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Increasing Power Transfer Capability of Transmission Lines Using the Quasi-Dynamic Operation and Monitoring System

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ABSTRACT

One of the key methods for reducing the possible interruptions and the pressures imposed on the operator is to employ the hidden capacity of the transmission lines. The basis of selecting the line capacity is the ability of the operator to preserve the allowed distance between the transmission line and the ground, trees, vehicles, and other obstacles that are directly under the line. One of the methods that increase the capacity of the employed line is the line monitoring equipment and using the dynamic capacity. Although the dynamic capacity method costs less than other options, it might be costly and laborsome. Thus, there should be a tradeoff between the dynamic and static capacity, known as the quasi-dynamic capacity. This term indicates that the dynamic capacity is used in studies for making logical decisions for changing the static capacity or operation of the operator. In many cases, this technology can be implemented temporarily and then removed or displaced for other applications. The purpose of this study is to present a quasi-dynamic method for determining and operating the line capacity to reduce the costs required to determine the complete dynamic capacity and improve the assumptions used in determining the static capacity.

1. INTRODUCTION

The most important factors that increase the conductor temperature include the current flowing through the line, solar irradiation, and ambient temperature. Also, the key parameters that can cool down the conductor include rain, wind, and ambient temperature. While the operator needs to know the maximum current flowing through the critical lines, the operator has no means to understand the weather condition along the line without significant investments in the devices. Thus, the electricity companies have to adopt a set of assumptions about the weather conditions. These assumptions should be sufficiently conservative to ensure the minimum risk of heating the conductor in the long term. Also, these assumptions should allow the required power to flow through the line. This is the challenge in determining the static capacity of the transmission lines. To determine the static capacity, the conductor temperature is calculated based on the ambient condition. The conductor temperature can be used to calculate the conductor sag, which is a fundamental measure for determining the line capacity. To observe security, the environmental conditions should be employed conservatively, as a result of which the calculated capacity is much lower than the real line capacity. Even if the assumptions are not sufficiently conservative, the air gap might exceed its allowed value in a short time. It should be noted that the conductor might exceed the maximum allowed temperature whenever the static capacity increases. The only way to decrease this risk is to get feedback via monitoring the conductor sag or the line elasticity [1-3].

Increases in the generation of electricity lead to the existing transmission line system being gradually congested. Primarily, it was reported that most of the electrical infrastructures were constructed in the 1950s and 1960s, which means that they have already been in service for about 60 years [4-7]. There are issues associated with this, as most of the old instruments have already exceeded their life cycles or are nearing the end of their lives [8-13]. Hence, current transmission line systems are loaded with a sizeable number of ageing assets. Therefore, among the possible mechanisms for accommodating the electricity demand are either constructing a new transmission line system or increasing the utilisation of the existing transmission line system. However, there are issues associated with the development of new transmission line systems. The challenges faced in developing a new transmission line system are complexities in obtaining new rights of way (ROWs) for constructing it and the high cost of development; these have caused tremendous stress for providers of utilities in an effort to establish alternative strategies that are intended to extend the current infrastructures [14-16]. Thus, the increased utilisation of existing transmission line systems has become of interest for electric utility providers throughout the world in order to cater to the increasing electricity demand. According to the study [17], there are several options available for the management of assets in deciding on increasing the utilisation of existing transmission line systems; these include uprating, upgrading, refurbishing, and life extension or expansion. Uprating is the best option for utilising an existing transmission line system [18]. It is defined as the process of increasing the power transmission capacity of a transmission line system. Many studies have been conducted on the increase in power transmission capabilities by using the method of uprating existing lines, which is associated with the implementation of thermal and voltage uprating mechanisms [19, 20]. Previous work revealed that thermal and voltage uprating methods associated with different techniques and processes have been employed all over the world to meet the ever-increasing electricity demand [21-25].

Considering the above discussion, using the monitoring device can increase the line operation. But the main challenge is that this method is costly in terms of the number of operators. The quasi-dynamic method is presented to resolve this problem. This paper describes the quasi-dynamic method, and its differences with the dynamic and static methods are explained. Also, the quasi-dynamic methods are classified in time intervals. Finally, the weather information implements various quasi-dynamic methods on a sample line [26-28].

The paper is structured as follows. Section 2 presents the Quasi-Dynamic method by increasing the risk. In Section 3, the existing procedures in the Quasi-Dynamic method is described. Section 4 provides operating regions in the Quasi-Dynamic method. Section 5 and Section 6 present operator intervention and Quasi-Dynamic scenario in time intervals respectively. Finally, the last section of the paper summarizes the results and conclusions of the research.

2. THE QUASI-DYNAMIC METHOD BY INCREASING THE RISK

Determining the line capacity dynamically or instantaneously in a short time is costly and makes implementation and management complicated. The time that the load exceeds the static capacity of the line might be short; thus, small increases of the line capacity might have positive effects on the system reliability and income.

The quasi-dynamic capacity concept is presented to help the companies counter such problems. The primary quasi-dynamic capacity concept was based on accurate analysis of the dynamic capacity data and considering conservative risks in selecting the line capacity that provided the advantages of this selection and reduced the costs. In other words, the operator calculated the dynamic capacity instantaneously and obtained a new capacity for the line. The obtained capacity is risky due to increasing the capacity compared to the static capacity that could be considered conservatively with low risk. The advantage of the above is that the upper capacity of the line is used, which increases the costs because it requires analyzer devices. Since the companies are unwilling to increase the risks, the primary concept was modified synchronous with the companies' requirements [2].

3. THE EXISTING PROCEDURES IN THE QUASI-DYNAMIC METHOD

Three procedures are considered for determining the quasi-dynamic capacity. Other scenarios are discussed in the following [1, 2].

Scenario 1: This scenario includes determining the risk level of the primary static capacity using the dynamic capacity. In this scenario, after complete evaluations, the static capacity increases by accepting a higher risk level. In this method, the dynamic capacity of the line is first determined using relevant data like weather, allowed sag; then, the new static capacity is determined with the risk of interest considering the obtained dynamic capacity. For example, if the allowed static current is lower than the minimum current of the dynamic capacity, the risk level is zero. In general, considering the dynamic capacity distribution, various risk levels can be determined for the static capacity. This type of quasi-dynamic capacity changes the procedure by accepting a higher risk level.

Scenario 2: In this scenario, the operator has access to two capacities. One is the current static capacity, and the other one is the dynamic capacity. Under normal operation conditions, the operator does not have to take a specific action when the load is under static capacity. When the load increases and reaches the static capacity of the line, the operator can allow the load to increase until it reaches the dynamic capacity of the line. In this case, the static capacity does not limit the current flowing through the line; the line is employed optimally until the load exceeds the dynamic capacity. The challenge of this type of operation is that it requires the operator to monitor the line constantly and take care of operation at the boundary points of the dynamic capacity so that the load passing the line does not exceed the dynamic capacity and the total capacity of the line is employed. This method is similar to the dynamic capacity method; the only difference is that the static capacity is used as a guide and alarm for the operator, and if the load exceeds the static capacity, the operator should operate more accurately.

Scenario 3: This scenario is a combination of the first and second quasi-dynamic methods. In this method, the operator determines a new static capacity for the line using the static data and accurate analysis of the static data, which is higher than the previous conservative static capacity. The difference between this method with the second method is that the operators should use the previous static capacity at low loads and the new quasi-dynamic capacity at heavy loads.

4. OPERATING REGIONS IN THE QUASI-DYNAMIC METHOD

In the third scenario of the quasi-dynamic method, the operator monitors the line capacity and the load flowing through the line with a higher reliability margin. In this method, three operating regions can be defined for the operator:

Green region: The flowing load is lower than the initial static capacity in this region, and the operator does not have to take any specific actions.

Yellow region: in this region, the flowing load is higher than the initial static capacity and lower than the new quasi-dynamic capacity. In this region, the operator should take care that the load does not exceed the quasi-dynamic capacity (the load is not in the third or red region).

Red region: this region is defined between the quasi-dynamic capacity and the dynamic capacity. If the operator operates correctly, the load does not enter this region. Also, if the load enters this region since the dynamic capacity is the limiting factor, it is possible that the load does not exceed the allowed capacity.

These regions are shown in Figure 1. In the third scenario, until the load is under the green region, the operator does not have to interfere. When the load enters the yellow region, the operator should ensure that the load does not enter the red region. In this technique, the operator counters two capacities, and unlike increasing capacity through determining the dynamic capacity, the operator is not affected by the calculations and continuous environmental changes of the dynamic capacity. This procedure is understandable and stable with low risk for the operators.

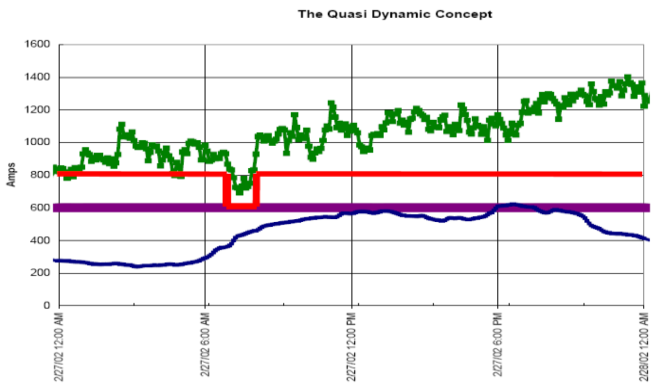

Figure 1. The operating regions generated by the quasi-dynamic scenario adopted from [1]

5. OPERATOR INTERVENTION

The operator intervention is defined as either passive or active. In the passive intervention, the operator observes different line parameters on the computer screen, and if the load is in the green region, no action is required. In this case, the operator only observes, hence the name passive. But when the operator observes that the load is in the yellow region, and one of the parameters, for example, the load is reaching its allowed limit that is the determined capacity, the operator should take proper action and intervene actively; for example, reducing the load flowing through the line. If the load is in the red region, the operator should intervene actively.

6. QUASI-DYNAMIC SCENARIO IN TIME INTERVALS

As mentioned in the previous section, the quasi-dynamic method operates based on increasing the risk regarding the static capacity. In this method, instead of defining annual time intervals for determining the capacity, it can be determined in shorter intervals like seasonal, monthly, daily, and hourly. The proper capacity for each time interval should be defined with the acceptable risk percentage.

For example, Figure 2 compares the capacity obtained in two methods; one is an hourly method, and the other is a 4-hour method at two temperature limits of 75 and 125 degrees of centigrade. As can be seen, the hourly capacity is more than the 4-hour capacity. Also, the capacity for tolerance temperature of 125 is higher than 75 as expected.

Another example of the time interval division is night/day. In this method, the line capacity is determined separately for night and day. Figure 3 and Figure 4 show the dynamic capacity's cumulative function for day and night. The difference in the capacity obtained in these two cases depends on the temperature condition, wind, and solar irradiation. Throughout the day, the temperature is high. Since wind blows are also high, the increasing temperature might be neutralized by increasing the wind blow and vice versa at night. Therefore, it cannot be generally said that capacity at night is higher or lower than a day. According to Figure 3 and Figure 4, the maximum current at day and night is 1100 and 1000 A. It can be concluded that the wind blow in a day is more effective than temperature increase, or reducing the temperature at night is less effective than reducing wind blow.

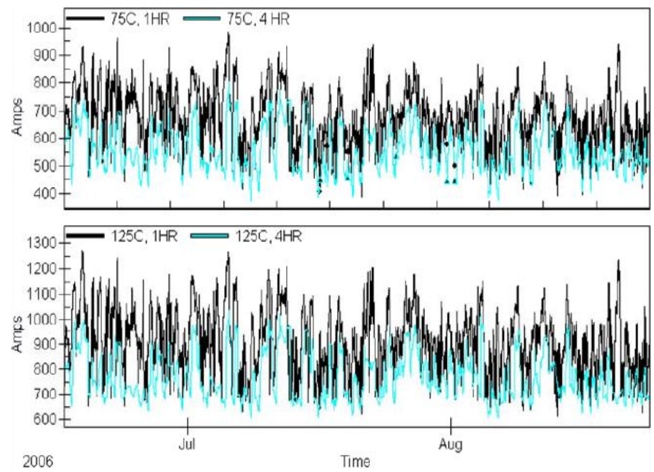

Figure 2. Comparison between the capacity of the hourly and 4-hour method adopted from [7]

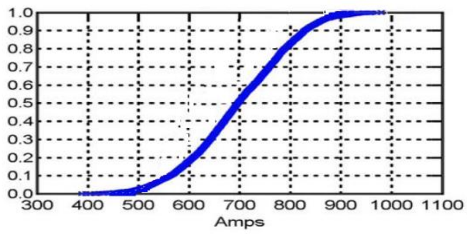

Figure 3. The cumulative function of the dynamic capacity in the day adopted from [7]

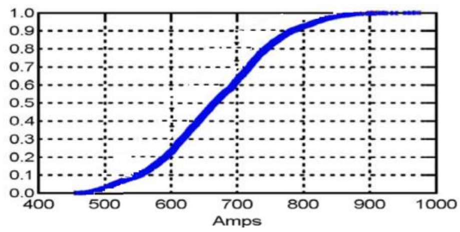

Figure 4. The cumulative function of the dynamic capacity at night adopted from [7]

It should be noted that the quasi-dynamic scenarios in different time intervals can be implemented as different methods with a given risk level.

7. RESULTS

The quasi-dynamic method and scenarios mentioned for increasing line capacity are implemented for a sample 63 kV line of 11 km. The weather information taken from the weather forecast station is described in 3-hour intervals, and the number of samples for each parameter is 8. Figure 5 shows the temperature values in the first month of the year. Figure 6, which is related to January (winter), the temperatures are relatively low, with an average of 8.59°C. In Figure 7, which is related to August (summer), various temperature values are shown. In this month, which starts from the 10th of Mordad to the 9th of Shahrivar, the temperature values are high, with an average of 23.86°C, which is 15 degrees warmer than the average in January.

To better compare temperatures in the first and eighth months, these two diagrams are represented in one diagram. As can be seen, for all days of the month, the temperature of the cold month is lower than the hot month (august). The statistical distribution or probability diagrams are shown in Figure 8, and Figure 9 can be used to classify the temperature distribution during the year. As seen in Figure 8, the most frequent temperature is about 10 degrees.

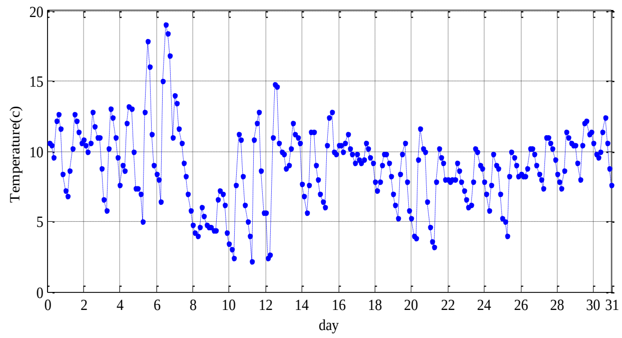

Figure 5. The temperature data of the first month (January)

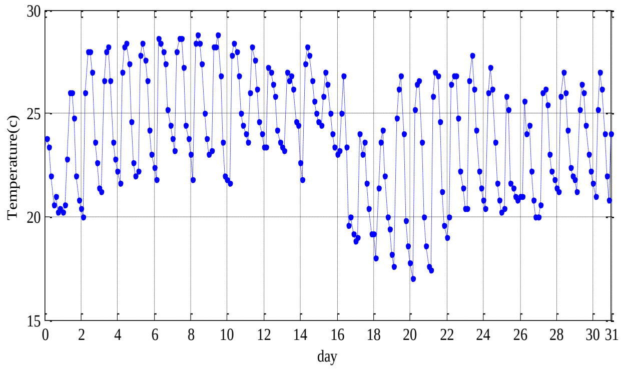

Figure 6. The temperature data of the eighth month (August)

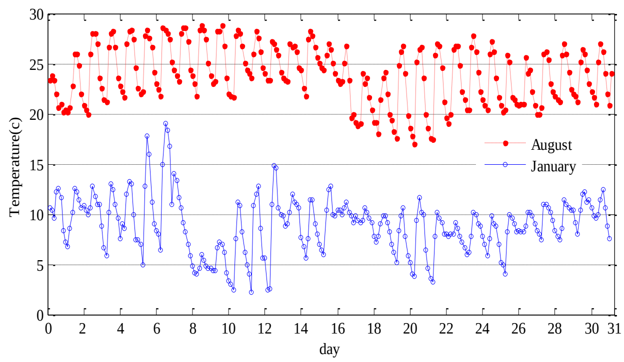

Figure 7. Comparison of the temperature data in the first month (January) and the eighth month (August)

As shown in Figure 9, where the distribution curve is step-wise, the number of days that the temperature varies between 10 to 12.5 degrees is more than other temperature ranges. Another important parameter that its data is accessible is wind. The existing wind data include speed and coincidence angle. The important point about wind is that the wind speed is random in a year, such that there is no particular trend for the wind speed in the year.

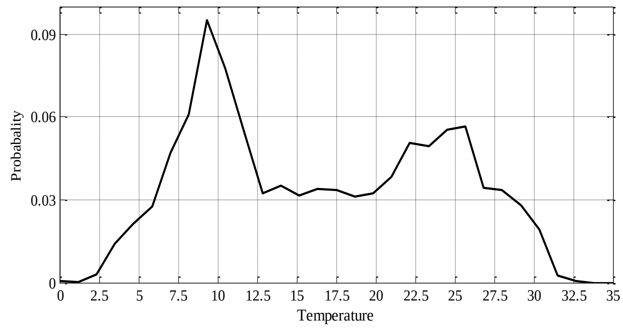

Figure 8. Statistical distribution of temperature during the year

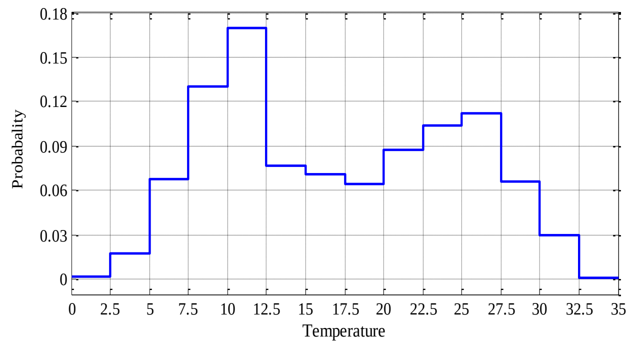

Figure 9. Statistical distribution of temperature during the year (temperature range of 2.5 degrees)

Indeed, it should be noted that the wind speed in a day has a specific trend; that is, the wind is low at night, while its speed is high during the day. In Figure 10, the wind speed in a day in March (third month) is shown. As can be seen, when there is no solar irradiation, the wind speed is zero at 3 or 9 P.M, but in the middle of the day, for example, at noon, the wind speed is 2 m/s.

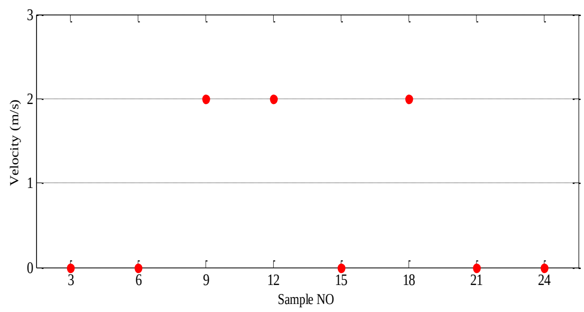

Figure 10. Wind speed data in a day

An important statistical analysis that should be carried out for the dynamic capacity of the line is the distribution and cumulative curve of the current values. Figure 11 shows the capacity distribution curve of the studied line in one year. The line capacity distribution is such that many of the values are close to 500A. Also, the capacity distribution is uniform between 600 to 1400 A, and there are a few cases for values above 1400A. Another important curve that is used to analyze the dynamic capacity of the line is the cumulative distribution of the capacity that is shown in Figure 12. As can be seen, the probability that the line capacity throughout the year is less than the corresponding current value along the horizontal axis is represented as a number between 0 and 1 along the vertical axis.

It should be noted that the dynamic capacity for different years is different. Thus, the dynamic capacity is represented independently for different months. Figure 13 represents the dynamic capacity of the studied line in January. The minimum and maximum line capacity in Jan are 468 and 1604 A, respectively.

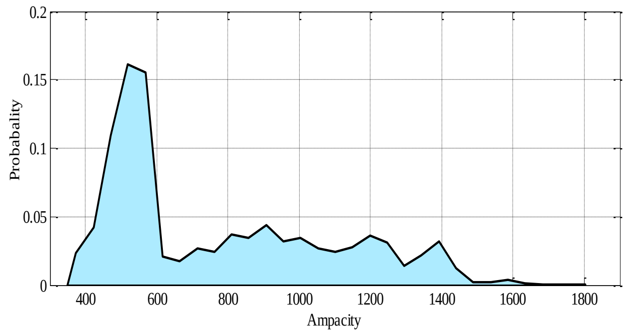

Figure 11. The capacity distribution curve of the studied line throughout one year

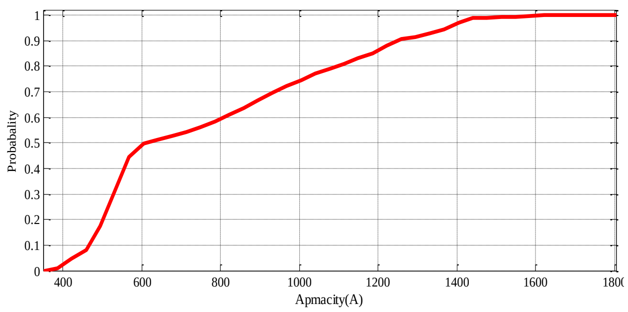

Figure 12. The cumulative distribution curve of the studied line throughout one year

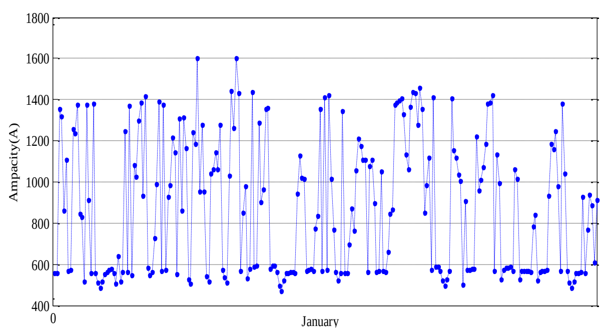

Figure 13. The dynamic capacity of the studied line in January

In Figure 14, the quasi-dynamic capacity for different seasons (spring to winter) with a risk of 15% is shown along with static and dynamic capacities. Three regions are defined for the operator in which the operator intervention might be active or passive depending on the region and the load changes.

In Figure 15, the quasi-dynamic and static capacities are represented as the boundary between different operating regions of the operator. As can be seen, the three regions are discriminated in green, yellow, and red. The green region represents the area under the annual static capacity that is 350A; in this area, all instantaneous capacities are lower than the static capacity. In the yellow region, the line capacity is defined between two seasonal static capacities with a specific risk level and the annual static capacity. Since the boundary of this region is determined with an initial risk, the dynamic point might enter this region. If the load enters this region, the operator should take a proper action line disconnecting the extra load to prevent risk.

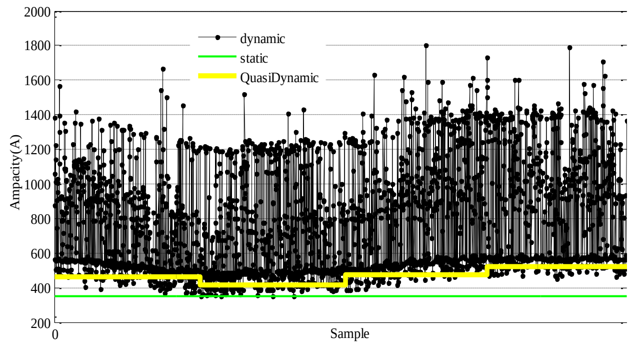

Figure 14. Seasonal quasi-dynamic capacity considering the dynamic and static capacities

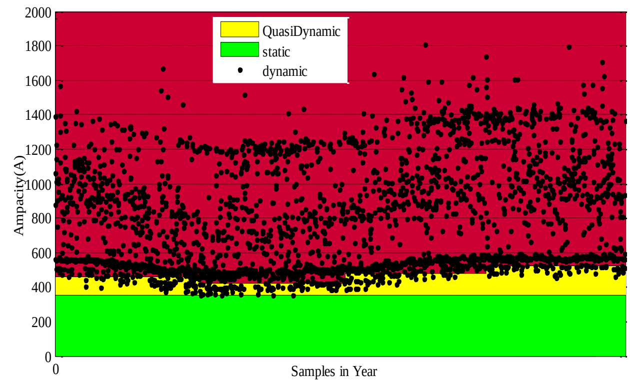

Figure 15. The operating regions of the operator in the seasonal quasi-dynamic scenario

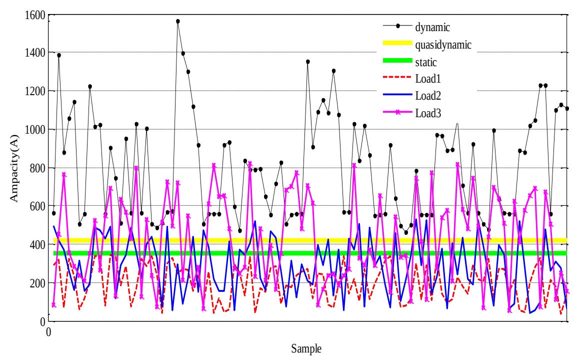

Figure 16. Operating regions of the operator in the seasonal quasi-dynamic scenario

In Figure 16, the load curves are shown for Load1, Load2, and Load3, which are low, medium, and high. As can be seen, Load1 is lower than the annual static capacity for all monitored samples. Thus, the operator's active and passive intervention would be negligible. For Load2, in some points, the values are higher than the annual static capacity and even the seasonal quasi-dynamic capacity. In this case, the load enters the yellow and the red regions, as a result of which the passive intervention of the operator is more. But the load is higher than the dynamic capacity at some limited points. In most points, the load is under the instantaneous capacity curve, resulting in the low active intervention of the operator. For Load3, the load exceeds the quasi-dynamic capacity, and at many points, the load exceeds the dynamic or instantaneous capacity. Thus, the passive intervention of the operator is high and active intervention is also required to disconnect a part of the loads to prevent damages to the line. In Figure 17, the monthly quasi-dynamic scenario is shown considering the obtained monthly capacities.

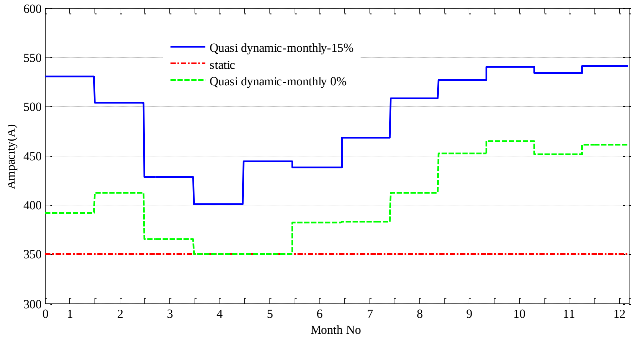

Figure 17. The monthly quasi-dynamic capacity considering static capacity

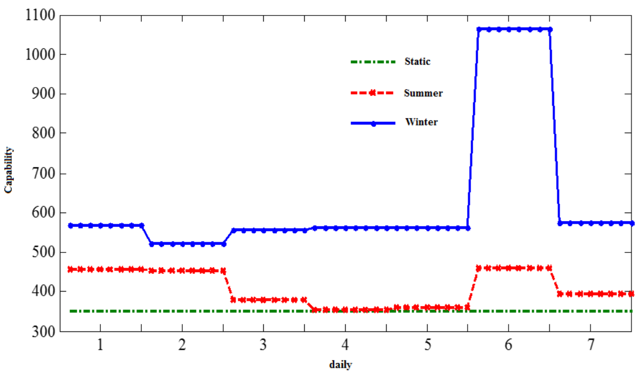

Figure 18. The daily quasi-dynamic capacity for one week in winter and summer

Figure 18 also compares two weeks of summer and winter. According to this figure, the daily quasi-dynamic capacity in winter differs from the annual static capacity in summer.

8. CONCLUSION

The power grid is under pressure to maintain a reliable supply because of constrained budgets and environmental policies. In order to effectively make use of existing transmission lines, it is important to accurately evaluate the line capacity. In this paper, first, the quasi-dynamic scenarios that increase the line capacity were explained. It was shown that by using the quasi-dynamic scenario, one could take advantage of the dynamic method and reduce the challenges caused by this method for the operator.

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