Monitoring Fault Diagnosis Based on Phasor Measurement Unit at Wide Area Systems

Azriyenni Azhari Zakri
Dept. of Electrical Engineering, Faculty of Engineering
Universitas Riau
Pekanbaru, Indonesia
azriyenni@eng.unri.ac.id
(IEEE Member: 92012627)

Mohd Wazir Mustafa
School of Electrical Engineering, Faculty of Engineering
Universiti Teknologi Malaysia
Johor Bahru, Malaysia
wazir@utm.my

Herman Syaibi
Dept. of Electrical Engineering, Faculty of Engineering
Universitas Riau
Pekanbaru, Indonesia
herman.syaibi22@gmail.com

Ibim Sofimieari
Dept. of Electrical Engineering
University of Port Harcourt
Choba, Nigeria
iesofimieari2@gmail.com

Abstract— **Increasing fault diagnosis of the electric power transmission system is vital to reducing power outages to consumers. Several methods are employed to determine fault diagnosis in electric power transmission lines. The purpose of the work is to monitor fault diagnosis using Phasor Measurement Unit (PMU) at Wide Area Systems. Measurement is performed by monitoring, controlling, and protecting by combining the functions of the phasor measurement device. PMU is a part of measuring the phasor of current and voltage values at the control center. So, this study was intended to design 9-bus systems IEEE based PMU using the software. The simulation is performed in a state of three-phase short circuit faults. It is then tested on all lines on the 9-bus systems IEEE with variations distances of 10%, 30%, 50%, 70%, and 90%. The simulation results are used as input for the fault diagnosis to determine the point of fault location on the 9-bus systems IEEE. Furthermore, it can calculate the error value, Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) of the three-phase short circuit fault diagnosis on each line of the 9-bus systems IEEE. The highest error value obtained on Bus-7 to Bus-5 of fault location distance of 90% is 0.48 %. RMSE is $3.02*10^{-3}$, and MAE is $2.46*10^{-3}$. Meanwhile, the smallest error value on Bus-6 to Bus-4 of a fault location distance of 10% is $6.3*10^{-4}$ %, RMSE is $3*10^{-3}$, and MAE is $2.6*10^{-3}$.**

Keywords— fault diagnosis, short circuit, PMU, wide area

I. INTRODUCTION

The transmission system is a major part of the distribution of electrical energy, without a transmission line, there won't be distribution of electrical energy. A fault in the transmission line can cause a break in the supply of electrical energy to the load, resulting in losses to consumers. For this reason, an increase in the fault diagnosis in the transmission line is needed for the distribution of electricity to consumers. Therefore, a measurement method for a large area related to monitoring the system in a large geographical area is necessary.

A wide-area measurement system is needed which includes monitoring, controlling, and protection by combining the functions of the phasor measurement device. The Measurement Phasor Unit (PMU) is a technology in electric power systems that has synchronous measurement devices that are synchronously updated and are real-time. PMU is also part of measuring the phasor value, which gives phasor values of current and voltage to the control center [1]. R. A. Reyes and J. L. Guardado have conducted their research the PMU modeling using software for monitoring the system under normal and fault condition circumstances. Observation is carried out on the state of the power system accurately. The output of PMU is in the form phasors of current and voltage. This simulation of PMU modeling provides the system as continuous [1]. B. Malikarjuna et al. have optimized the placement of PMU on electric power systems in India. The phasor value measurement system uses PMU to improve efficiency, reliability, and monitoring. They used Simulated Annealing (SA) to optimize the placement of PMU which requires 25% of the total number of buses in the electricity system [2]. Furthermore, Mohammed Mahdi, V. M has proposed the prediction of the stability of the power system using data of PMU output. System observation is carried out before the fault occurs, and the situation after a fault occurs and collects voltage data as input for predicting system stability. The stability of the electric power system is stated to be safe or unsafe. The condition before the fault and after a fault occurs is predicted using Artificial Neural Networks (ANN) to as certain stability of the system [3]. Based on the literature review conducted by other researchers related to PMU, the researchers will propose optimizing the application of PMU on the system 9 bus IEEE to predict the stability of the electric power system. Modeling of this electrical power system is run using Matlab/Simulink. Then, every placement of PMU on the channel will be analyzed in determining the location of the short circuit fault. There are three main functions in measuring a wide area. This is data acquisition, data transmission, and data processing. This operation is managed by the measurement system, communication system, and energy management of each system [4].

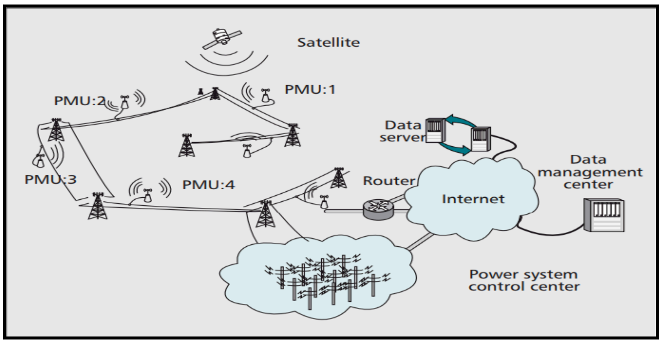

Fig. 1. The architecture of wide-area measurement based on PMU [4]

Wide area measurement based on PMU is defined as a system that performs computations on the electricity network with a high degree of accuracy, for a larger range of areas, and better than a conventional monitoring measurement system. The measurement results are used to increase the stability of the system under conditions of normal and disturbance. The important thing about measuring for a wide area is using synchronized measurements, high sampling rates [5]. Monitoring system did real-time, fastly, and accurately throughout the system are essential in the development of the current power system. PMU can be used in the electricity network to meet these challenges [6].

II. THE MEASUREMENT BASED ON PMU

A. PMU

PMU is a technology that makes electric power systems have phasor measurement equipment that can be updated continually [7]. PMU can measure phasor of current and voltage on the bus installed by the PMU. The result of a measurement is given continuously to PMU as the equipment needed in the electrical system [1].

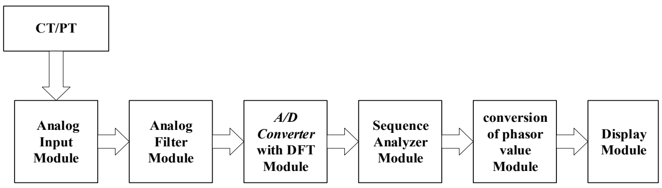

Fig. 2. Diagram of PMU

Figure 2 is a PMU consisting of microprocessor-based devices that use the ability of a digital signal processor to measure 50/60Hz AC voltage and current waves at a rate of 48 samples per-cycle (2400/2880 samples per second). Analogue AC waves are sampled randomly by A/D converter for each phase. To provide synchronous time to all systems, the satellites from GPS are used as inputs to lock on the oscillator, and waves from all systems are sampled with one-microsecond accuracy. PMU uses a digital signal processing technique to calculate phasors of voltage and current each bus [8].

B. Fault Location Based on PMU

The fault diagnosis uses PMU output by calculating simple reactance, the impedance is taken by reference to one terminal to comparing the measured line impedance (Z_{1L}), and the impedance calculated when a fault occurs (V_s / I_s), to determine the fault location. An assumption that the fault resistance value is zero. The calculation got accurately and, this reactance depends on the angle Is equal to If. Generated location of the fault [9]. For each type of fault, the problem can be solved by equation (1) [10].

$$\mathrm{Vs} = \mathrm{m} \,.\, \mathrm{Z}_{1\mathrm{L}} \,.\, \mathrm{I}_{\mathrm{s}} + \mathrm{R}_{\mathrm{f}} . \mathrm{I}_{\mathrm{F}} \quad (1)$$

$$\mathrm{k} \left| \frac{\mathrm{Z}_0\text{-}\mathrm{Z}_1}{3 \,.\, \mathrm{Z}_1} \right| \quad (2)$$

To minimize the effect of the equation with Is (I measured on the location of the fault) and reduce the equation (R_f * I_f /I_s). To do this, use imaginary parts and solve them with these equations [9].

TABLE I. THE IMPEDANCE VALUE OF EACH TYPE OF SHORT CIRCUIT FAULT

Type of Fault	The impedance of Positive Sequence ($\boldsymbol{mZ_{1L}}$)
A-G	$\mathrm{Va}/(\mathrm{Ia} + 3\mathrm{kI}_0)$
B-G	$\mathrm{Vb}/(\mathrm{Ib} + 3\mathrm{kI}_0)$
C-G	$\mathrm{Vc}/(\mathrm{Ic} + 3\mathrm{kI}_0)$
A-B & A-B-G	Vab/Iab
B-C & B-C-G	Vbc/Ibc
C-A & C-A-G	Vca/Ica
A-B-C	Vab/Iab or Vbc/Ibc or Vca/Ica

$$\mathrm{Im}\left(\frac{\mathrm{Vs}}{\mathrm{Is}}\right) = \mathrm{Im}\,(\mathrm{m} \,.\, \mathrm{Z}_{1\mathrm{L}}) = \mathrm{m} \,.\, \mathrm{X}_{1\mathrm{L}} \quad (3)$$

$$\mathrm{m} = \frac{\mathrm{Im}\left(\frac{\mathrm{Vs}}{\mathrm{Is}}\right)}{\mathrm{X}_{1\mathrm{L}}} \quad (4)$$

This study has built IEEE 9-bus system modeling using PMU. In this model, a wide area measurement method is applied PMU by running a three-phase short circuit simulation at the fault distance point of 10%, 30%, 50%, 70%, and 90%.

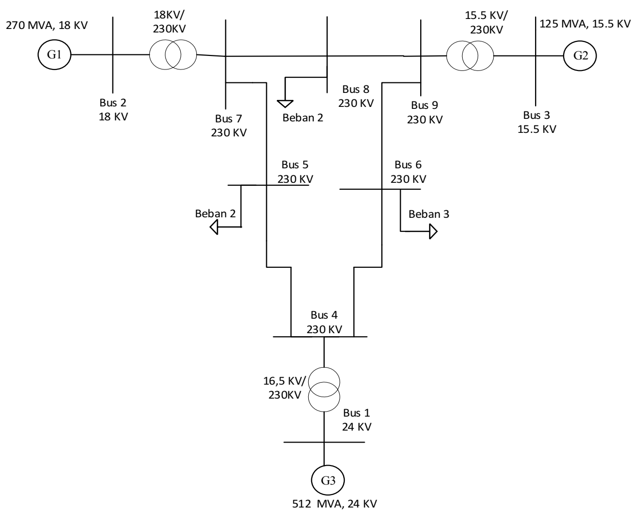

Fig. 3. Single line diagram of the IEEE 9-bus system

Figure 3 is a single line IEEE 9-bus system that is modeled using Matlab/Simulink. Data obtained of three-phase short circuit simulations will be used as input for fault diagnosis to determine the fault location in the transmission system. The electrical power system used in this study is a line diagram of the IEEE 230 kV 9-bus system, where the system consists of three generators, three transformers, six transmission lines, and three loads.

Figure 4 shows the model of PMU is an integrated part of monitoring, protection, and control systems, and it can be applied to a wide area system. PMU synchronizes the voltage, and current measurement also can be easily controlled of the types of fault in the electric power system while being monitored to protect the power system from power outages [11].

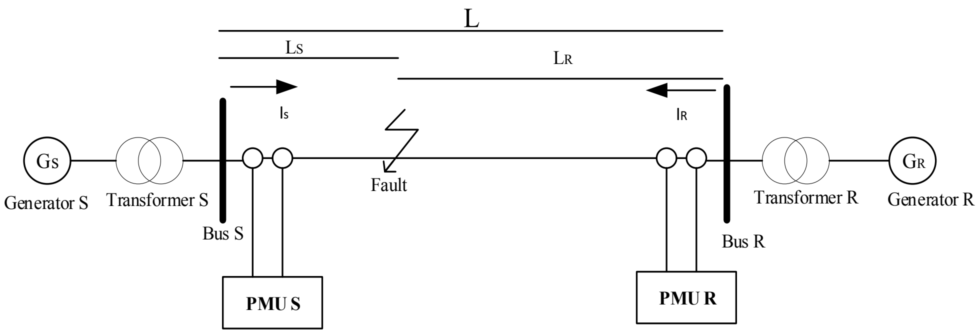

Fig. 4. Modeling of PMU for fault diagnosis

C. RMSE & MAE

RMSE) and MAE are used for evaluation studies of a model built. RMSE is the rule of a quadratic scaling to measure the magnitude of the average error, where the difference in the average square root of the actual value to the predicted value. While MAE measured the magnitude of the error for model predictions. The sample test is the average of the absolute difference in the actual value and predictive value, where the difference in each data has the same weight. The RMSE and MAE equations of the amount of data can be seen in equation (5) and (6) [12].

$$SE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i\text{-}y_i^{'})^2} \quad (6)$$

$$E = \frac{1}{n}\sum_{i=1}^{n}|y_i\text{-}y_i^{'}| \quad (7)$$

Where:

y_i = value of actual target

$y_i^{'}$ = value of predictive output

n = amount of data

III. Result & Discussion

The results of three-phase of short circuit fault simulation obtained in the line for the IEEE 9-bus system, with a distance at the point of the fault of 10%, 30%, 50%, 70%, and 90%. Figure 5 is the result of this simulation, will be used as input in the fault diagnosis to determine the location of the three-phase short circuit fault for each transmission line. After a fault diagnosis is carried out, and then calculate the percent error, that is; RMSE and MAE of the three-phase short circuit fault diagnosis on each line on the IEEE 9-bus system at a distance variation determined. When a three-phase short circuit occurs, the PMU is installed on each bus to provide monitoring results of the current phasor and voltage phasor values.

In Figure 6, it uses PMU which is installed on each bus to monitor the current signal in a positive sequence when there is a three-phase of short circuit fault from bus-7 to bus-8 with a fault distance of 10% (from bus-7). From the positive sequence, the current signal can be observed an increase in the value of the magnitude of the positive sequence current in the event of a three-phase short circuit fault.

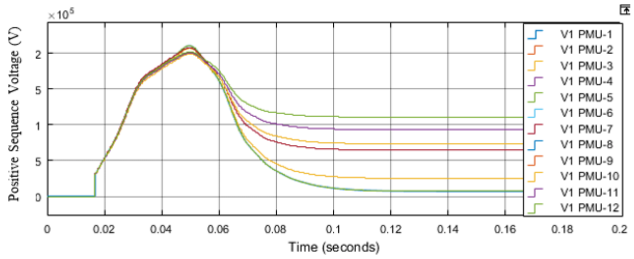

Fig. 5. The voltage of positive sequence when three-phase of a short circuit fault

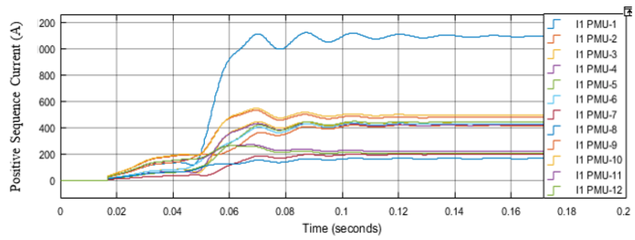

Fig. 6. Current of positive sequence signal when three-phase short circuit fault

TABLE II. Fault diagnosis at location distance of 10% from bus-7 to bus-8 based on PMU

PMU	Fault Diagnosis (Km)	Fault Diagnosis Via Software (Km)	Line Length (Km)	Line	The Error Percentage (%)
PMU-1	7.62	76.46	76.176	bus-7 to 8	0.37
PMU-2	68.83				
PMU-3	66.05	241.84	106.646	bus-8 to 9	126.77
PMU-4	175.79				
PMU-5	19.02	212.35	170.338	bus-7 to 5	24.66
PMU-6	193.33				
PMU-7	381.15	1031.39	179.86	bus-9 to 6	473.44
PMU-8	650.26				
PMU-9	159.01	414.44	89.93	bus-5 to 4	360.84
PMU-10	255.43				
PMU-11	426.49	976.14	97.336	bus-6 to 4	902.85

Table 2 is showing the measurement results of all PMUs on bus-7 channel to bus-8 used as input in performing a fault diagnosis in the electric power transmission system to determine the location of the faulty line on the IEEE 9-bus system. The diagnosis fault of three-phase short circuit on the line bus-7 to bus-8 varies in distance from 10%, 30%, 50%, 70%, and 90%.

Table 3 shows that the results of the RMSE and MAE values for each channel on the IEEE 9-bus system will result in an error not exceeding 0.1, this means that the tolerance level from the results of running this model is still in an ideal value. The values of RMSE and MAE obtained a diagnosis of three-phase short circuit disorders in determining the location of the fault with a large area measurement method.

RMSE AND MAE ON EACH LINE ON THE IEEE 9-BUS

Line	RMSE	MAE
bus-5 to bus-4	0.002350	0.001694
bus-6 to bus-4	0.002983	0.002609
bus-7 to bus-5	0.004154	0.003366
bus-9 to bus-6	0.004484	0.003516
bus-8 to bus-9	0.002584	0.001904
bus-7 to bus-8	0.001811	0.001208

In Figure 7, a graph has displayed the percent of three-phase of short circuit fault diagnosis errors for measuring large areas using PMU to determine the location of a fault. Three phases short circuit fault is simulated on all-electric power transmission lines in the IEEE 9-bus system with variations in distances of 10%, 30%, 50%, 70%, and 90%.

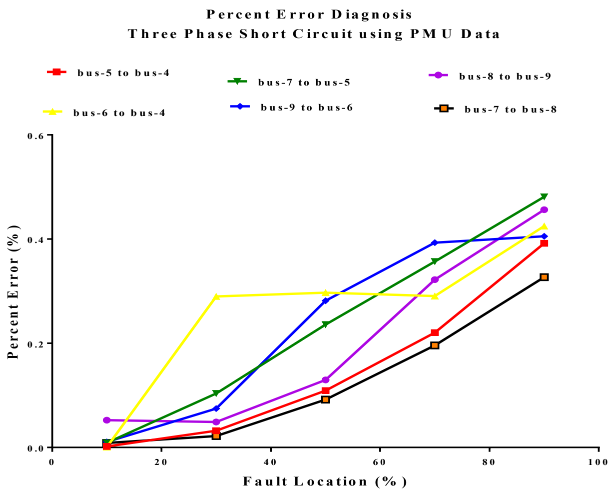

Fig. 7. The percent calculation of the fault diagnosis

Figure 8 displayed a graph of the error comparison between RMSE and MAE in each transmission line on the IEEE 9-bus system. The simulation results are run on three-phase short circuit fault using PMU. The error value obtained between RMSE and MAE is not much significant, but still within the range of tolerance errors set, and included in the category of minimal error values, meaning that the model that has been developed for this system is excellent.

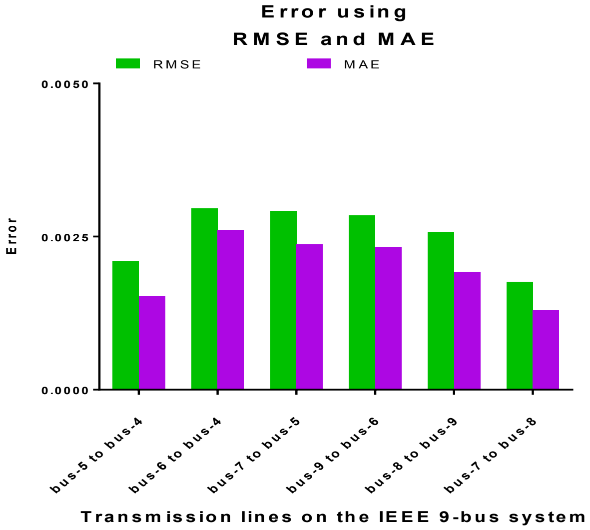

Fig. 8. Chart of RMSE dan MAE

IV. CONCLUSION

Based on the simulation results of three-phase short circuit fault with a wide area measurement method using PMU, a diagnosis of the fault was performed in determining the fault location in the transmission line on the IEEE 9-bus system. Designing a measurement method for a large area using PMU can display the current value and voltage phasor on each bus used as a system monitoring. In the event of a PMU current fault and the PMU voltage installed on each bus will read the current value and voltage factor values on each Bus. After simulation on each channel on the IEEE 9-bus system with variations in the distance of 10%, 30%, 50%, 70%, and 90%. Then the most significant error is obtained on the bus-9 to bus-6 with the fault location distance of 90% of bus-9, which is equal to 0.72%, RMSE $4.48*10^{-3}$, and MAE $3.5*10^{-3}$. The smallest error on the bus-6 to bus-4 with a 10% fault location distance from bus-8 is $4.03*10^{-4}$ %, RMSE $2.98*10^{-3}$, and MAE $2.6*10^{-3}$.

ACKNOWLEDGMENT

The author would like to thank the Ministry of Research, Technology, and Higher Education (RISTEKDIKTI), Republic of Indonesia.

REFERENCES

[1] Rihan, M., M. Ahmad, and M.S. Beg, *Vulnerability Analysis of Wide Area Measurement System in The Smart Grid*. 2013. p. 1-7.

[2] Mallikarjuna, B., M.J.B. Reddy, and D.K. Mohanta. *A Case Study on Optimal Phasor Measurement Unit Placement for Emerging Indian National Smart Grid*. 2016. IEEE.

[3] Mohammed Mahdi, V.M. *Artificial Neural Network Based Algorithm fo Early Prediction of Transient Stability Using Wide Area Measurements*. 2017. IEEE.

[4] Qiu, M., et al., *Balance of Security Strength and Energy for a PMU Monitoring System in Smart Grid*. 2012. p. 142-149.

[5] Bobba, B.R.B., et al., *Enhancing Grid Measurements*. 2011. p. 67-73.

[6] Shahraeni, M. and M.H. Javidi, *Wide Area Measurement System*. Advanced Topics in Measurements, 2012: p. 304-321.

[7] Dobackhshari, A.S. *Transmissions Grid Fault Diagnosis by Wide Area Measurement System*. 2013. IEEE.

[8] CERTS, E., *Phasor Technology and Real-Time Dynamics Monitoring System (RTDMS) Frequently Asked Question (FAQs)*. 2006: Electric Power Group and CERTS.

[9] Zimmerman, K. and D. Costello, *Impedance Based Fault Location Experience.* SEL Journal of Reliable Power, 2005. **1**(1): p. 1-27.

[10] Yin, H. *PMU Data Based Fault Location Techniques*. 2010. IEEE.

[11] Waqar, A., et al. *Modeling and Simulation of Phasor Measurement Unit (PMU) for Early Fault Detection in Interconnected Two Area Network*. in *1st International Conference on Power, Energy and Smart Grid (ICPESG)*. 2018.

[12] Chai, T. and R.R. Draxler, *Root Mean Square Error (RMSE) or Mean Absolute Error (MAE) Arguments Against Avoiding RMSE in The Literature.* Geoscientific Model Development, 2014. **7**(3): p. 1247-1250.