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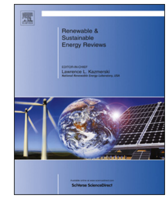

Review of dynamic line rating systems for wind power integration

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ABSTRACT

When a wind power system is connected to a network point there is a limit of power generation based on the characteristics of the network and the loads connected to it. Traditionally, transmission line limits are estimated conservatively assuming unfavourable weather conditions (high ambient temperature, full sun and low wind speed). However, the transmission capacity of an overhead line increases when wind speed is high, due to the cooling caused by wind in the distribution lines.

Dynamic line rating (DLR) systems allow monitoring real weather conditions and calculating the real capacity of lines. Thus, when planning wind power integration, if dynamic line limits are considered instead of the conservative and static limits, estimated capacity increases.

This article reviews all technologies developed for real-time monitoring during the last 30 years, as well as some case studies around the world, and brings out the benefits and technical limitations of employing dynamic line rating on overhead lines. Further, the use of these DLR systems in wind integration is reviewed.

Contents

1. Introduction

Taking into account the levels of CO_2 emissions [1–13] and in order to fulfil the Kyoto Protocol commitments, the contribution of renewable energy to the future generation will have to increase significantly from current levels. A good example is that the European Commission has set itself an ambitious target of 20% of total energy consumption to be supplied by renewable energy sources in 2020.

One of the challenges to achieve this goal is the need to expand or strengthen the distribution network in order to accommodate the large penetration of wind power. However, commissioning time of distribution network projects is usually longer than the time needed to build a wind farm. Therefore, recently built wind farms might be

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ready to generate power, but their evacuation lines have insufficient transmission capacity. Accordingly, wind power plants have to limit their generation in this situation. However, the now ever present solutions for the "smart grid" suggest the possibility of using the existing network more efficiently, so that wind power evacuation is not limited due to network congestion [14].

Another aspect to consider is the repowering of wind farms, i.e. the replacement of existing wind turbines by new-generation wind turbines [15,16]. The replacement of those first generation turbines has several advantages. For example, modern wind turbines often include control systems of reactive power and immunity to voltage dips, which are very important for the electrical system operation. But the increase of wind power penetration can reach a limit due to an insufficient capacity of the network in which the energy is injected.

Wind power is cheap and clean. If wind power is curtailed due to congestions in the grid, the curtailed amount of power has to be produced in other power plants, usually thermal, which are more expensive and have higher impact on the environment. For this reason, investment in the grids is justified. As an example, in the European transmission network 10-years development plan, the development of renewable energy is found to be the major driver for grid development. Projects of pan-European significance help avoid 30–100 TW h of renewable energy spillage globally, reducing it to less than 1% of the total supply [17].

However, the high population density, the intensive use of land and the increasing rejection of new electrical installations determine that a small amount of space is available to be dedicated to electrical lines. Dynamic line rating (DLR) systems are an option for delaying the construction of new lines. The cost for monitoring a circuit, including installation of the equipment and the software, is less than 2% of the cost of achieving equivalent gain by conventional techniques [18].

Line rating represents the line current which corresponds to the maximum allowable conductor temperature for a particular line without clearance infringements or significant loss in conductor tensile strength due to annealing. Transmission of electric power has traditionally been limited by conductor thermal capacity defined in terms of a static line rating, which is based on constant weather conditions over an extended period of time, days, months or years. So, transmission line limits are estimated conservatively assuming unfavourable weather conditions (static limit). Typically, low wind speeds (0.6 m/s), full solar radiation (1000 W/m^2) and high air temperature (40 °C) are assumed for the static line rating calculation [19]. Usually, the weather conditions result on a higher conductor cooling and for this reason the actual thermal capacity is higher than the calculated static line rating. For this reason, in the last two decades, technologies and strategies have emerged to allow the real-time or pseudo-real-time measurement of transmission line characteristics and weather conditions, enabling the calculation of real-time rating [20]. Different experiences with real time monitoring show an increase of 10–30% in thermal capacity over the capacity estimated conservatively [18].

Dynamic line rating (DLR) estimates line ampacity (maximum current carrying capacity of a transmission line) in real time with instant monitored weather conditions, taking account of the wind cooling effect. When wind energy is high, wind incident on lines is expected to be higher than the one considered for calculating the static limit. Therefore, transmission capacity of lines increases along with wind speed, because of the increased cooling. So, a correlation between wind power and the evacuation capacity of close lines exists (dynamic limit). Thus, when planning wind power integration, considering the dynamic line limit rather than the static limit increases estimated capacity [21–27].

These systems need only be installed on critical spans, where limit violations may occur. The identification of critical spans can be carried out with the help of design information and by inspection of transmission lines [28]. This allows the system operator to ensure that conductor temperature does not exceed the design limit, and line utilisation under all conditions is maximised.

Ampacity limit is usually related to sag limit, which is related to a certain conductor temperature value. However, in some cases, when the limit is determined by the annealing of the conductor, ampacity limit is directly related to the conductor temperature. The values of sag and temperature can be measured directly or calculated from measurements of other magnitudes. So, a dynamic line rating can be performed using several monitoring methods including weather monitoring, tension monitoring, sag monitoring and line temperature monitoring [22,29,30].

The way to determine the dynamic line limit is by using DLR systems [30]. These systems monitor actual weather conditions and rate the real capacity of the lines under study. So, it is possible to know if a given line can support more or less load. However, the way of monitoring the network also provides a series of questions, such as where to place the sensors. The ideal would be to install them in all lines, but this is much more expensive and if not, there may be uncertainties because weather conditions are different in different points/spans. Some commercial systems to measure ampacity have been presented in the market, based on several strategies. This paper introduces a literature review, of all technologies developed for real-time monitoring during the last 30 years, as well as some case studies around the world, and brings out the benefits and technical limitations of employing dynamic line rating on overhead lines. Further, the use of these DLR systems in wind integration is reviewed.

2. Dynamic line rating systems

DLR systems can be classified according to the magnitudes that are monitored. The magnitudes that are needed for the calculation of ampacity are weather magnitudes: wind speed and direction, solar radiation, and ambient temperature. Making a thermal calculation, ampacity is calculated as the current intensity value which equals conductor temperature to its maximum allowable value (Fig. 1). This thermal calculation is defined and applied through the publication of Standards by the IEEE [31] and CIGRE [32] which provide the mathematical models defining the thermal behaviour of the conductor.

Due to the uncertainties related to wind speed measurements, many DLR systems measure directly the overhead conductor temperature. This magnitude is used to calculate the effective wind speed that cools the conductor. The effective wind speed is

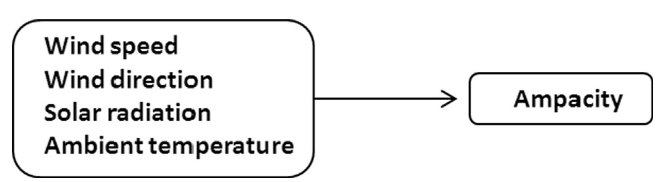

Fig. 1. DLR: meteorological variables.

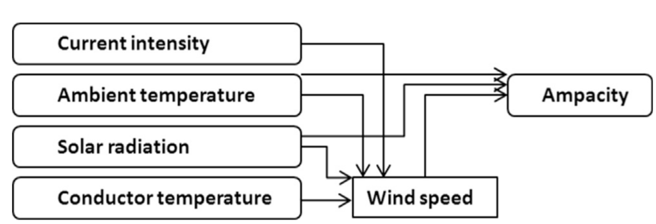

Fig. 2. DLR: conductor temperature and meteorological magnitudes.