International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-4, November 2019

Calibration of Dynamic Line Rating Model for Phasor Measurement Unit Based Wide Area Measurement System in Smart Grid Application

Mohammad Kamrul Hasan, Musse Mohamud Ahmed, Sherfriz Sherry Musa, Denis Lee

Abstract*: The inefficiency of power transmission lines always becoming an issue in power system analysis. One of the most applicable methods Dynamic Thermal Current Rating (DTCR) to measure the thermal line ratings of existing transmission lines. This DTCR system operated through Phasor Measurement Units (PMUs) in Wide Area Measurement (WAM) system of the Sarawak Energy. To calculate the line rating based on measured or predicted weather conditions of the overhead transmission lines. However, the existing DTCR system of Sarawak Energy facing several accuracy issues. Therefore, this paper intended to perform an extended study on the sensitivity analysis of conductors in overhead transmission lines using the dynamic thermal rating model. The parameters (wind speed, the density of air, solar radiation) that influence the thermal line ratings considered in measuring, assessing the conductors' thermal effects and then these parameters were considered for the line rating models that dynamically will adjust the weather information of the conductor in overhead transmission lines on WAM systems. The performance of this study carried out using Matlab based simulation. The result shows that the proposed model that uses the dynamic factors brings the expected outcome in measuring the accurate ratings of the overhead transmission lines.

Index Terms - Smart Grid; PMU; DTCR; WAM; Heat Balance Model

I. INTRODUCTION

This PMU device in Wide-area measurement system is applied to measure, control and monitor the phasor measurement for both voltage and current at the remote end of the transmission lines. PMUs are the key to a real-time monitoring system that can guarantee a firm operation for transmission lines [1-2]. In addition, data gained from PMU can be applied for whole power system analysis. Due to the high-cost device, the placement of its device must be optimized and it cannot be placed across the network. Fig. 1 shows the overview of PMU measurement. The need for monitoring system in Dynamic Thermal Current Rating (DTCR) is vital for the data collection. The data type used for the system evaluation heavily influences the DTCR quality. Hence, different companies use different devices for DTCR [3]. Dynamic rating is an approach used to ensure the whole power system operation in a more effectual form. It also can be delineated as a required tool to increase the utilization level of smart grid solution.

In Dynamic Line rating system, magnitudes such as wind speed, wind direction, ambient temperature, and solar radiation are required for ampacity calculation. Moreover, the conductor temperature magnitude can be used to calculate the effective wind speed [4].

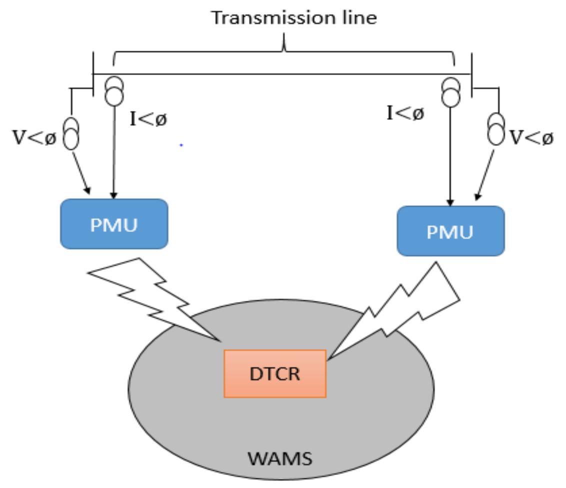

Fig.1: PMU Measurement System

There are nine main considerations used to evaluate the dynamic system monitoring in term of accuracy and complexity [5]. These categories are:

- Static rating or no rating (STR): Ratings based on national as well as the international standard for lines
- Seasonal rating (SER): Rating for seasonal conditions such as summer, winter, and autumn
- Weather Model (WM): Rating is based on the average weather for several years

Manuscript published on November 30, 2019.
* Correspondence Author

Mohammad Kamrul Hasan*, Department of Electrical and Electronic Engineering, Faculty of Engineering Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

Musse Mohamud Ahmed, Department of Electrical and Electronic Engineering, Faculty of Engineering Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

Sherfriz Sherry Musa, Department of Electrical and Electronic Engineering, Faculty of Engineering Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

Denis Lee, Sarawak Energy Berhad (SEB), 93050 Kuching, Sarawak, Malaysia

- Weather Forecast (WF): Technique used for line system monitoring where data in real-time is gained
- Conductor Temperature Evaluation (CTE): Method used to measure the temperature of the conductor. For instances, temperature sensors
- Tension Monitoring (TM): Tension tested by putting load cells in series with insulators string.
- Line Sag Measurement (CGM): The line sag can be measured in the worst-case section of the transmission line.
- Clearance-to-Ground Measurement (CTGM): Measurement was taken from the distance of conductor sag and ground
- On-line monitoring for the entire transmission line: The overhead line can monitor by some equipment.

Therefore, the key consideration of this work is to calibrate the overhead transmission lines thermal factors dynamically in thermal rating model over static approaches. To do so, the IEEE thermal model has considered adjusting the factors dynamically. Moreover, this study also assesses the conductor temperature that estimated using PMU measurements by the existing DTCR application in the WAMs. A least-squares method applied to minimize the measurement errors.

II. RELATED WORKS

Due to the thermal effect, the amount of current flowing through the conductor might reach its maximum value, which finally leads to conductor sag [6]. Sag on the overhead line is significantly based on the temperature, type, and weight of the conductor and the length of span [7]. As the age of the conductor increases, the sag on the conductor also increases. This is generally due to the external factors like weather condition (wind and ice), conductor thermal and conductor load. Sag parameter is a new factor developed by the BUTE-HVL with regard to the DLR system since it is can measure the average temperature of the conductor at a specific line-span [8]. Using the DLR model the conductor ampacity is measured. DLR model can be implied in forecasting the conductor sag and temperatures. On the other extreme, it had been applied wind speed and direction, insolation, geographical data, ambient temperature, atmospheric conditions, conductor sag, power line data, transmission tower data as a parameter. This is to measure the dynamic line rating and conductor temperature of the overhead transmission lines. Nowadays, the use of Global Positioning System (GPS) is widely accepted and impeded by the power industries for overhead line monitoring [7].

For the conductor sag, the calculation can perform from an equation of six parameters namely span value, measured sag and temperature value at the sagging process, elasticity modulus, weight per meter, and conductor creeps [9]. Eqn. (1) represent the relationship of the conductor total weight of conductor and square of span length [10].

$$S_{sag} = \frac{W\, l^2}{8\, T} \tag{1}$$

where S_{ag} is the conductor sag, W is the total weight of conductor and T is the tension value.

III. CURRENT RATING BASED ON IEEE AND CIGRE STANDARD

The maximum operating temperature of an energized conductor can be simply calculated by integrating all the related weather parameters such as ambient temperature, solar radiation, wind speed and wind integration into heat balance Eqn. (2) [11]. The authors have discussed the comparison of the ampacity calculation based on the CIGRE and IEEE standard [12]. Based on their findings on heat balance, the Equation is mainly depended on joule and magnetic heating concept. Meanwhile, there were various estimations based on types of cooling that analyzed conserving the IEEE and CIGRE standards. The analysis suggests that the results are also similar to measured data. In consequences, the accuracy of the standards with respect to the line rating calculations has agreed against the direct measurement.

Thus, IEEE and CIGRE standards are acceptable in the power industry in terms of ampacity calculation. Since IEEE standard has been accepted and implemented in Sarawak Energy (SE), the IEEE standard considered in this paper for the whole estimation, measurement, and implementations of the dynamic thermal current rating. In the IEEE standard, the heat balance model is one of the important factors. As mentioned in [13], the heat balance model of steady-state in Eqn. (2).

where, Tc is the conductor temperature and Qs, Qc, and Qr are heat gain through solar, heat loss through convective and

$$I^2R\,(T_c) + Q_s = Q_c + Q_r \tag{2}$$

heat loss through radiation respectively. Equation (2) represents the heat thermal balance model in steady-state condition where a total of heat gain and heat loss is equal. In this case, the line has reached equilibrium.

Due to the small impact of errors in the steady-state situation, the heat balance Equation applied to a real-time solution even though this case seems not suitable for predicting conductor temperature. It is important to note, however, that thermal dynamic of the line should be properly considered in the situation of the high variability of weather conditions. Threemodels of overhead line calculations that have been widely used are the IEEE, CIGRE and International Electrochemical Commission (IEC) [13]. Authors in [14] had explained the detail Equation of each heating type in the Equations (3), (4), (5).

where *D* is the conductor diameter and ϵ is the emissivity.

$$q_r = 0.0138 D\varepsilon \left[\left(\frac{T_c + 273}{100}\right) - \left(\frac{T_c + 273}{100}\right) \right] \tag{3}$$

where α refers to the solar absorptivity, QSE is the total solar and sky radiated heat intensity corrected for elevation, θ is the

$$q_s = \alpha\, Q_{SE} \sin(\theta) A \tag{4}$$

effective angle of incidence of the sun's rays, and A' is the projected area of the conductor.

where q_{c1} used for less wind speed which is less than 3mph, q_{c2} is for higher speeds, p_f and (air density), μ_f is the dynamic viscosity, K_f is the thermal conductivity, K_{angle} is the wind direction factor, Tc is the conductor temperature and T_a is the ambient temperature. Figure 2 shows heat balance in a conductor [14]. For non-steady state heat balance condition, the algorithm used is explained in Eqn. (6)[17].

$$mC_p \frac{dT_c}{dt} + q_c + q_r = I^2 R\ (T_c) + q_s \qquad (6)$$

where m is the mass per unit length of the transmission line, Cp is the specific heat of the line, T_c is the conductor temperature, qc is the heat loss through convection cooling, qr is the heat loss through radiation cooling, qs is the heat gain from solar radiation, I is the line current, and R (T_c) is the line resistance per unit length at the specified line temperature.

.

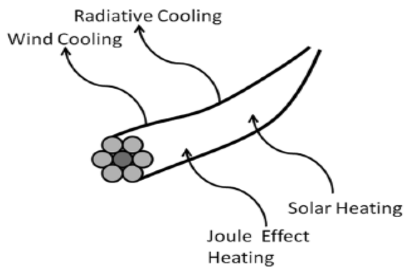

Fig.2: Heat Balance in Conductor [13]

So far, challenges have focused on accuracy and reliability of DLR deployment as a big issue in power system and it cannot be denied that the cost needed to improve the reliability of the system is high [6].

IV. CALIBRATION OF THE THERMAL MODEL

In the overhead transmission line, when the conductor temperature increases, the collisions between the molecules also increases and this leads to the occurrence of corona in the high electric field. The corona occurrence is depended on the rate of the collision of the molecules in the transmission line [15]. This means that the increment in molecules collision results in higher corona losses. Since conductor temperature is a significant issue in the transmission line, it should be estimated accurately for electricity dispatch center [15]. Hadoop Map Reduce is an efficient system used to estimate the conductor temperature [16]. It contains a file called Hadoop Distributed File System, which designed, to consistently store and stream sets of large data within a high bandwidth. Besides, Map Reduce is a basis for distributed computation. It summarized that the functionality of Hadoop Map Reduce framework is useful for the smart grid application by adding services and creating a smart system of electricity dispatch in the future. The implementation of a sensing probe on the transmission line has proposed to be one of the most economical and efficient ways of increasing the existing line capacity [17]. The sensing probe mainly used to monitor the conductor temperature and measure some important parameters in real-time. With the sufficient of recorded data, the line rating can be determined from the calculation of algorithms that fixed on the existing model. The

$$qc1 = \left[1.01\ 0.0119 \left(\frac{DV_W P_f}{\mu_f}\right)^{0.52}\right] K_f\ K_{ang;e}(T_c - T_c \qquad (5)$$

conductor temperature was based on the current flow along the line as well as the ambient circumstances such as wind condition, solar radiation, and ambient temperature [17]. In addition, non-uniformity of the transmission line is normally due to the variation of conductor temperatures in the line.

In the existing DTCR model, the transmission line is modeled as a series impedance, instead of a π-circuit impedance. The series resistance is calculated for each PMU sample with no consideration for measurement errors. Therefore, in the proposed model the π-circuit impedance is considered in calibrating the thermal factors. Hence, a methodology, PMU measurement-based data were used to classify the errors using existing DTCR application in the WAM system, and then an electrical measurement approach is taken into considerations. In the beginning, the conductor temperature was calculated using the existing model in the DTCR. The series model is assessed with the dynamic thermal factors that idealize the differences between input active power and output active power equals to a resistive loss in the line. It was estimated on a least square error basis to minimize

$$V_1.I\cos\ \delta_1 - V_2.I\cos\ \delta_2 = (I^2 R) \qquad (7)$$

the measurement errors.

In the Eqn. (7), V_1 is input voltage, V_2 is output voltage, I_1 is current input, I_2 is current the output, where, $I = I_1 = I_2$. δ_1 is the angle between in the put voltage and the input current, and δ_2 is the angle between out the ut voltage and the output current. V_1, V_2, I_1, I_2, δ_1, and δ_2 were from the PMU measurement; therefore the R can be directly calculated using Eqn. (8).

$$R(T_C) = R_{ref}[1 + \alpha\ (T_C - T_{ref})] \qquad (8)$$

where R_{ref} is the resistance at the reference temperature and α is the thermal coefficient of resistivity. By rearranging the

$$T_C = T_{ref} + [(1/\alpha)\ (R(T_C) / T_{ref} - 1)] \qquad (9)$$

Eqn. (8), T_c can be estimated as in the Eqn. (9).

Beside the PMU measurement, there were also some required constant values of DTCR configuration needed for the calculation.

V. RESULT AND DISCUSSION

The performance of the dynamic thermal model is evaluated using a Matlab simulation. The simulation parameters that considered for the dynamic thermal modeling are listed in Table 1

Table 1: Constant parameter values in existing DTCR [15-17]

Parameters	Sym-bol	Unit	Parameter value
Solar absorption coefficient	α	-	0.9
Solar radiation intensity	S	Wm^{-2}	1200
Nusselt number	N_{nu}	-	7.69
Conductor emissivity	ε	-	0.7
Stefan's constant	σ_B	Wm^{-2}	5.6704 x 10^{-8}
Overall conductor diameter (DRAKE)	D	cm	2.862
Conductor surface temperature	T_c	^oC	-
Ambient temperature	T_a	^oC	36
Wind velocity	V_w	ms^{-1}	0.5
Specific mass of air	γ	kgm^{-3}	1.029
Dynamic viscosity of air	η	Nsm^{-2}	2.043 x 10^{-5}
The thermal conductivity of air	λ	$wm^{-1o}C$	-
Reference temperature	T_c	^oC	36
Resistance at a reference temperature	$R(T_c)$	Ω/km	0.0674

Figure 3 shows the graph of calculated conductor temperature against time (minutes). The calculations were based on the PMU measurement on a day, which is 21st February 2018. The data was selected because it was considered good data with no errors regarding the system. The data of PMU measurements were also taken from only one line of the transmission line. The calculated conductor temperatures were figured in graphs form so that the data could be analyzed easily. Figure 3 demonstrates the relationship between conductor temperatures and times in minutes for the duration of one day. It is observed that there is no specific linear relationship between these two data. Hence, it can be mentioned that the conductor temperature was not affected by time but severely affected by the variation of environmental factors. According to conducted studies, wind speed, solar irradiation, and ambient temperature are the most environmental parameters that need to be taken into consideration for this issue. In fact, in the existing DTCR, such parameters were assumed constant values instead of being dynamic variables. This does not comply with one of the three standards thermal cur-rent rating model in the IEEE Std.738-2012. According to standard, the weather condition, line current, and conductor temperature are always varying in the thermal model of the dynamic type. Similarly, the relation between conductor temperature and times (minutes) for one week is shown in Fig. 4, where it is clearly demonstrated that there is a variation of conductor temperature for a duration of time.

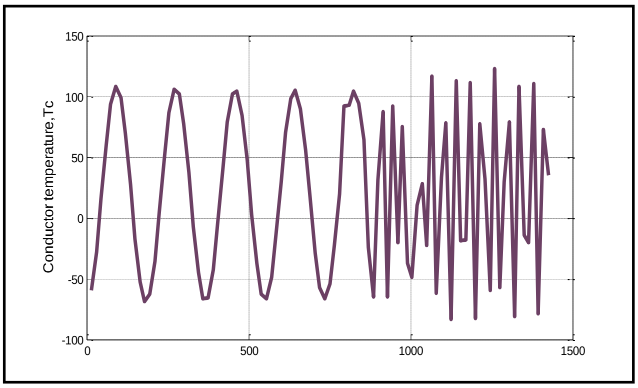

Fig. 3: Conductor Temperature vs Time (minutes) for one day

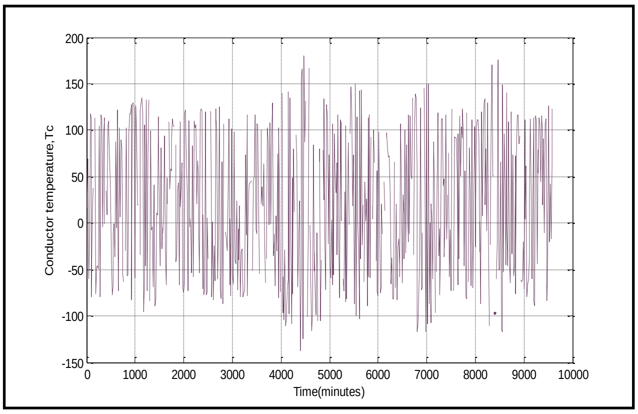

Fig. 4: Conductor Temperature vs Time (minutes) for one week

From the results, it can be summarized that the existing model still suffers the challenge in fulfilling the Dynamic model type stated in IEEE Std.738-2012. Therefore, it can be said that this might be one of the reasons why many system operators are not making much use of the DTCR software to guide their transmission line operation perhaps due to some uncertainty and reservation in the calibration and accuracy of the thermal model.

VI. CONCLUSION

This paper has analysed and evaluates the conductor temperature and its ampacity models. It also discusses and proposes the dynamic thermal influences over the static models for the overhead transmission lines that summarize and overcomes the calibration issues in DTCR application of WAM systems. In-depth, it uses the IEEE Standard 738-2012 dynamic thermal modeling as the core methodology in the calibration of the existing DTCR software. It is overserved that the weather factors significantly influence the operation of DTCR that severely the effects estimation process of the DTCR software in WAM System.

ACKNOWLEDGMENT

The research work was supported and sponsored by Research and Innovation Management Centre, Universiti Malaysia Sarawak under the Grant F02/DPD/1639/2018. A special thanks to Sarawak Energy for smart grid access, data, and support.

REFERENCES

1. Rana AS, Thomas MS & Senroy N (2015, December), Wide Area Measurement system performance based on latency and link utilization. In 2015 *Annual IEEE India Conference (INDICON)*, pp. 1-5. IEEE.
2. Nanda P, Panigrahi CK & Dasgupta A (2017, March), PMU implementation for a Wide Area Measurement of a power system. In *Devices for Integrated Circuit (DevIC)*, pp. 690-694. IEEE.
3. Morozovska K & Hilber P (2017), Study of the monitoring systems for Dynamic Line Rating. In *8th International Conference on Applied Energy, ICAE 2016, Beijing, China, 8 October 2016 through 11 October 2016* (Vol. 105, pp. 2557-2562). Elsevier.
4. Fernandez E, Albizu I, Bedialauneta MT, Mazon AJ & Leite PT (2016), Review of dynamic line rating systems for wind power integration. *Renewable and Sustainable Energy Reviews 53*: 80-92.
5. Balango D, Németh B & Göcsei G (2015, June), Predicting conductor sag of power lines in a new model of dynamic line rating. In *Electrical Insulation Conference (EIC)*, pp. 41-44. IEEE.
6. Musavi M, Chamberlain D & Li Q (2011, November), Overhead conductor dynamic thermal rating measurement and prediction. In *2011 IEEE International Conference on Smart Measurements for Future Grids (SMFG)*, pp. 135-138. IEEE.
7. Kamboj S & Dahiya R (2014, April), Case study to estimate the sag in overhead conductors using GPS to observe the effect of span length. In *2014 IEEE PES T&D Conference and Exposition*, pp. 1-4. IEEE.
8. Balango D, Németh B & Göcsei G (2015, June), Predicting conductor sag of power lines in a new model of dynamic line rating. In *2015 IEEE Electrical Insulation Conference (EIC)*, pp. 41-44. IEEE.
9. Polevoy A (2014), Impact of data errors on sag calculation accuracy for overhead transmission line. *IEEE Transactions on Power Delivery 29*(5): 2040-2045.
10. Douglass D, Chisholm W, Davidson G, Grant I, Lindsey K, Lancaster M & Reding J (2016), Real-time overhead transmission-line monitoring for dynamic rating. *IEEE Transactions on Power Delivery 31*(3): 921-927.
11. Mutule A, Grebesh E, Oleinikova I & Obushevs A (2016, June), Methodology for transmission line capacity assessement based on PMU data. In *Power Systems Computation Conference (PSCC)*, pp. 1-5. IEEE.
12. Van Staden, P., & de Kock, J. A. (2012, July). The practical comparison of conductor operating temperatures against IEEE and CIGRE ampacity calculations. In *Power Engineering Society Conference and Exposition in Africa (PowerAfrica), 2012* IEEE (pp. 1-7). IEEE.
13. Greenwood DM, Gentle JP, Myers KS, Davison PJ, West IJ, Bush J W, & Troffaes MC (2014), A comparison of real-time thermal rating systems in the US and the UK. *IEEE Transactions on Power Delivery 29*(4): 1849-1858.
14. Gentle JP, Myers KS, Bush JW, Carnohan SA & West MR (2014, July), Dynamic line rating systems: Research and policy evaluation. In *2014 IEEE PES General Meeting| Conference & Exposition*, pp. 1-5. IEEE.
15. Reid GJ & Vermeulen HJ (2014, September), Effects of conductor temperature on corona inception. In *2014 49th International Universities Power Engineering Conference (UPEC)*, pp. 1-5. IEEE.
16. Pan SK, Chen CP & Jiang JA (2014, August), Conductor Temperature Estimation Using the Hadoop MapReduce Framework for Smart Grid Applications. In *2014 IEEE Intl Conf on High Performance Computing and Communications, 2014 IEEE 6th Intl Symp on Cyberspace Safety and Security, 2014 IEEE 11th Intl Conf on Embedded Software and Syst (HPCC, CSS, ICESS)*, pp. 1243-1247. IEEE.
17. Wijethunga AH, Wijayakulasooriya JV, Ekanayake JB & De Silva N (2015, December), Conductor temperature based low cost solution for dynamic line rating calculation of power distribution lines. In *2015 IEEE 10th International Conference on Industrial and Information Systems (ICIIS)*, pp. 128-133. IEEE.