Electrical Power and Energy Systems 65 (2015) 76–82

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Estimation method for dynamic line rating potential and economic benefits ☆

Sanna Uski

VTT Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT, Finland

ARTICLE INFO

Article history:
Received 17 October 2013
Received in revised form 18 September 2014
Accepted 22 September 2014

Keywords:
Ambient Adjusted Rating (AAR)
Ampacity
Dynamic Line Rating (DLR)
Economic benefit
Net Transfer Capacity (NTC)
Transmission lines

ABSTRACT

The determination of economic benefits of increasing transmission capability by dynamic line ratings is a multifaceted task. In addition, there are many parties concerned within the complex electricity markets. This paper suggests a method for the evaluation of economic feasibility and benefits, as well as for the minimum potential assessment of employing dynamic line ratings. The suggested deterministic method considers very conservative assumptions in order not to compromise the power system reliability, even though the method is intended for the power system planning and not for the operation purposes. The method is applicable for congested transmission connections between electricity market price areas and it is demonstrated with a distinct case study of congestion on the power transmission from Sweden to Finland. Despite the very conservative assumptions used in the ampacity calculation to be on the safe side, the method can clearly point out the motivation to consider the implementation of dynamic line ratings on congested transmission connections in order to relieve bottlenecks and provide benefits for the society.

Introduction

The power lines are conventionally designed and operated with the worst case limitations and static ratings. The power transmission limiting feature on thermally limited lines is typically the line sag. On the maximum sag with prevailing ambient conditions, the actual current capability, i.e., ampacity, is most of the time larger than the static rating. This overlooked transmission capacity potential could be utilized by employing dynamic line ratings (DLR). High reliability would be maintained—and case-specifically even increased—by the transmission line ampacity and state monitoring. There are several technical applications available today for the DLR monitoring.

There exist different calculation standards and methods for the determination of the power line ampacity, e.g., by IEC [1], IEEE [2] and CIGRE [3]. The text books on power line design may present some of the different calculation options, e.g., in [4] the IEC equations are given as one alternative. There may be slight differences between the results obtained by the different calculation methods. The IEEE and CIGRE methods have been compared analytically and even experimentally, e.g., in [5–7].

There has been development of the dynamic line ratings and their determination and measurement over the recent decades, started in the late 1970s [8]. Since then, there has been a great number of publications and discussion on DLR.

However, the economic benefits of the DLR are quite rarely discussed in the publications. Chu presented in [9] a method for the selection of power lines on which the implementation of DLR would have the largest financial return through the savings in fuel costs. Greenwood and Taylor touch the question of the economic benefits of the DLR in [10] in the form of improved and cost-effective utilization of the network assets without compromising the network reliability when employing DLR.

Quite often DLR is studied and implemented in the cases when it is almost the last alternative, e.g., there is no time or possibility to build a new power line to increase the power transmission capacity. However, employing DLR could also be beneficial and bring economic savings in other situations. Usually it may be difficult to calculate the monetary value of employing DLR in the whole for the parties concerned, e.g., for the electricity consumers.

This paper suggests a method for the estimation of the economic feasibility of DLR to be applied in the congested power transmission connections. This method calculates the line ratings as ambient adjusted ratings (the term used and defined, e.g., by CIGRE in [11]). Ambient adjusted ratings are most of the time more conservative than the actual ampacity of the lines. This is because

☆ The work presented in this paper is done in the Smart Grids and Energy Markets (SGEM) research program funded by Cleen Ltd. and Tekes.

E-mail address: sanna.uski@vtt.fi

http://dx.doi.org/10.1016/j.ijepes.2014.09.034
0142-0615/

the influence of wind, that is significant in increasing ampacity, is ignored. Thus, only some of the potential of DLR is displayed by ambient adjusted ratings with the ambient temperature as the only variable.

The method is demonstrated with the analysis of publicly available data in a distinct case study. In this case study, the costs related to the congestion are easy to determine. The selected demonstration case concentrates on the congestion in the power transmission from Sweden to Finland in the AC connections in the northern parts of the countries. Finland and Sweden are part of the same electricity market, and congestion on the cross-border connections directly affects the electricity prices in the electricity market by creating price areas on either side of the transmission bottleneck. Publicly available data of the temperature, electricity market and system operation of 2011 are used in the demonstration case.

Method description

The estimation method for the dynamic line rating potential and economic benefits is based on the calculation of the hourly ambient adjusted ratings of the power lines for a certain period of time, e.g., a year.

The calculation of the ambient adjusted rating uses a combination of equations as well as some assumptions from a power line design text book [4], IEC [1] and CIGRE [3].

In this method, more conservative assumptions are preferred to be used for the ampacity calculation to be on the safe side.

The hourly ambient adjusted rating data series is calculated with the hourly temperature data series, the ambient temperature being the only variable. The used temperature data series is based on the historical temperature measurement data of multiple locations in the vicinity of the concerned power lines. The calculation for the hourly ambient adjusted ratings is covered more thoroughly in Section 'Ampacity of transmission line'.

For each hour of the year, the highest temperature value of the n different locations is selected for the temperature data series. In addition, a temperature security margin T_{marg} is added to the highest value, as

$$T_{\mathrm{h}} = \max\{T_{1,\mathrm{h}}, T_{2,\mathrm{h}}, \ldots, T_{\mathrm{n,h}}\} + T_{\mathrm{marg}}, \quad h = 1, 2, \ldots, 8760. \qquad (1)$$

In the case the temperature data sampling is greater than one per hour, the highest instant value within an hour would be selected.

The temperature security margin has two functions. The first function is to consider a possible higher temperature along the power lines in question. Thus the margin considers a systematic ambient temperature difference between the warmest spot along the line and the temperature measurement data locations. The second function is to consider temperature changes and variations within the temperature data sampling period, e.g., the inter-hour variations in the case of one per hour sampling. As the defined temperature data series is used for the estimation purposes (and not for the actual operation, or definite DLR potential calculations either), the temperature margin can be selected suitably and conservatively by analyzing the available temperature data, or by guessing.

The calculation of transmission capacity continues by determining the Net Transfer Capacity (NTC) hourly data series on the cross-border or between bidding areas. The NTC is calculated by using the same method that is generally used for NTC determination for the interconnection concerned, but now using the individual considered transmission line ambient adjusted rating data series instead of the conventional line ratings.

The historical data series of the power transmission ($P_{\mathrm{x-y}}$) in the connections in question is analyzed on the same time period (e.g., a year), as for which the temperature data based NTC data series is calculated. The relevant transmission congestion situations and hours are identified with the help of the hourly data series of the electricity price SP on the related bidding areas x and y, as well as the transmission capacity $NTC_{\mathrm{x-y}}$ given for the market for each hour. Only the hours on which a transmission bottleneck due to the static transmission line ratings is deemed to be the cause of price areas are considered. Hours with a limited NTC are omitted. I.e., the following conditions are true

$$\begin{cases} SP_{\mathrm{y,0}} > SP_{\mathrm{x,0}} \\ P_{\mathrm{x-y}} \approx NTC_{\mathrm{x-y,0max}} \end{cases}, \qquad (2)$$

where 0 denotes the historical situation and data. The situation and data with NTC based on the calculated ambient adjusted rating is denoted by 1. A transmission bottleneck is assumed to be relieved or possibly even removed if the calculated NTC with the DLR on an hour that is transmission capacity congested, is larger than the NTC in the historical electricity market data, i.e.,

$$NTC_{\mathrm{x-y,1}} > NTC_{\mathrm{x-y,0}}. \qquad (3)$$

The hours on which the NTC increase potential is very small could be neglected in the economic benefit calculation by discretion.

It would be a complex task and require confidential data and information to determine

- how big an increase in the NTC could be allowed (i.e., there may be other constraints that set limits before the NTC based on the calculated ambient adjusted ratings);
- how much additional transmission capacity would be needed to remove the bottleneck, thus resulting a uniform electricity price in both bidding areas;
- and what would be the electricity prices of the bidding or price areas with an increased NTC.

It is clear, however, that the prices with an increased NTC would be between the original area prices

$$SP_{\mathrm{x,0}} \leqslant SP_{\mathrm{x,1}} \leqslant SP_{\mathrm{y,1}} < SP_{\mathrm{y,0}}. \qquad (4)$$

Without the knowledge of the magnitude of congestion relief and the resulting electricity prices, this method assumes that the electricity price in area y would be the average of the two original area prices. I.e.,

$$SP_{\mathrm{y,1}} = (SP_{\mathrm{x,0}} + SP_{\mathrm{y,0}})/2. \qquad (5)$$

In the case an increased NTC would reduce the electricity prices according to Eq. (5), the money saved by consumers SV due to the considered x–y congestion relief under the conditions of Eqs. (2) and (3) would be

$$SV = \sum_{\mathrm{h}=1}^{8760} (SP_{\mathrm{y,1,h}} - SP_{\mathrm{y,0,h}}) P_{\mathrm{x,cons,h}}. \qquad (6)$$

It is assumed that the consumption $P_{\mathrm{x,cons,h}}$ would be the same regardless of the electricity price difference.

The method also assumes that a different generation dispatch enabled by an increased NTC at 1 h, does not affect the bids for the following hours the rest of the year. Thus, the historical data series can be used as is. Running the power generation fleet differently could in fact affect, e.g., the water reservoirs, fuel reserves and the value of the fuel reserves that in turn could influence the bids in the future.