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Study of the Monitoring Systems for Dynamic Line Rating

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Abstract

Power system components usually have standard static ratings that determine the load constraints. Load constraints are designed for extreme conditions and are one of the reasons, why power systems do not use all of their potential transmission capacity. In the 21st century, efficiency and the cost of energy production and distribution have become a very popular topic, because the energy production and its transmission cost has a direct influence on sustainability. Dynamic Rating is a smart grid application, which allows using more of the system capacity by monitoring system conditions. This paper presents a literature review on the topic of Dynamic Rating. We focus on Dynamic Rating of overhead lines. Overhead lines are of great interest for Dynamic Rating applications, because of their high cost and high potential for further improvement. Different tools for analysis of real time data and ways of application of Dynamic Rating to the power system are taken into consideration.

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1. Introduction

The term Dynamic Rating needs more detailed explanation. In this paper we define Dynamic Rating as the technique that allows increasing (decreasing) the capacity of the power system component, without violation of the safety margins. Dynamic Rating uses data about physical and electrical properties of power system components to improve power system transmission capability [1] [2]. Dynamic Rating can be used when connecting power plants with variable production capacity to the grid, such as solar power stations, wind farms, tidal or wave power plants [1] [2] [3].

A brief illustration of Dynamic Rating applications profitability could be done considering the example of a wind farm production. Usually, power lines connected to wind power plants are operated under static

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ratings. Static ratings are chosen for the power capacities close to the worst case scenarios. However, wind speeds are usually not constant and power production rarely reaches the maximum rate that it is designed for. In this case Dynamic Rating can be implemented to facilitate line transmission capability in order to be able to transfer more energy. This effect can be obtained, because there is direct dependence between wind speed and cooling of the overhead line [2].

Together with the influence from power fluctuations in the system, it is also interesting to investigate the correlation between wind speed, wind direction, wind power production and cooling of power transmission components such as overhead lines and power transformers. Moreover, the effectiveness of the Dynamic Rating application depends on the tools used to monitor the system conditions, and the accuracy of real time measurements [2]. Electric power customers demand constant, sustainable power supply. The popularity of intermittent energy sources and the increasing power consumption require researchers to come up with new solutions to increase transmission capacity and improve power quality. Power systems are usually designed for extreme conditions and have standardized steady-state ratings. This factor allows to increase transmission capacity by the monitoring of environmental and operating conditions, which can increase transmission capabilities, fulfilling safety requirements [3] [4].

2. Dynamic Rating of the Overhead Lines

The dynamic rating of overhead lines is usually referred to as the Dynamic Line Rating. The correct application of the Dynamic Line Rating requires the calculation of the heat balance of the conductor. There are different ways to calculate the heat balance, presented in the literature [5] [6] [7]. According to the IEEE Standard for calculating the current-temperature relationship of bare overhead conductors the heat balance can be expressed as in (1) [8].

$$P_j + P_s = P_c + P_r \quad (1)$$

where P_j is the Joule heating; P_s is the solar heating; P_c is the convective cooling and P_r is the radiative cooling.

According to the CIGRE standard, heat balance equation for the overhead conductor is extended with the magnetic heating P_M the corona heating P_i and the evaporative cooling P_w [5] [9]. The heat balance equation according to CIGRE is shown in (2).

$$P_j + P_M + P_s + P_i = P_c + P_r + P_w \quad (2)$$

The comparison of these two methods for the heat balance calculation is presented in [5]. The maximum allowed conductor current can be calculated using (3), which is proposed in [1] [10] [11] [12].

$$I^2 R_{T_c} + q_s = q_r + q_c \quad (3)$$

where I is the current in the conductor; R_{T_c} is the conductor resistance at the temperature T_c ; q_s is the solar heating; q_r is the radiative cooling; q_c is the heat loss due to forced convection.

In other sources equation for the current allowed in the conductor is expressed with heat losses from radiation and wind flow [11].

$$I = \sqrt{\frac{h_w + (h_r - (\omega_s / \pi \theta) \eta) \pi D \theta}{R_{ac}}} \quad (4)$$

where h_w is the heat dissipated due to wind velocity; h_r is the heat dissipated due to radiation.

In equation (3) an element of a great interest is the heat loss due to forced convection q_c . The forced convection is highly dependent on the wind speed and wind direction. At low wind speeds (5) should be used, however, equation (5) is not applicable for high wind speeds. Equation (6) should be used, for calculation of heat balance at high wind speeds [2] [8] [13]. However, there is no clear definition between

low and high wind speeds, therefore, according to the IEEE standard it is recommended to use both (5) and (6), and choose larger of the two obtained values as the correct one [8] [13].

$$q_{c_low} = K_{angle} \cdot [1.01 + 1.35N_{Re}^{0.52}] \cdot k_f(T_s - T_a) \quad (5)$$

$$q_{c_high} = K_{angle} \cdot 0.754N_{Re}^{0.6} \cdot k_f(T_s - T_a) \quad (6)$$

where K_{angle} is the wind direction coefficient; N_{Re} is the Reynolds number; T_a is an ambient temperature; T_s temperature at the conductor surface and k_f is the thermal conductivity of air at the average temperature of the boundary layer. The wind direction coefficient K_{angle} is calculated using (7).

$$K_{angle} = 1.194 - \cos \varphi + 0.194 \cos 2\varphi + 0.368 \sin 2\varphi \quad (7)$$

where φ is the angle between wind direction and the conductor axis.

3. Monitoring systems

The Dynamic Line Rating requires use of a monitoring system that will collect all the necessary data. The type of data that is used for system evaluation influences the quality of the Dynamic Rating. Therefore, ratings can vary from very detailed ones, which change several times per hour, to seasonal ratings, when the system experiences changes in ratings several times per year. The evaluation of system ratings is based on stored data for several years, or the information from online monitoring systems [4].

Different companies produce different equipment for Dynamic Rating data collection. Monitoring equipment can be installed on the overhead line at some point close to the control room, and will send the on-line data to the control system with a small delay. Monitoring systems can have different functions. Some of them are used for monitoring of the weather conditions or measure conductor temperature or monitoring the tension in the conductor [14] [15]. We have also made an evaluation of the existing systems. It has to be mentioned, that the existing sources and methods have been graded in terms of complexity and accuracy of the chosen system. To evaluate system monitoring, all of the methods were divided into the following categories:

- A - Static rating or No-rating (STR): a standard rating of the lines and transformers, which is specified by international or national standards.
- B - Seasonal rating (SER): also known as summer-winter rating or in several cases summer-autumn-winter rating.
- C - Weather model (WM): rating based on the collected average weather data for several years. It has better accuracy than the seasonal rating.
- D - Weather forecast (WF): online monitoring method, when real time weather data is collected near the conductor or transformer and ratings are set according to the forecast.
- E - Conductor temperature evaluation (CTE): an on-line monitoring method, when the conductor temperature is measured with the help of temperature sensor.
- F - Tension monitoring (TM): the process of tension monitoring is done by placing load cells in series with insulator strings. The loads cells must be electrically insulated from the conductor. Tension monitoring is useful, because there is direct relation between the sag and tension of the conductor. Most of the tension monitoring systems requires installation of weather monitoring equipment for further evaluation of system parameters and calculation of the ampacity of the line [14].

- G - Line sag measurement (CSM): it is more advanced system that can actually measure the sag of the line by placing such equipment in the worst case parts of the power system can be operated within safety margins.
- H - Clearance-to-ground measurement (CTGM): new generation of on-line monitoring systems for the overhead lines are measuring not sag, but a clearance-to-ground. This is more relevant of measurements, because it directly gives information about the conductors distance to the ground.
- I - On-line monitoring of every overhead line segment, or full scale monitoring (FSM): This method can be combination of several cases proposed above. The main feature of the following category is the placement of small sensors along the line. However, placing numerous devices along the power line is expensive today.

Depending on the technique used to obtain information for the Dynamic Rating monitoring, tools were analyzed in Table 1. The information from Table 1 can be used to distribute monitoring systems into A-I classes above. It has to be mentioned that some of the line monitoring devices can be assigned to several categories at the same time, because they provide different data sets for the correct system evaluation. Therefore, for the correct estimation of advantages of each of the monitoring devices the information on accuracy of each of the modules has to be combined and analyzed. Monitoring and analysis of the environmental and power conditions are very important for application of Dynamic Rating. Therefore, it is important to select suitable tool for Dynamic Rating application.

Table 1. Overview of different existing real-time monitoring systems for evaluation of the overhead line conditions

N	Monitoring System Name and/or Patent Number	Categories					
		D	E	F	G	H	I
1	EMO (Easy Monitoring Overhead Transmission) by Microtronics [14] [16]		x				
2	Stick-on current and temperature wireless sensor [14] [17]	x	x				
3	DTS (Distributed Temperature Sensing) [14] [18]		x				
4	Net Radiation Sensor [14]				x		
5	ThermalRate™ System [19]	x	x				
6	TLM™ Conductor Monitor [20]		x			x	
7	Ampacimon [21]				x		
8	Power Donut [22] [23]		x		x		
9	SMT(System for Monitoring the Temperature) [22]		x				
10	CAT-1 [22] [24]	x	x	x			
11	TAM (Tension and Ampacity Monitoring System) [22] [25]	x		x			
12	Sagometer by EPRI [22] [26]	x			x		
13	The Promethean Devices Real-Time Transmission Line Monitor (RT-TLM) [22] [27]		x		x		
14	SAW Technology [22] [28] [29] [30]		x				
15	LINEAMPS by ELECTROTECH [31]	x					
16	Power Line Sensornet (PLS) [32] [33]						x
17	DYNAMP by EPRI [34]	x					
18	SAGSEC. Patent Number: US 6,229451 B1 [35]				x		

4. Conclusion

The conclusion is that a significant amount of studies has been done on the topic of Dynamic Rating; however there are some research questions that can be of particular interest for more detailed studies. The results of the current study have led to several interesting research questions for future studies:

One question is to consider a more detailed evaluation of the wind cooling effect on the overhead line conductor. A separate study of the wind direction effect on the line cooling has to be performed. The results are expected to give the approval or refutation of (7). Laboratory experiments have to be performed to obtain the necessary data on overhead line cooling under different wind conditions. It would be interesting to determine the effect of different weather conditions, like wind speed, wind direction, humidity etc. in laboratory conditions and outdoors, and compare the results with the measurement from the sites with applied Dynamic Rating.

Furthermore, the results from this study could be compared with real time data from the sites, where the dynamic line rating is already applied. This allows estimating direction of the future Dynamic Rating studies. Another topic for future discussion is more detailed analysis of line monitoring systems and future development of classification proposed in Section IV. The analysis will consider advantages and disadvantages of each of the Dynamic Line Rating techniques and estimate possible power gains for different applications. The Dynamic Transformer rating is also a topic of future research interest. The measurements of the cooling effect of ambient conditions are of particular interest.

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Biography

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