A Cost-Effective Solution for Grid: Data-Driven Dynamic Rating (DDDR) for Grid Transformers

Kumari Nidhi[1], Mrs. Priyanka Maheswari[2]

[1] M. Tech Student, Electrical Engineering Department, RKDF University, Bhopal, M.P.
kumarinidhi1099@gmail.com[1]
[2] Assistant Professor& HOD, Electrical Engineering Department, RKDF University, Bhopal, M.P.
priyankabits4@gmail.com[2]

ABSTRACT

Real-world testing can be done by implementing the DDDR algorithm in a live grid and monitoring its performance over time. This can involve installing sensors to collect real-time data on transformer conditions, load demand, and other relevant parameters. The performance of the DDDR algorithm can then be compared to traditional static transformer ratings to determine its effectiveness in improving grid efficiency and reducing the need for costly upgrades or replacements. Both simulations and real-world testing can provide valuable insights into the performance of the DDDR algorithm and help grid operators make informed decisions about the use of their transformer assets. This paper a performance evaluation of a data-driven dynamic rating (DDDR) algorithm for grid transformers. The DDDR algorithm uses real-time data to dynamically adjust the rating of transformers based on their current operating conditions. The performance of the DDDR algorithm is evaluated through simulations of different grid scenarios using historical data from a real-world grid. The simulations show that the DDDR algorithm can effectively increase the capacity of transformers without compromising their reliability. The algorithm is also able to respond to sudden changes in the grid conditions, such as voltage fluctuations and load variations. The research concludes that the DDDR algorithm can provide a cost-effective solution for grid operators to increase the capacity of transformers and improve the overall efficiency of the grid.

Keywords- Data-driven dynamic rating, grid transformers, real-world testing

1. INTRODUCTION

Transmission line capacity can be significantly increased by using dynamic thermal rating (DTR) depending on actual environmental data. DTR can reduce the inconsistency among electrical use and supply and enhance line usage, both of which have significant economic advantages. By using a lineampacity calculation model based on CIGRE standard, DTR may be calculated. The transmitting lines' ambient environmental factors are important aspects that influence the DTR, but it is also important to consider the uncertainty of the DTR and the discrepancy between the measured value and the true value.

1.1 DYNAMIC THERMAL RATING SYSTEM

For the overhead wires, National Grid & many other transmission utilities typically take a steady seasonal thermally ratings into account. This ratings is a cautious estimate that is almost certainly lower than the real thermal ratings, which varies depending on the weather. The thermodynamic balance between the heat produced inside the conductors & the heat lost by the conducting thru convection & radiation is used to compute the thermal rating.

The factors that have the greatest impact on thermal rating include wind speed, wind direction, conductivity properties, ambient temperature, & overhead line profile. Typically, transmitting companies use conservative values for the important elements to determine the seasonal thermally ratings for the overhead power lines.

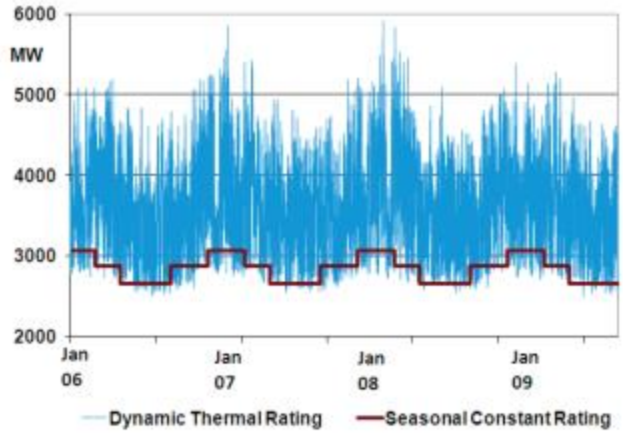

Figure 1.1 Dynamic thermal rating & seasonal constant thermal rating

However, the actual thermal rating may be greater than the constant seasonal ratings when taking into account the actual wind speed & air temperature. The heat balancing equation (1), combined with the hourly temperatures & wind speeds observed in previous years, are used to determine the hourly thermally ratings of the aforementioned transmission line.

2. FEASIBLE REGIONS OF TRANSFORMER LOADINGS

A load profile does not violate the HST limit, if its loadings are located in the yellow area. Important notice should be discussed. The green area in should be considered as the area without accelerated ageing only for the load profiles fully located within the green area. If even a small part of a load profile is located in the yellow area, the green area should not be referred to the area without accelerated ageing. Let us explain why: the circle 2 in Fig. 2.1 shows that even if the load is instantaneously reduced, the temperatures take time to reduce to new steady-state value. Thus, the transient temperature could be still in yellow areas while a loading returned back to the green area.

Moreover, while temperature is reducing to a steady-state value, the ageing will be accelerated since the temperature is still higher than the design temperature. Despite the fact that this interrelation affects the ageing, it does not affect the feasible region of current or HST limit. Therefore, the suggested feasible region is that this interrelation affects the ageing, it does not affect the feasible still valid for current & temperature limitations.

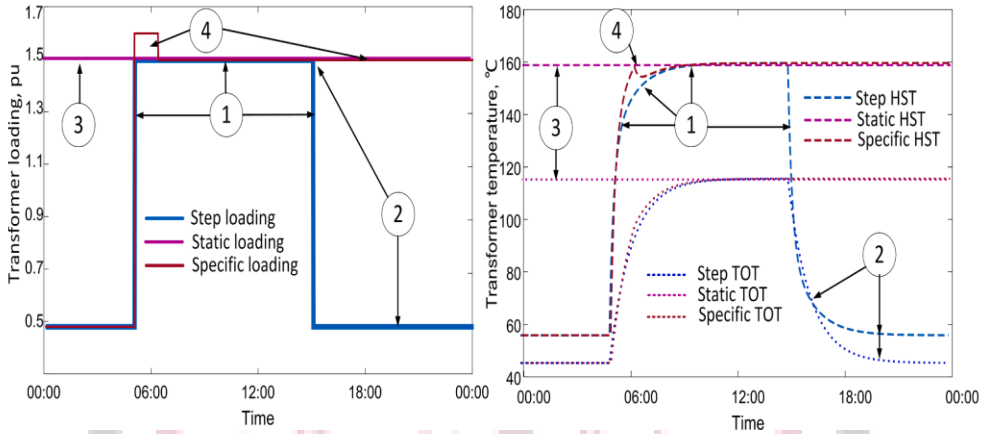

Figure 2.1 Interrelations between transformer loading & temperatures, calculated by IEC thermal model

Another important observation should be discussed. There is a specific load profile(s) (brown line in Fig. 2.1) with the loading higher than steady-state DTR around 06:00 but their transient temperatures still remain below the steady-state temperature (see circle 4). Therefore, we conclude that the feasible region, obtained earlier in the can be actually even higher in terms of loadings. Although we agree with this statement, we note that such a load profile can be obtained only under DSO control (reducing a transformer loading just after its HST reaches its steady state limit). Therefore, such load profiles have the advantage for short-term planning. Thus, we neglect them in the suggested feasible region, which we use for long-term estimation of DTR. Moreover, this neglection actually reduces a feasible region that allows estimating DTR with margin. Summarizing above-mentioned results: all load profiles located in the green area only are always feasible for both normal ageing & current/temperature. In contrast, all load profiles located in the yellow area only are always not feasible for normal ageing but feasible for current/temperature limitations.

3. RESULTS

DTR used together with DER management provides an additional degree of freedom for system operators in power systems scheduling. At the same time, this degree of freedom changes during a year following DTR seasonal variations. Therefore, DTR should be estimated for all current & temperature limitations per month (Fig. 5.4). From Fig. 5.4 we see that dark green bars (DTR based on the design HST) exceed nominal rating of the transformer during almost all months. However, in summer months, such DTR should be set lower than nominal rating to avoid the violation of the design HST. As we said earlier, the dark green bars are a classical example of DTR, studied in many works. However, these works ignore other bars shown in the Fig. 5.4 This leads to very conservative estimation of DTR. In contrast, this work allows determining the part of DTR, which was omitted before.

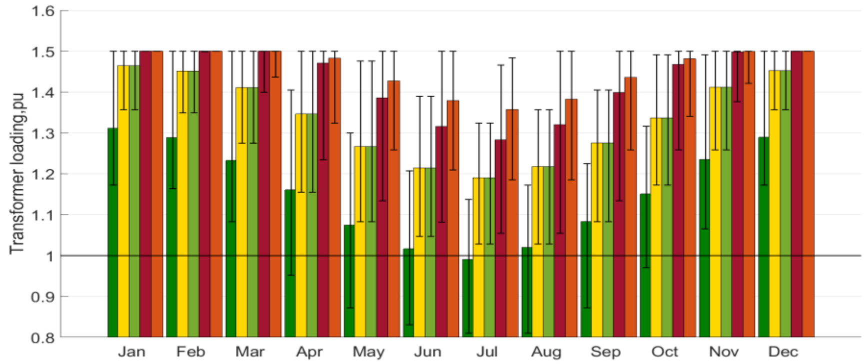

Figure 3.1 Mean DTR with maximum & minimum deviations in each & every month.

We would like to explain some particular bars in Fig. 3.1. For instance, yellow & light green bars are the same in both cities. This means that HST limit = 120 ◦C is always reached before TOT limit (95 ◦C or 105 ℃) in both climates. This happens since Tamb of studied climates is always below than critical Tamb + 45 ◦C . Therefore, HST remains the unique limiting factor for these two current & temperature limitations. Moreover, the reader can notice that red & orange bars do not have any deviations in winter months. This means that the current limit is always reached earlier than temperature limits. Thus, bars, whose loading is equal to 1.5 pu, are current-limited & bars, whose loading is below 1.5 pu are temperature-limited. Therefore, Fig. 3.1 is an example showing how the limiting factor of DTR is shifting between current to temperature during the year. Moreover, Fig. 3.1 represents an example of how different current & temperature limits pre-define the amplitude of DTR.

In addition to DTR amplitude, we estimate DTR duration. The typical DTR duration curves are calculated & presented in Fig. 32. Therefore, Fig. 3.2 shows how different current & temperature limits pre-define the duration of DTR. Where N – a numerical order of y-data (DTR sorted in a descending order). DTR duration in x-axis shows the amount of time (in %) when DTR exceeds the value selected on the duration curve. For instance, the classical DTR (dark green curve) exceeds a nominal rating of a transformer for 88,5% of time & 79% of time. This also means that the classical DTR is below nominal rating for 11.5% & 21% of time in these cities correspondingly. This result correlates with conclusions of many authors, stating that DTR can be below the nominal rating for a short period of time.

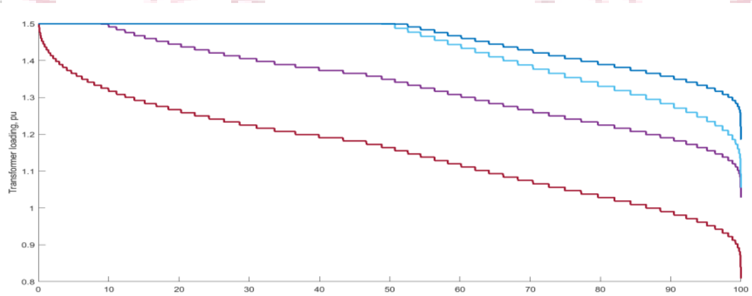

Figure 3.2 DTR duration curves

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