REAL-TIME MONITORING OF TRANSMISSION LINE PARAMETERS

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ABSTRACT

As competitive energy markets maximize utilization of high-voltage transmission assets to lower overall electricity costs, correctly modeling and monitoring transmission lines in real-time applications becomes a center focus to grid operators. The relationship between conductor resistance and temperature is often neglected, and maximum conductor temperature is commonly assumed to determine line impedance values and static line ratings. When the thermal characteristics of a transmission line are included directly in utility applications, system state estimation calculations will better reflect reality, and the economic generation dispatch will better utilize the capabilities of existing transmission line facilities.

INTRODUCTION

In the world of competitive wholesale energy markets, generation is procured to serve system load at the lowest possible cost. As cheap generation is purchased to meet demand, power is imported across the transmission network, and the network is pushed close to its thermal limits. When a transmission line is loaded too close to its limit, grid operators must adjust the generation profile to displace generation imports across the overloaded line. To carry out this process of monitoring the transmission network for congestion while optimizing generation, utilities use equipment ratings, along with Power Flow (PF) and Optimal Power Flow (OPF) algorithms in their control rooms. PF is used to carry out important tasks like contingency analysis, transient stability studies, and planning studies [1]. Great importance is placed on correctly modeling a power system and collecting accurate measurement data, and any error in either of those inputs will create similar error in the estimated system state [2]. To improve the accuracy of these applications and utilization of the existing transmission network, great attention is paid to detecting and correcting measurement error, but many underlying assumptions made in formulating the transmission line model go unnoticed. It is the goal of this paper to discuss research aimed at the latter. This paper will be structured as follows: Section II will present transmission line thermal characteristics. Section III will review literature related to Dynamic Line Ratings. Sections IV and V will review literature aimed at incorporating thermal transmission line thermal characteristics into PF and OPF, respectively. Section VI will conclude the paper.

LITERATURE REVIEW

An Efficient Approach for Energy Consumption Optimization and Management in Residential Building Using Artificial Bee Colony and Fuzzy Logic

The energy management in residential buildings according to occupant's requirement and comfort is of vital importance. There are many proposals in the literature addressing the issue of user's comfort and energy consumption (management) with keeping different parameters in consideration. In this paper, we have utilized artificial bee colony (ABC) optimization algorithm for maximizing user comfort and minimizing energy consumption simultaneously. We propose a complete user friendly and energy efficient model with different components. The user set parameters and the environmental parameters are inputs of the ABC, and the optimized parameters are the output of the ABC. The error differences between the environmental parameters and the ABC optimized parameters are inputs of fuzzy controllers, which give the required energy as the outputs. The purpose of the optimization algorithm is to maximize the comfort index and minimize the error difference between the user set parameters and the environmental parameters, which ultimately decreases the power consumption. The experimental results show that the proposed model is efficient in achieving high comfort index along with minimized energy consumption. For every residential building, it is the most important issue to effectively manage the energy as well as achieve higher occupant's comfort. The reason behind the fact is that the energy consumption increases rapidly with the passage of time and becomes more and more expensive and the user cannot compromise on his/her comfort. Therefore, the energy consumption minimization and user comfort maximization need to be balanced to achieve both goals. Therefore, a trade-off is required between the user comfort and the energy utilization [1–3]. In any residential building, we need a control system for maintaining user comfort as well as energy consumption minimization. In order to determine the user comfort, we need three basic comfort parameters, namely, visual comfort, thermal comfort, and air quality [4]. The thermal comfort is represented by temperature inside the building. In order to preserve the temperature in the comfortable area of the building, the auxiliary cooling or heating system is required. For maintaining the visual comfort of the user in the residential building, the illumination is considered [5]. For managing the user visual comfort, the electrical lighting system is used. For the measurement of air quality in the comfort zone of the residential building, CO_2 concentration is measured. The ventilation system keeps the concentration of CO_2 as low as possible [6]. In order to maintain the comfort of residential building according to user demand, these three parameters are considered. We have also considered these three parameters to maintain the user comfort in residential building.

Many energy management systems have been proposed in the literature for energy savings and consumption. In previous works, many approaches have been introduced which are based on conventional control systems [7–9]. Some of these controllers are optimal controllers, adaptive controllers, and PID (Proportional Integral Derivatives). There are many disadvantages associated with these conventional controllers. For example, these controllers were not user friendly and it was difficult to monitor and control the parameters. In order to control the environmental parameters in the building, the application of optimized fuzzy controllers has been proposed in [10]. In order to control heating, air-conditioning, and ventilation, many other predictive control approaches apply weather prediction [11, 12]. The authors in [13] used multiagent control system in which information fusion has been used. The authors have used ordered weighted averaging aggregation for indoor energy and control management. They have maximized user comfort and minimized energy consumption. Many different types of factors including social factors, personal factors, and buildings factors have strong influence on user comfort. In order to understand the complex relationship among these different factors, a model has been proposed by the authors in [14]. The authors in [15] have presented a methodology in which they have considered both the indoor and outdoor environmental factors and user comfort and energy utilization management. Many types of different classification, prediction, and optimization algorithms have been used in the literature for different purposes related to energy control and management systems. As compared to other optimization algorithms, artificial bee colony algorithm is a new algorithm, which has been previously used in few proposed methods for energy management and control related applications. The authors in [16] applied artificial bee colony optimization algorithm for optimal management of micro grid. Keeping in consideration different parameters, the objective was to give scheduling of short-term load forecasting using minimized operation cost of micro grid. The aim of the paper was to minimize the total operating cost of the micro grid using different types of optimization algorithms and the authors concluded that artificial bee colony algorithm provided the best results. In order to bring optimization in process placement schemes of energy efficient data centers, the authors in [17] applied multiobjective artificial bee colony. The objective of the paper was to minimize energy cost for effective and efficient control and management of data centers as the cost of energy is higher in data centers as compared to office buildings. The authors in [18] applied artificial bee colony for temperature dependent optimal power flow. The objective was to minimize the fuel cost, minimize power loss, and improve voltage profile. Artificial bee colony was applied by [19] for energy management system in combination with Markov chain.

Transmission Line Conductor Temperature Impact on State Estimation Accuracy

State estimation has become a tool of vital importance in modern control centers. If the accuracy of the state estimation could be increased this will mean that a more reliable representation of the power system is obtained and the operation and control functions can make better decisions. This paper studies the influence of changes of the transmission lines resistance due to temperature on state estimation performance. The possibility to account for this effect in state estimation is shown by the use of Line Heat Balance equation and weather data. THE secure operation of power system must be ensured by the Control Center operators, and a primary need of the operators is reliable information. Establishment of Supervisory Control And Data Acquisition (SCADA) systems was an important achievement, however data obtained from SCADA may not always be correct containing e.g. measurement or circuit breaker status errors. Moreover, not all the measurements are available in the Control Center. These concerns were first recognized by Fred Schweppe, who proposed and investigated State Estimation (SE) methods [1] giving the most likely state of power system from possibly limited raw measurement data. Nowadays, state estimation is an important and a widely used control center tool. It forms the basis for a number of applications, such as:

- System observation
- Security assessment
- Optimal power flow
- Transmission system usage billing.

The performance and reliability of SE is strongly dependent on the accuracy of the defined power system model. A number of methods has been developed for model parameter verification and estimation, as summarized in [2], [3], [4]. State vector augmentation and the residual analysis methods are addressing estimation of rather limited number of selected parameters, while processing of several sequential snapshots either by the enlarged conventional SE or Kalman filter is more suitable for the multiple erroneous parameter identification. The usefulness and importance of these methods.

Analysis of the Load Flow Problem in Power System Planning Studies

Load flow is an important tool used by power engineers for planning, to determine the best operation for a power system and exchange of power between utility companies. In order to have an efficient operating power system, it is necessary to determine which method is suitable and efficient for the system's load flow analysis. A power flow analysis method may take a long time and therefore prevent achieving an accurate result to a power flow solution because of continuous changes in power demand and generations. This paper presents analysis of the load flow problem in power system planning studies. The numerical methods: Gauss-Seidel, Newton-Raphson and Fast Decoupled methods were compared for a power flow analysis solution. Simulation is carried out using Matlab for test cases of IEEE 9-Bus, IEEE 30-Bus and IEEE 57-Bus system. The simulation results were compared for number of iteration, computational time, tolerance value and convergence. The compared results show that Newton-Raphson is the most reliable method because it has the least number of iteration and converges faster.

Research on Sag Online Monitoring System for Power Transmission Wire Based on Tilt Measurement

Sag online monitoring system for power transmission wire based on tilt angle measurement was proposed, the mathematical model of catenary for power wire was established. Sag calculation models of power wire in the situation without swinging and swinging were derived. By measuring the power wire axial angle and swing angle with dual-axis tilt sensor, the sag could be accurately calculated with the wire swinging. By testing the sag detection system, the result showed that the sag detection system could meet the engineering requirements of sag measurement. With the continuous development of society, there is more and more power density, industrial electricity consumption increases gradually. In power shortage areas, if relying on local resource generation only, the situation that demand exceeds supply of electricity would appear, which restricts the social development of industry and agriculture, and retards the progress of society. However, after use of the new transmission line method, the cost and environmental issues were becoming increasingly prominent. Improving existing wire conveying capacity would be one of the directions of power grids. Improving the wire conveying capacity, can not only solve the problem of peak or fault short conveying capacity shortage, but also can reduce the new line investment, reduce the number of new lines, and ensure the development of regional economy, which have important social and economic benefits [1-3]. In process of power transmission, wire ampacity is the essence of limiting the transmission capacity of transmission line. In order to prevent overload, the design for the rating capacity of the transmission line, construction is a static, conservative values, which is often based on the most adverse weather conditions. But in fact, such bad weather conditions rarely occurred, so transmission potential of the wire cannot be used efficiently in the vast majority of cases. As there is a definite relationship between the transmission line sag and transmission power, by measuring the line sag, the transmission power limit could be determined reasonably and accurately, then a more direct judgment, whether transmission power beyond the limit of thermal stability or not, could be achieved. In addition, the sag could vary with the temperature of the line, when the distance of the line sag to the ground vertically or crossing reduced, the safe running of the grid would be affected [2][4]. Therefore, in process of power transmission, by monitoring the transmission wire sag data in real time stability and accurately, energy could be delivered more effectively and reasonably, thus ensuring the security of the power system.

Investigating the impacts of conductor temperature on power handling capabilities of transmission lines using a multi-segment line model

Overhead transmission lines experience substantial changes in weather conditions along their lengths. The change in weather conditions affects the temperature of the conductor and the line impedances. Therefore, the line impedance cannot be considered as uniformly distributed values, rather it varies along the length of the line. This paper utilizes a line model segmentation approach to encounter this non-uniformity in line electrical parameters. The approach divides the line into multiple segments as necessary. It then creates an equivalent line model with an equivalent line impedance. This line model is capable of considering any major changes in ambient conditions, and its impact on the line ampacity and power handling capability. The proposed approach is tested on a 2 bus transmission network, and then compared with the "static" approach, in which changes in weather conditions are neglected. However, as long transmission lines pass through various geographic locations and different weather conditions, this assumption of constant temperature and uniformly distributed impedance throughout the line cannot be precise. Ambient conditions vary along the length of the line, impacting the temperature of the conductor in a non-uniform way at different locations. Different conductor temperatures at different locations introduce the non-uniform distribution of the transmission line impedances along the transmission lines. Previous studies in the field of dynamic line rating and temperature dependency of the transmission lines show the change in line thermal rating when the weather conditions are taken into account [9 - 13]. Most of the studies consider the line impedance to be uniformly distributed throughout the line, though some studies have been done for the nonuniformity of the line impedances with longitudinal variation of line geometry for electromagnetic transients [14, 15, 16], as well as for steady-state system analysis [17, 18]. The steadystate analysis of the non-uniformly distributed line impedance will be used in this paper to develop a line modeling approach. This paper utilizes a line model segmentation approach to deal with the longitudinal non-uniformity of the line impedances caused by the changes in ambient conditions along the length of the line. This segmentation of the transmission line is based on the change in longitudinal conductor temperature of the transmission line. An equivalent circuit model of the transmission line has been developed using the multiple segments of the line. This equivalent circuit of transmission line is capable of taking the non-uniformly distributed line electrical parameters into account [19]. The impact of different wind speeds at different locations of the transmission line was dealt with dividing the line into multiple equal-length segments based on the total length of the line in [20]. This paper proposes the line segmentation based on the change in weather conditions at any point along the line.

IEEE Standard for Calculating the Current-Temperature of Bare Overhead Conductors, IEEE Std. 738, 2012

A method of calculating the current-temperature relationship of bare overhead lines, given the weather conditions, is presented. Along with a mathematical method, sources of the values to be used in the calculation are indicated. This standard does not undertake to list actual temperature-ampacity relationships for a large number of conductors nor does it recommend appropriately conservative weather conditions for the rating of overhead power lines. It does, however, provide a standard method for doing such calculations for both constant and variable conductor current and weather conditions. The standard describes a numerical method by which the core and surface temperatures of a bare stranded overhead conductor are related to the steady or time-varying electrical current and weather conditions. The method may also be used to determine the conductor current that corresponds to conductor temperature limits. The standard does not recommend suitable weather conditions or conductor parameters for use in line rating calculations. The purpose of the standard is to provide a well-documented method by which the temperatures, steady-state, transient, and real-time thermal ratings of overhead power line conductors can be calculated given suitable weather, conductor parameters, and (for ratings) maximum conductor temperatures.

D. Douglass, W. Chisholm, G. Davidson, I. Grant, K. Lindsey, M. Lancaster, D. Lawry, T. McCarthy, C. Nascimento, M. Pasha, J. Reding, T. Seppa, J. Toth and P. Waltz, "Real-Time Overhead Transmission-Line Monitoring for Dynamic Rating," IEEE Transactions on Power Delivery, vol. 31, no. 3, pp. 921-927, 2016.

Dynamic thermal rating (DTR) is more accurate and can better utilize the transmission/distribution capacity of an electric power system compared to static thermal rating. It is beneficial to integrate DTR into power system planning problems where modelling the DTR is vital. This paper presents a new modelling method for DTR that consists of three sequential steps: a multivariate polynomial regression between the DTR and its four affecting factors, an hourly normalization, and an autoregressive integrated moving average (ARIMA). Three types of polynomial regressions were developed based on the analysis of the heat balance model for calculation of the DTR. For the purpose of comparison, several other modelling methods for the DTR were designed based on a widely used

wind speed modelling method. The performance of the different modelling methods was verified using case studies from Austin, USA and Wawa, Canada. The results show that the model of the DTR obtained using the proposed method is superior in terms of both probability distribution and fitting accuracy. YNAMIC thermal rating (DTR) calculates the maximum conductor capacity based on real-time ambient and conductor conditions. Thus, the DTR is a more accurate estimation of the capacity compared to the static thermal rating that is usually estimated under conservative conditions. The DTR is often higher but can also sometimes be lower than the static thermal rating [1,2,3,4,5]. This means that the DTR can better utilize the capacity of existing electric power systems without any overestimation of the capacity under extremely adverse conditions. Due to the extra capacity provided by the DTR, investment in new transmission/distribution capacity can be deferred or avoided and network congestion can also be mitigated [1], implying a substantial financial benefit. Consequently, the DTR has received considerable attention and has become an important smart grid technology. A DTR system consists of sensing and communication devices and the software to determine the DTR for the conductors [1]. Due to the development of advanced sensing and communication technologies and decreasing costs thereof, DTR systems are now suitable for commercial installation [6,7]. A number of demonstration programs have been set up to investigate the impacts of the DTR on power systems, including projects conducted by the U.S. Department of Energy [1] as well as in the U.K. [8,9,10]. To fully recognize the benefits of DTR to power systems and to accelerate its application, much recent research has been conducted to determine the optimal number and location for DTR installations [11], low carbon operation [12], congestion management [13], reliability analysis [14,15], benefits to distribution network [16,17], fuzzy method for calculating DTR Time Series Modelling for Dynamic Thermal Rating of Overhead Lines Junpeng Zhan, Member, IEEE, C. Y. Chung, Fellow, IEEE, and Elemer Demeter, Member, IEEE D
and network planning [19]. Integrating DTR in power system planning problems is of great benefit [3,19]. However, an appropriate model for DTR is vital for obtaining an accurate solution to a planning problem. The DTR can be modelled using a Monte Carlo sampling method based on its probability density function (PDF) [19] or based on the PDF of its four affecting factors and its heat balance model [9]. Another modelling method is time series modelling, with the autoregressive integrated moving average (ARIMA) model being a widely used option [20]. In [15], a low-order ARIMA model was used to represent a DTR time series for reliability analysis. However, the ARIMA model in [15] is not suitable for modelling the DTR for prolonged periods of time, e.g., one or several years, which is necessary in a planning problem; this is because the DTR varies within a large range that is difficult to directly model using a low-order ARIMA model. To solve this problem, a new modelling method for the DTR using an ARIMA model is proposed in this paper. The DTR is affected by four factors: wind speed and direction, ambient temperature, and solar radiation [21]. Seasonal and diurnal cycles affect the last two factors, but wind speed is volatile and significantly affects the DTR. Consequently, the DTR has both seasonal and diurnal cycles but the diurnal cycle may disappear in times of volatile wind speed. To cope with the volatility of the DTR, a multivariate regression between the DTR and its four affecting factors is proposed to reduce the large-range variation of the DTR before ARIMA modelling. To retain the seasonal and diurnal distribution of the DTR, an hourly normalization method [22,23] is incorporated in the proposed modelling method.

CONCLUSION

In this paper, we reviewed three major applications developed for the purpose on monitoring real-time transmission line thermal parameters: Dynamic Line Ratings, Temperature Dependent Power Flow, and Temperature Dependent Optimal Power Flow. The purpose of Dynamic Line Ratings is to estimate the current conductor temperature to determine a real-time thermal limit. This typically identifies additional capacity on a particular line, as the environmental conditions experienced in practice are often more favorable than the conditions assumed when formulating the static line rating. DLR applications only focus on one transmission line parameter, and do not estimate real-time line impedances. TDPF and TDOPF employ a more holistic approach to thermal monitoring, by incorporating the transmission line thermal behavior as an additional input while estimating the power system state. This process estimates the thermal state as well as the full electrical state, including line impedances, end-point voltages, and line loading. Outside of the benefits to system reliability and economics, monitoring the physical state of a transmission line conductor may have additional advantages. For example, tension monitors installed along a transmission line may be able to detecta physical attack or natural disaster [27]. When the tension in a line conductor far exceeds the expected tension based on weather and loading levels, it could be that a transmission line tower has failed [27]. Transmission line physical security is also mentioned in [4], where a sudden (and abnormally large) measurement in tower tilt may indicate a natural disaster or manmade attack has damaged the tower. Such information is critical to utilities, and may provide a utility additional time to manage the impending loss of a transmission line.

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