].

WAProtector can be expanded to be used to monitor as many as 1000 data points proving the program's flexibility and versatility according to the needs of a system as illustrated in Fig. 4. The measured parameters are the key parameters for an evaluation of system performance and reliability [8].

When operating offline, WAProtector can improve dynamic models in electric power systems, regulate frequency fluctuations, conduct analysis and planning before and after an outage, and organize load consumption in the energy sector. In online mode, it can monitor state estimations, detect voltage stability, control asynchronous modes, identify frequency ranges, and visualize power system parameters in real-time.

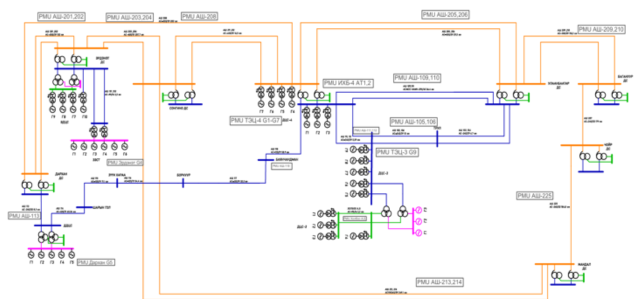
Additionally, the coordinated load-shedding function allows for effective control of line equipment loads. This function was successfully used for the islanding automation of lines 257 and 258.

IV. Analysis of Voltage Stability and Frequency Range Detectors

The voltage stability detector allows for continuous monitoring of voltage levels at connected points in the integrated system, enabling prompt actions to maintain stability during fluctuations. Similarly, the frequency range detector monitors frequency levels to ensure they remain within acceptable limits [9].

All of these functions have been modeled in PowerFactory by adopting a 220kV network arrangement with PMUs in the Mongolian EPS. The PowerFactory program shows the real behavior of islanding automation, where loads are disconnected in the case of line breakdowns. The analysis will show how voltage levels change on other busbars when the overhead line connecting to Russia is disconnected.

Fig. 3. Location scheme of PMU for Mongolian EPS



Selendum, Russia overhead lines 257 and 258 transmit power to the Darkhan substation in Mongolia Currently, the imported active power is 189.0 MW at a frequency of 50 Hz. However, due to rising electricity demand, imports from Russia have increased to 335 MW.

Fig. 4. Power flow modeled scheme of EPS Mongolia on Power Factory program

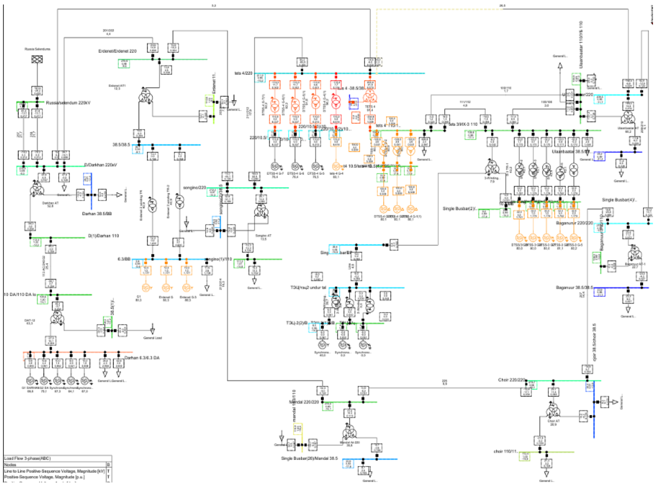
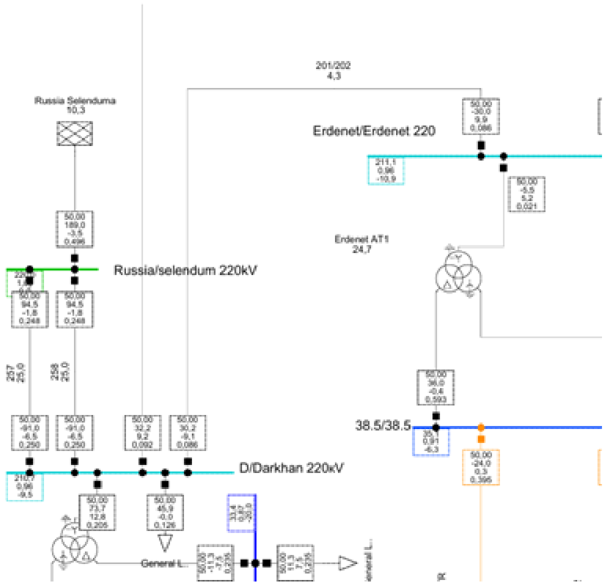


Fig. 5. 220kV scheme with PMU



In this 110kV islanding: Kharaat and Bor-Ondur, two lines were disconnected, and 23.8 MW from the CPS power within the sectional functional electrical energy system at the second state of Islanding Automation. By then, the imported power had risen to 283MW, as illustrated in Fig. 6.

Line 255 would discharge lines 257 and 258 at Selendum 220/110kV substation thus lowering the frequency of the power system to 47.92 Hz in 2.18 seconds.

Fig. 7. shows how the frequency of the system rises due to the action of UFLSH-1 (Under Frequency Load Shedding).

Fig. 6. Import power and load dependence

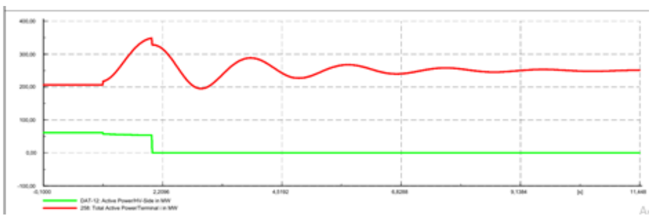
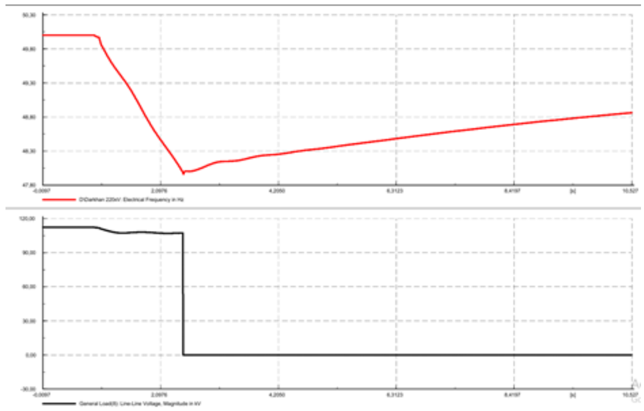
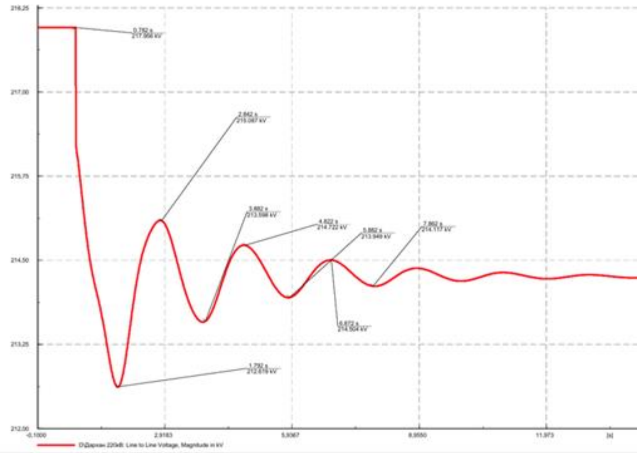


Fig. 7. Overhead lines 257 and 258 were fails. At this time, the frequency and load of the system.



When line 257 fails, fluctuations in voltage occur at the Darkhan 220kV bus connected to it, leading to a voltage drop, as shown in Fig. 8.

Fig. 8. Darkhan 220kV voltage fluctuations when overhead line 257 fails.



The equation of voltage deviations and voltage jumps:

$$\delta U_i = \frac{|U_i - U_{nom}|}{U_{nom}} * 100\% \qquad (1)$$

Here, U_i, U_{nom} represent the changes in voltage values. The minimum permissible voltage variation is ±5%. As long as the voltage change across the bus remains within this range, it is considered acceptable.

According to equation (1), the calculation proceeds as follows:

$$\delta U_i = \frac{212.619 - 220}{220} \cdot 100\% = 3.35\%$$

The equation of voltage fluctuations:

$$\delta U_{t1} = \frac{|U_i - U_{i+1}|}{U_{nom}} \qquad (2)$$

According to equation (2), the calculation proceeds as follows:

$$\delta U_{t1} = \frac{217.965 - 212.619}{220} \cdot 100\% = 2.43\%$$

$$\delta U_{t2} = \frac{212.619 - 215.087}{220} \cdot 100\% = 1.12\%$$

$$\delta U_{t3} = \frac{215.087 - 213.508}{220} \cdot 100\% = 0.72\%$$

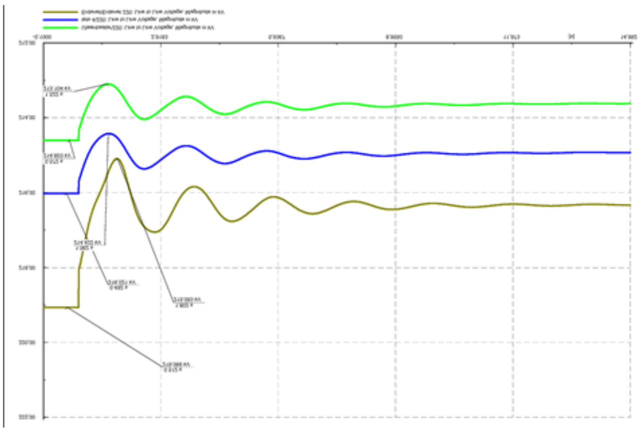
The voltage fluctuation peaked at 2.43%, then decreased by 1.12% and 0.72% before stabilizing. In this scenario, the voltage changes remained within an acceptable range. With an imported power level of P = 185.5 MW, overhead line 257 was disconnected. If the amount of imported power increases, a significant voltage drop is expected.

When overhead line 257 is cut, the voltage changes on the busbars of Erdenet-220kV, CHPP-4-220kV, and Ulaanbaatar-220kV are illustrated in Fig. 9 and Table I outlines the differences in voltage fluctuations and changes based on the distance between the substations. The impact on voltage drop varies by location: Erdenet experienced a drop of 3.973 kV, CHPP-4 had a drop of 1.599 kV, and Ulaanbaatar saw a drop of 1.499 kV.

TABLE I. DISTANCE BETWEEN SUBSTATION

Darkhan substation	L=153км	Erdenet substation-220kV
Darkhan substation	L=200км	CHPP-4-220kV
Darkhan substation	L=229км	Ulaanbaatar substation - 220kV

Fig. 9. Voltage on the bus of Erdenet substation-220kV, CHPP-4-220kV, Ulaanbataar substation-220kV



CONCLUSION

The advantage is high precision synchronization measurements, by which information about the operational mode of the power system is collected from diverse geographical locations at the same time. WAMS implementation enables a new automation system to stabilize Mongolia's energy grid and receive up to 345 MW of the load from Russia.

This improvement has allowed for significantly increased integrated system modelling in the PowerFactory program for regime calculations. Mainly, the islanding automation protects the main overhead lines 257 and 258 of Mongolia's electricity system.

Automatic islanding for controlling the power of lines 257 and 258 has been successfully implemented as the means to keep the total energy system stable, and a centralized automation system has been developed. In 2023, there were seven successful islanding and AROG (automatic load shedding when a generator disconnects) system operations in the WAMS framework to stabilize integrated system.

To further enhance the reliability and stability of the system, the installation of additional PMUs and continued development of islanding automation are essential.

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