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Benefit analysis in power generation dispatch using dynamic line ratings on transmission lines

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Abstract— This paper analyzes the different ampacity limits used in power transmission lines, static line ratings (SLR) and dynamic line ratings (DLR). This paper seeks to quantify the economic benefits that are obtained and how much the wind generation increases based on different line ampacities. With information from monitoring systems and weather stations, ampacity predictions are made for use in the market and operational phases of the power system. Different simulations are carried out on the IEEE 24-bus system, using different ampacity values calculated based on considered risk levels. The results show the economic benefits of using DLR on the system lines.

Key words. - Dynamic line rating, forecasting ampacity, wind generation.

1. Introduction

On many occasions, wind farms are forced to be unable to produce at their maximum capacity because transmission lines are congested at critical points in the grids. Existing lines do not have the capacity to transport all the production that wind farms can offer at times when the wind resource is strong [1][2]. This line congestion problem is caused by the increase in renewable generation connected to the grid, which poses a challenge to the system since renewable resources are variable and unpredictable.

At present, different ways are proposed to solve congestion problems on the lines. In this respect, [3] offers different paths to follow for congestion management. As in this case, more and more studies are focusing on analyzing how to manage contingencies in real time, some of this studies have shown in certain cases, that the use of real-time system data makes the network more efficient. Unfortunately, in reality, obtaining this information and using it in realtime seems to be a more complex task to carry out, since it involves different phases of the system such as the market and the operation of the network [4]. The installation of new power lines could be a solution for this problem, however, it is very costly.

The use of the dynamic ampacity limit on the lines would be other solution to consider. In many occasions overhead transmission lines work at a lower capacity than they could work, this is due to the fact that they operate with static current limits. These static current limits are very conservative and in reality the values used to calculate the ampacity are not equal to the real values that occur at any given moment. The influence that meteorological factors have on the temperature of the conductors allows the lines to work with a higher load than the one they are working with. Weather conditions such as ambient temperature, solar radiation and wind speed have a high influence on the temperature of the conductors. This solution is particularly interesting in relation to wind energy by the fact of the influence that the wind has on the cooling of the lines. Information from meteorological stations can be combined with the information obtained by monitoring systems to obtain real data on the line temperature and on lines real transport capacity [5]. Since energy dispatch planning is done days before, it would be very beneficial to have real-time information on line ampacity [6].

The first part of this paper presents an analysis of the ampacity limits used in transmission lines. It discusses the benefits that dynamic limits can bring, economic benefits and more functionality on the network. It may allow a higher penetration of renewable energy in the grid. With the intention of quantifying these benefits, the second part of the article presents the simulations carried out in an IEEE 24-bus system. Based on the data obtained, the impact that the dynamic limits can produce in the operation of the system is analyzed.

2. Thermal Line Ratings

The temperature that a conductor reaches depends on different parameters [7]. First of all, it will depend on the load current and the electrical characteristics of the conductor. Atmospheric parameters also have a influence on this temperature, especially wind and sun. Safety limits mark the maximum temperature that a conductor can reach, it is necessary that the temperature be lower than the assigned temperature. If this maximum temperature is exceeded by more than 10°C, it could cause injury to human beings in the immediate perimeter of the line. Other problems that can occur if this maximum temperature is exceeded are electrical discharges that can damage the distribution lines or even damage nearby buildings.

By using devices that monitor the position and stress of the line conductor and combining this information with that obtained from weather stations, the realtemperature of the line can be calculated and based on this temperature the actual ampacity at any moment can be calculated.

A. Static Line Rating

Static Line Ratings (SLR) are calculated based on unfavorable conditions for the carrying capacity of power lines. The unfavorable conditions under which these calculations are made are not present for most of the time of the day. The weather conditions taken into account depend on the location and the different risk tolerances that the emergency utilities want to assume. Estimates of temperature, wind speed and direction and solar radiation for each time of the year are taken into account, and with these data and thermal equilibrium models, static ampacity values are established. As described in CIGRE Technical Guide 299 [8] with a bare conductor thermal equilibrium model, using conservative climatic conditions, e.g., low perpendicular wind speed, seasonal air temperature close to maximum and maximum solar radiation, the static ampacity values of the lines are calculated.

Depending on the time of the year, the static ampacity values can be recalculated, which will depend on the regional climate and will make the data used closer to reality. These seasonal static limits are widely used and are applied to all lines in the area or region, so that in winter the capacity limits are higher due to the lower temperature.

B. Dynamic Line Rating

The maximum current capacity that a conductor is capable of carrying based on the ambient conditions and the temperature of the conductors in real time is known as the dynamic line rating (DLR). Monitoring systems installed on the lines and weather stations nearthe lines provide data and information that is used to calculate these dynamic limits. This information can beused to calculate different ampacity values. Theinformation can be used in real time to operate the network on the spot. The information received also canbe used to predict the behavior of the network and predict the ampacity of the lines in the near future. If the actual data is used to calculate dynamic ampacity predictions, it can help to operate the network more appropriately [9]. In these cases, it is necessary to use monitoring systems to ensure that the maximum temperature that the line can support is not exceeded. Predictions always have a margin of error; it cannot be accepted that the current exceeds the established values for a certain time.

One of the categories among which dynamic limits are classified is the Dynamic Line Ratings with Ambient-Adjusted (DLR-AA), in this case all meteorological variables except ambient temperature are considered constant. The other main category is classified as Dynamic Line Ratings with Real-Time Monitoring (DLR-RTM), in this case the change of all meteorological variables are considered [10].

Using continuously monitored real environmental data, higher accuracy and closer to real ampacity values can be obtained with the DLR-RTM. The problem with these data is that they can only be used once they have been measured, i.e. when the network is already operating. If these data could be used for upstream phases such as energy dispatch or the electricity market, system efficiency could be increased. In order to use thedata in these earlier phases, it is possible to make more accurate predictions based on the historical data that the measurement devices have obtained. In this sense the DLR-RTM is used to perform ampacity predictions and thus analyze the points of the network that may have capacity problems and may suffer congestion. In this way a more balanced and optimal energy distribution can be carried out, achieving a better integration ofrenewable energies.

1) DLR for ampacity forecasting

In order to get the most out of the available measurements it is necessary to perform dynamic ampacity forecasting hours or days before it is carried out [11]. Currently, in the electricity system, the market is managed the day before the energy is dispatched. If atthat time the transmission capacity that the lines will have on the day of dispatch were known, the system would operate more efficiently. Due to technicalbottlenecks, lower cost generation plants, such as wind power, which could produce more than they do at various times, are forced to reduce their output. This is because the output lines of such generation plants cannot cover all the energy that can be generated. Forecasts can be made at different time horizons ranging from hours to days. Based on the different time horizons used the forecasts made are used in different applications. There are short-term forecasts, which havea time horizon of less than six hours and are usually applied for contingency management. Long-term forecasts, with a time horizon exceeding twenty-four hours, are usually applied in energy dispatch and in the daily supply of electricity in the market. In [12], a prediction model and the results obtained using those predictions are proposed.

When forecasting using information about the sun or wind, which are highly variable resources that change frequently and are difficult to predict, it is important to consider that there is a possibility of making errors in the predictions. It is necessary to analyze the risk of error that is assumed and thus find the most optimal solution between the cost of errors in the predictions and the benefit obtained. It is also necessary to ensure that these errors do not exceed the established safety limits. A study on the benefits of DLR using different levels of uncertainty in the predictions has been carriedout in [13].

2) Benefits of DLR

The use of DLR is mainly aimed at increasing the carrying capacity of the lines. The increase in the admissible current of each line has the advantages summarized below:

First of all, it increases the reliability of the electrical grid. It avoids that lines work very loaded or close to their maximum current limits. Increasing the capacity of the lines in this way avoids having to build new lines and infrastructures to be able to transport a greater amount of energy, which would entail a cost that is avoided in this manner. It also allows a greater integration of renewable energies, especially wind energy. A greater amount of wind means, greater cooling of the lines, and this makes DLR particularly interesting in grids with wind generation. This increase in renewable energies will reduce the total cost of system dispatch, because more generation will be obtained from renewable energy sources that have a lower cost than other generation sources.

- Increased wind power generation

The use of SLR on the power lines located at the exits of wind farms causes technical restrictions. These restrictions are due to the congestion that occurs on these lines when the wind resource is high. These lines do not have enough capacity to be able to transport all the generation from the wind farms to the grid. In these cases, wind energy production is reduced, and the energy needed to supply the system is produced by other non-renewable energy generators. These generators that have to replace wind generation are more polluting and more expensive. The use of DLR systems on the lines connecting the wind farm with the grid is very effective, since there is a strong relationship between the wind capacity and the cooling of the lines. At times of high wind generation, high wind conditions ensure a good cooling effect on the conductor. Therefore, it can be said that there is a complementarity between wind power generation and DLR.

The relationship between increased line capacity and wind generation is discussed in [14]. With the use of DLR it is possible to produce between 20% and 50% more wind generation at times when wind generation is higher. This increase in wind generation means a reduction of other generation technology that will be non-renewable and more expensive, so it is a great saving for the total dispatch of the system. Taking into account the problems that are bringing pollution to the planet and climate change, the fact of being able to use renewable sources of generation that do not pollute compared to other sources of generation that do is an advantage.

- Economic benefits

In recent years, the growth trend of renewable energy has been increasing. If this trend continues, installed renewable capacity is expected to increase worldwide, especially wind power. With the increase in new sources of generation comes the need for an increase in transmission line capacity. To increase this capacity, different actions can be carried out, such as improvements in the existing system infrastructure, installation of new conductors with higher capacity on existing lines or the installation of new transmission lines. These options for increasing capacity involve a large economic investment. Therefore, it is interesting to analyze the benefits that could be achieved by increasing the capacity of the lines through the use of technologies that allow the lines to operate with DLR.

In [15], the effect of congestions that occur in situations where lines are unable to transport in periods of high demand is analyzed. If these technical constraints to which the network is subjected can be reduced, thecosts produced by the same constraints will be reduced. A reduction in the number of hours that lines are congested is observed through the use of DLR.

In order to analyze the economic benefits that a monitoring system can bring, the cost reduction resulting from the introduction of cheaper generation in the market is taken into account. In this way it is possible to increase the capacity of the lines at times with a lot of wind, taking advantage of the power of the wind in cooling the conductor [16].

Different studies demonstrate the economic benefit obtained by using DLR in [17] a new two-stage stochastic optimization model is proposed that incorporates the effect of dynamic line rating on grid operation, with a higher penetration of wind generation, explicitly considering uncertainty in both wind generation and line rating. Through several case studies, they have demonstrated the benefit of usingDLR (rather than using static line rating) in terms of overall cost minimization.

3. Study cases of DLR in IEEE 24-bus system

This section discusses simulations carried out on the IEEE 24-bus system with the objective of quantifying the benefits of installing DLR devices. The simulations have been carried out with the DigSilent Power Factory program and a python script. The IEEE 24-bus system has been modified. The objective is to analyze the different cost of energy dispatch for a week with different values of ampacity of the lines. I addition, is analyzed the distribution of generation dispatch to compare the difference in wind productionfor each of the proposed scenarios.

A. Network Description

The IEEE 24-bus system is described in [18]. In [18][19] the specification of generators, demand and transmission lines information can be found. For this analysis, some changes are made to the original network and the data used. Generator in node 16 and innode 7 are replaced by a wind farms. The wind generation data used have been obtained taking into account the wind generation production of a wholeweek, this information has been obtained from REE data. Correction factors have been used to adjust the wind generation data to appropriate values for the system. Prices have been simplified, costs of generation technologies are 19 €/MWh, 83 €/MWh, 62 €/MWh, 32 €/MWh, and 0 €/MWh, for nuclear, coal, gas, hydro and wind, respectively. The system loaddata has been modified by obtaining a full week's demand data. These data have been obtained from REE. Correction factors have been used to adjust the demand data to the appropriate load values for thesystem. Once the load value of the total system has been obtained, the distribution of each load has been made based on the percentages obtained from [18].

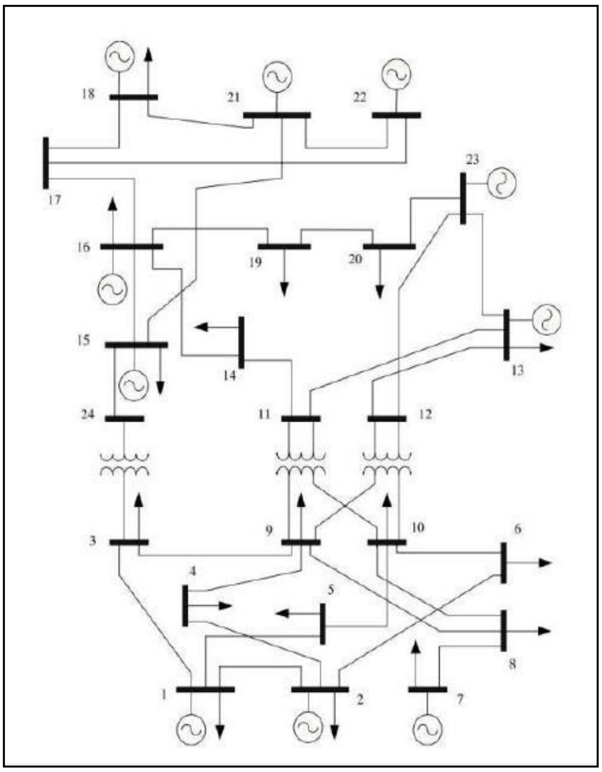

Fig. 1. IEEE 24-bus system

B. Case Study Description

Different five scenarios have been proposed for the simulations based on the ampacities used in each of them. The ampacity value used in each scenario has been obtained from [20]. To obtain the real ampacity data on the line, data have been taken from different meteorological stations and combined with forecasts obtained from the state meteorological agency with different time horizons. The line ampacity predictions are carried out by means of a probabilistic proposition, which is performed with input data obtained in time horizons between 30 minutes and 24 hours. Based on these obtained data, by means of linear regression models, a probabilistic model for the output variable is obtained. Different risk values are determined to be used for ampacity prediction. This risk level refers tothe percentage of probability of exceeding the maximum allowed temperature of the conductor. When higher risk levels are used, the transport lines have higher transport capacities, leading to higher line utilization, but lower line safety.

An analysis has been carried out on the effect of the application of DLR on the system lines, in order to analyze the influence of the increase in ampacity and the effects it has on the cost of the system. The ampacity values used are the following: measured ampacity, static ampacity values and predictedampacity with a risk of 2.5%, and with a risk level of 10%. These risk levels have been used as the most representative data, a balance between risk and network utilization is obtained. Values of 25% and 50% have been discarded because they represent a high risk to the security of the network. Values of 1% and 0.5% have been discarded because of the small influence that theserisk level values would have on the ampacity.

C. Results

The power dispatch data obtained, as well as the distribution of generation among different types of generators allow compare the cost of energy production with different values of ampacity limits on the line. The program also collects load data from each of the lines in the system. The simulation with static limits shows that some of the lines of the system, those closest to the point of wind generation, are overloaded, working at maximum capacity. The results of some of the individual cases show that for example for many operating hours the line 07-08, the line connected to one of the wind farms, is loaded to 99.99% when the ampacity limits are static. This load value is reduced by 10-20% in most cases by using dynamic ampacity limits based on real measurements and predicted data.

The cost of generation dispatch calculated with different ampacity data can be seen in Table I. The cost of generation dispatch is lower using data measured by monitoring systems. The cost of dispatching energy for all the week using predicted ampacity data is lower than the costs obtained using static ampacities. This has been observed for the different risk levels chosen.

I. Table. Production and system cost for energy dispatch in one week

Ampacity		Cost [€]
Scenario 1	Measured data	7077414,93
Scenario 2	Prediction 2,5% risk level	7104835,46
Scenario 3	Static 2,5% risk level	7116731,07
Scenario 4	Prediction 10% risk level	7072547,36
Scenario 5	Static 10% risk level	7082440,03

II. Table. Wind energy production

Ampacity		Wind power (MWh)
Scenario 1	Measured data	142311,88
Scenario 2	Prediction 2,5% risk level	141354,75
Scenario 3	Static 2,5% risk level	140969,327
Scenario 4	Prediction 10% risk level	142505,036
Scenario 5	Static 10% risk level	142085,141

The wind power generation results obtained for the different ampacity scenarios can be seen in table II. It can be observed that when using ampacity limits based on real line measurements and ampacities obtained from predictions, the penetration of wind energy into the system is higher than when using static ampacity limits.

4. Conclusion

This paper presents an analysis of how replacing static line limits with dynamic limits is beneficial both economically and environmentally. Among the different aspects analyzed, it is shown that a week's energy dispatch is done for less cost when the lines make better use of their capacity. It must be taken into account that the higher the risk levels, the lower the cost but at the same time the lower the safety of the network.

The increased use of renewable generation, such as wind power in this case, makes it possible to reduce emissions from other types of power plants. If the lines connecting the wind farms become congested and wind generation is forced to reduce its output, that part of the demand will have to be generated by more expansive and more connected to the wind farms are not so overloaded, for example by using dynamic ampacity limits, it is possible for the wind farms to produce more power, thus avoiding more costly plants coming on line and reducing the total cost of power dispatch.

These simulations are a representation and in order to carry it out, system phases such as the market have been simplified, taking generation price values without entering into all the other factors that imply in the costs. This study will continue to add more details to the different phases of the system to obtain an even more representative picture, it will be convenient to analyze how reserves vary and the cost that this entails.

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