Review

Demand Respond Program and Dynamic Thermal Rating System for Enhanced Power Systems

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Abstract: This paper reviews the development of demand response (DR) and dynamic thermal rating (DTR) system for enhancing the operation and reliability of power system. The advantages and prospect of the DR program are discussed. The case for DTR system is established by comparing it against the traditional static thermal rating (STR) system. Various line monitoring methods and devices required for the implementation of the DTR system are presented. The challenges for deploying the DTR system from the perspective of selecting appropriate transmission lines for DTR deployment, identifying critical spans for deploying DTR sensors, managing the reliability of the DTR system, and the integration of the DTR system with existing and future power systems are discussed. Finally, the two main standards governing the operation of the DTR system, namely the IEEE 738 standard and the CIGRE standard are compared to elucidate the employability of the DTR system.

Keywords: demand respond, dynamic thermal rating system, transmission network, power systems

1. A case for Demand Response

Past studies show that a significant amount of electricity can be saved with proper demand-side management strategies [1]. Therefore, it is one of the motivations to find out what is demand-side management strategy is and how is it being implemented. One way to increase the power transmission line's capacity is through a demand-side management program. There are two paths in electrical demand-side management. The first is through a demand response program, and the second is through implementing an electrical efficiency program. The electrical efficiency program methods effect mostly constant with time, while demand response program effects vary. However, the implementation of an electrical efficiency program usually involves investment cost, while a demand response program involves implementing managerial measures to free up the generating/transmitting capacity by influencing the load demand. Electrical demand response programs focus on how the electrical demand is planned to avoid big variation between peak and low demand. A capital grant or feed-in tariff-based incentive policy were normally suggested to encourage the use of renewable energy to implement electrical efficiency program strategies successfully, but renewable energy equipment installation such as solar panel, wind turbine, etc. were found to be challenging due to many barriers such as cost, renewable source availability, etc. [2].

An electrical demand response program is a tariff or program established to induce lower electricity consumption during peak demand or when grid reliability is jeopardized. There is significant scope for the Electrical demand response program to increase the efficiency and use of electrical system assets such as overhead transmission lines, generators, etc. Demand-side management has been studied since the early 1980s. It can be used as a tool to accomplish different load shaping objectives, such as valley filling, peak clip-ping, load shifting, strategic conservation, strategic load growth and flexible load shape [3]. A study showed that lower energy is required to purchase from the grid due to the electrical demand response program [4]. An overview of multiple electrical demand response programs and their theoretical background was provided by [5] and [6] studied their presence in few countries. A lot of studies are being conducted in the field of electrical demand response program in different categories, which include intelligent appliances [7], energy management systems [8-10], load shifting [11], smart grids [12],[13], power quality [14], comfort optimization [15], demand aggregation [16], integration of renewable energy [17], contracts [18], pricing [19], risk management [20].

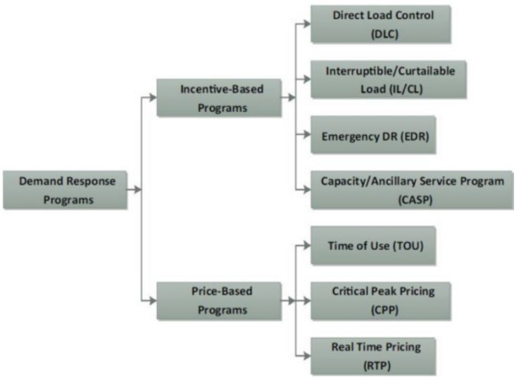


Figure 1. Classification of Demand Response Programs.

Electrical demand response programs are divided into two groups. The first group is incentive base demand response program, while the second type is the price base program [21]. The former targets to reduce customers' energy consumption by providing time-varying or fixed incentives considering power system stress periods, while the latter seeks to motivate customers' participation in altering the consumption patterns with response to time-varying electricity prices [22]. In the early developments of a demand response program, the absence of power generation on the energy demand side causes the demand response program to rely on large industrial loads mostly. Demand response program is applied through two kinds of demand response programs in power system, Incentive-based programs and price-based programs [23]. The incentive base demand response program pays large energy consumers to change their energy consumption patterns by load reduction or shifting. The price-based demand response program motivates consumers to voluntarily adjust their energy consumption through electricity price fluctuation in the power market [24].

Demand response program is one of the well-known programs used extensively to optimize energy systems with other performances economically. Demand response program includes different series of optimization programs [25]. TOU flattens the load curve by shifting some load from peak o off-peak periods, which minimizes the total cost [26].

There are two types of main categories of demand-side management as shown in Fig. 1. First is the static demand-side management program, which aims to equilibrate energy via control of energy consumption. Static demand-side management comprises activities such as advertisements or educations to encourage end-users to change their typical energy consumption pattern without onus, but the complete implementation of these methods purely depends on the customers' volition eventually. Dynamic demand side is the second category of demand-side management. Onus of clients and their participation in integrated resources planning to attain demand-side management goals is required for dynamic side demand management. These methods aim to equilibrate energy via control of efficiency [27].

In conclusion, a demand response program motivates energy consumers to interact with energy suppliers by introducing electricity price or compensation. The demand response program takes advantage of controllable loads to improve the system's power quality during peak demand conditions.

1.1. Demand Response Program with Distributed Energy Resources

Demand response programs had proven to be lower cost and higher efficiency in terms of economy and improvement of power system reliability. With the improvement of intelligent grid technology, communication signals can be sent between utilities and end-user promptly to release demand responses effectively. The advancement of smart grid technologies makes distributed energy resources possible. Distributed energy resources refer to electric power generation resources directly connected to low voltage (LV) or medium voltage (MV) distribution systems [28]. Distributed Energy Resources is generally divided into distributed energy generation and electrical energy storage.

Distributed energy generation includes conventional generation units like micro gas turbines and renewable generation units such as solar photovoltaic and wind. Unlike the complete controllability of conventional generation, renewable energy generation depends mainly on environmental conditions. Renewable energy generation is characterized by uncertainty, volatility and intermittency.

Store electrical energy into a storable source by converting energy from power network to storable source and retrieved in the same form of converted electrical energy whenever needed is called electrical energy storage. Electrical energy storage act as a mitigation plan to ride through when there is a massive change in demand so that power supply will not be interrupted. Stored electrical energy can be applied for peak shading, load shifting and act as a power reserve.

There are two types of electrical energy storage, which is moveable and stationary. Moveable electrical energy storage refers to an electric vehicle that can tie into the power grid. Mechanical, electrical, chemical and thermal electrical energy storage are the three basic types of stationary electrical energy storage.

Coordination of distributed energy generation and electrical energy can mitigate the volatile and intermittent energy problem of renewable energy generation. The integration level of renewable energy can be raised by electrical energy storage. Previous studies show that integrating electrical energy storage and renewable energy generation can bring the integration percentage from 20% to 25% [29].

1.2. Advantages of Distributed Energy Resources

Demand response program has brought much positive influence to the power system. The influences are witnessed in the integration of distributed energy resources; the range of demand has been enlarged. The evolution of smart grid technologies enhances information communication between different parties among power systems, further improving the benefits of distributed energy resources with better integration. In real-world operation, utilities have to pay for long-term reserve just to prepare for significant accidents that rarely occur, which is necessary but uneconomic. Through bilateral contracts and distributed energy resources, some end-users can curtail or postpone their energy consumption when such accidents happen to prevent utilities from paying for long-term reserves to prepare for significant accidents that rarely occur. From the demand side point of use, an electrical consumer may profit by participating in distributed energy resources. The electrical energy consumer can provide the power system with electricity by renewable sources like solar panels and wind turbines. Integrating more renewable energy resources decreases the reliance on fossil fuel power plants at the utility side. The demand-side resources utilized renewable energy instead of high-cost fuel combustion generator on the supply side raise utilization efficiency of the whole power system, which leads to postponement of new infrastructure investment. The postponement of new infrastructure investment can benefit the supplier and ultimately bring the benefits to the demand-side due to the lower cost to produce electricity. Besides, demand sides get better reliability power during peak demand when more users participate in domestic power generation through distributed energy resources.

1.3. Prospect of Distributed Energy Resources

Distributed energy resources have a bright future in the economic and secure system operation for their vast potential. However, the challenges of reliable market frameworks, operation strategies, and the lack of experience still is the biggest threat to distributed energy resources. Although several studies describe the consumer behavior based pricing mechanism, there are still issues in distributed energy resources. Distributed energy resources integration into the demand side changes the power flow from unidirectional to bidirectional results in security and stability issues. Another challenge faced by distributed energy resources is controllable load that may causes inconveniences to the demand side. Demand-side not obeying contract and peak load shifting may cause another demand peaks among some of the significant challenges that distributed energy resources face.

2. Line Rating vs Thermal behavior

Overhead transmission lines are thermally limited. Transmission line capacity had been known to be hugely affected by thermal rating. By truly understanding the relationship of transmission lines with thermal rating, we can exploit the most allowable capacity out of transmission lines without jeopardizing the reliability of the transmission line.

2.1. Types of Overhead Line Thermal Rating

Static thermal rating and dynamic thermal rating are the two types of thermal rating. Static thermal rating (STR) is the rating of a transmission line considering the worst-case scenario of ambient conditions. On the other hand, dynamic thermal rating (DTR) is the rating of a transmission line at the present ambient conditions and typically leads to a higher rating than STR [30]. Utilities have the freedom to determine line rating conditions that they will like to maintain as long as the utilities are responsible for the safety and reliability of their transmission assets.

2.1.1. Static Line Rating

Many utilities still use fixed ratings due to lower initial costs. Fixed ratings have a lower initial cost because there is no need for investment in communication and real-time monitoring equipment [31].

This usually results in the underutilization of transmission conductors, increasing operation costs and preventing their efficient use. Making matters worse, the risk of line overload is not eliminated because the rating assumptions, although conservative but not necessary, represent an actual worst-case scenario. Traditional deterministic line ratings are generally lower than ratings evaluated by probabilistic methods [32]. Most deterministic static thermal rating approaches assume wind direction perpendicular to the conductor, thus assuming maximal convective cooling. Overheating the conductor can occur if the wind blows parallel to the conductor when the transmission conductor is loaded to the total static thermal rating capacity. Nominal thermal rating is a common deterministic rating that depends only on the manufacturer defined conductor. Research results also show that using this static rating method can substantially increase the risk of thermal overload of transmission lines [33].

Deterministic or probabilistic methods establish fixed ratings, to increase the effective throughput of power transmission lines while ensuring adequate safety margins for their operation. Initially, transmission lines were operated based on static thermal ratings (STRs), which were established using deterministic methods based on very conservative assumptions: low wind speed, high solar radiation, and high ambient temperature. The conditions are chosen so that the actual line capacity is almost always higher than the calculated static thermal ratings. The values of static thermal ratings are independent of weather conditions along the transmission line corridor and fixed. Because of the conservative assumptions, deterministic static thermal rating methods are expected to ensure the high safety of transmission line operation. The probabilistic static thermal rating was introduced in 2000. It is a way where a typical meteorological year is used to determine the static thermal rating and has been adopted by many utilities. In this method, weather conditions from weather stations in the area of interest are used with the IEEE 738 standard [34] to calculate the spectrum of conductor maximum current carrying capacity over a year. The cumulative distribution function (CDF) that gives the maximum current carrying capacity from calculations and selected risk tolerance, the static rating, is evaluated as the corresponding quantile. A typical meteorological year is a compilation of weather data for a specific location generated from records covering a period much longer than a year. It is designed to represent the range of weather phenomena for that location while retaining the consistency of annual and long-term averages [35]. A study confirms that the deterministic static thermal rating method ensures higher line operation safety but significantly underutilizes available transmission capacity [35]. The line can be utilized up to 75% of its average available ampacity using probabilistic thermal rating. However, this significantly increases the risk that the line will rise above its operational thermal limit temperature. As a result, uninformed use of probabilistic thermal rating can decrease the useful life of transmission conductors and increase the transmission system failures probabilities causing outages and blackouts. However, it is convenient to perform statistical analysis of essential weather parameters; however, it shows that specific weather data is not appropriate for the direct evaluation of probabilistic thermal rating. Local weather datasets are based on average parameter values and do not consider extreme values. This can lead to overestimation of the transmission line when actual extremes weather occurs [35]. Transmissions lines that pass through the worst weather element with the longest length span are the critical path of a transmission line that can have the minimum load ability [36]. Attempts to operate existing transmission lines nearer to their actual time-varying ampacity resulted in the development of dynamic thermal rating (DTR).

2.1.2. Dynamic Thermal Rating

Calculating the Current-Temperature Relationship of Bare Overhead Conductor model from IEEE 738 standard is the one that widely used for overhead conductor heat balance calculation [37].

From an asset management perspective, stressed transmission conductors can lose tensile strength and dramatically decrease useful transmission lifetime. Construction of new power transmission lines and upgrades to existing lines is the most straightforward solution; however, upgrading or constructing a new plant requires significant capital investments. Moreover, legal, societal and environmental concerns often cause lengthy approval processes for new constructions and upgrades. The transmission capacity of an overhead line is the current ("ampacity") that corresponds to the maximum acceptable temperature of conductors. Ampacity is limited by the performances of the material and phase-to-ground clearance available span by span on the line; the temperature of conductors depends on the current it carries, and local weather conditions; dynamic thermal rating with real-time monitoring methods can unlock the untapped capacity of existing transmission lines without compromising their reliability [38].

Dynamic thermal rating methods monitor weather conditions along the line or the conductor temperature and calculate a steady-state or transient thermal rating. In 1977, Davis proposed using measured meteorological data in real-time to assess the maximum allowable capacity of a transmission line [39]. Real-time line rating is now a well-proven tool to unlock the usable capacity of transmission lines. For example, a statistical weather model is developed using time series with compensation, focusing on wind speed and regression method because wind speed has the most significant influence on the transmission thermal rating weather parameters [40]. However, increases in the equipment and communication costs of dynamic thermal rating systems and the necessity of finding the bottlenecks along the entire transmission line are hampering their widespread adoption. This represents a significant improvement from the traditional Static Thermal Rating (STR), which is based on the worst weather conditions of the considered period of the year; moreover, the static thermal rating does not take into account the considerable thermal time constants of transmission lines (not even more than ten minutes), additional transient capacity can be unlocked from here by fully utilize the authentic dynamic performances of conductors according to the current actual weather conditions.

Dynamic Thermal Rating (DTR) uses weather or monitors the temperatures of conductors and load forecasting to estimate their future trends to determine the actual capacity of a transmission line. By fully utilizing the natural capacity of conductors corresponding to the actual current weather conditions. Dynamic Thermal Rating provides Transmission system operators additional dispatching flexibility and assists transmissions system operators in decision-making to avoid grid congestions, especially in terms of timing required for re-dispatching procedures. For this reason, Dynamic thermal rating is increasingly used to assess the reliable operation of power systems. Recently, the scientific literature has been growing interest in applying probabilistic methods to weather-based dynamic thermal rating procedures to account for meteorological parameters' stochastic nature. Past studies show that the weak point of predicting the transmission line's ampacity for the next hours is the accuracy of weather forecasting [41]. In order to assess the weather forecast error impact on the accuracy of dynamic thermal rating, weather forecasting errors are analyzed. Probability Distribution Function is usually assigned to each meteorological variable to account for the forecasting uncertainty. For example, in a paper [42] the wind speed, wind direction and ambient temperature are random variables with assigned means and standard deviations and the capacity of the line is forecasted using Taylor series expansion of the thermal model for conductors. If with deterministic dynamic thermal rating the capacity of a transmission line is a weather dependent value, with probabilistic dynamic thermal rating, the short-term capacity of a line is described by a time-dependent Probability Distribution Function.

A study in [43] shows that wind convection is the significant cooling contribution to the conductor at low conductor load. However, during high conductor load, convection cooling from wind is less significant as most of the temperature rise is contributed by Joule heating from the conductor current. The same study also found that cooling from solar radiation has a lesser effect when the surrounding is at high wind speed and high conductor temperature conditions. On the other hand, cooling due to heat radiation is most apparent when low wind speed around the line conductor environment. As the environment condition varies along different line span of the transmission system, each line capacity is calculated for each span, and the overall line capacity is determined based on the minimum capacity over all the line spans. Weather data can be collected based on the sensor installed on the transmission tower or generated through numerical model weather to change the line capacity according to weather data variation [35]. Due to the need for planning of electricity generation and transmission ahead, availability of line capacity is desired to be known several hours or a day ahead. Rating forecast helps avoid congestion by making utilities able to make informed decisions to dispatch the generation capacity accordingly through distributed energy resources.

2.2. Dynamic Thermal Rating vs Line Ageing

Usually, Dynamic Line Rating is applied in an hourly manner. The current rating is updated every hour based on real-time information. However, a dynamic line rating system can be scheduled to have different frequencies of the rating update—the number of fretting events that the conductor experiences will decrease as the frequency of the rating decreases. Consequently, the reliability of the power line with a dynamic line rating is increased by lowering the number of possible failure events [44].

As the law of physic and material, we know that reliability always goes down when the age of equipment increases. The Maher study clearly shows that deterioration of failure rates as equipment ages hurts reliability indices. It is vital to consider overhead line age when evaluating reliability for both load points and system indices [45]; research result shows that either a feeder bus is considered repairable or non-repairable components, the failure rate increase directly as feeder bus aged consistently; the studies also show that the failure rate increased sharply after a certain threshold of feeder bus age is reached.

The average expected lifetime of an aluminum conductor steel reinforced (ACSR) overhead line is 46 years for lines operating in heavily polluted environments and 54 years for lines operating in moderately clean or clean environmental conditions [46]. The difference of both conditions lifetime is 14–15 years. Mechanical fatigue and contamination are the most significant negative impact on the conductor's strength. When the temperature of the line changes due to external conditions, the material will experience thermal expansion or thermal shrinkage. In short, the rate at which the material responds to temperature changes. Since the ACSR cables are made of two different materials, the thermal shrinkage rate or expansion is different. The differences in expansion rates cause the formation of cavities between aluminum and steel strands.

After many thermal expansion/shrinkage cycles, the cavities are filled with the surface contaminants of the line, for example, water, dust and metal oxides. Contaminants in between the conductor strands can lead to galvanic corrosion and therefore degrade the overhead line. When a contaminated line experiences thermal shrinkage, the pollution between strands creates additional mechanical stress on the material fitting, leading to the breaking of outer aluminum strands [46]. Once the friction forces act on the metallic conductor surface, it causes wear and tear of the conductor wires due to applied force. This event is called the "fretting event". At the broken conductor strand, the current density increases. This may lead to the line's sag increase locally and reduce the line's additional mechanical stress tolerance [46]. Aluminum Company of America argues further that the difference in creep at higher temperatures is minimal compared to room temperature for ACSR owing to the shifting of stress from the aluminum strands to the steel core when temperature increases. In all aluminum or other single-metal conductors, creep may reach hazardous values at high temperatures under certain conditions of span tension.

2.3. Line Rating Method for Dynamic Thermal Rating

Determining the actual state of the monitored line (e.g. the sag) is one of the key points in determining and using DLR. However, DLR cannot be measured, but it is always derived from the actual line loading and line status (e.g. the sag).

The DLR monitoring equipment is installed single or multiple along the monitored line. A single transmission line may be several kilometers long and may pass different kinds of terrain, geographical locations and varying weather conditions along the line. The location for the DLR monitoring device should be the most critical location along the transmission line so that if the line is secured on this location, it is also secure elsewhere along the line at all times. Regardless of the DLR monitoring method used, it cannot be fully installed at the whole line; therefore, the selection of monitoring equipment locations is very important.

2.3.1. Indirect Line Rating Method and Devices

The indirect method refers to the method that computes the line sag without directly measuring the physical line sag and line temperature. The indirect method is based on the heat transfer between the conductor and the environment and acts accordingly on a sequence of heat losses and heat gains. Any change in the thermal conditions produces a thermal transfer until the conductor reaches thermal equilibrium. This thermal equilibrium is called the heat balance, as shown below:

$$Q_j + Q_s = Q_c + Q_r, \qquad (1)$$

where Q_j and Q_s are the heat gains by the Joule effect and solar radiation, and Q_c and Q_r are the heat losses by cooling and radiation. The inputs of the above equation are the wind speed and direction, the solar radiation, the ambient temperature and the current intensity. Due to the nature of wind variations in time and space, average values are commonly as input for the heat balance equation. These average values are generally available in weather reports. On top of that, a set of conductor parameters must be included as inputs.

Measuring the weather around the line is considered an indirect monitoring method. The system calculates the line rating by using indirect weather conditions method and line ampacity through its program. This method sometimes is called weather dependent line rating. There are multiple researchers addressed this method as stated in reference [39]. There are two capabilities for this weather measurement system. The first capability of this system is the measurements are continuous therefore the real-time line ratings can be updated continuously at typically of 5mins to 1hour frequency. The second capability of the system is its ability to collect weather data to help predict future weather conditions and, therefore, forecast the future line rating. Forecasting of line rating is possible due to weather patterns are seasonal, cyclical nature.

Table I below shows devices that are based on the indirect method.

2.3.2. Direct Line Rating Method and Devices

The direct methods are based on monitoring and observing the limiting element of a power line, the line tension or sag (or temperature in case it would be the limiting element before the tension/sag). The direct methods monitor the line characteristics based on, e.g. the line mechanical tension, the line angle of catenary, the line fundamental frequencies, or line temperature, and the sag is calculated. It should be noted that the measured line temperature is local quantity, and temperature can vary along the line even on short distances. The accuracy and reliability of the direct tension/sag monitoring method accuracy and the method reliability rely on the actual sag monitoring method used. Usually, the direct methods measuring some characteristic of the line to determine the sag are very accurate due to the strong dependent of the monitored feature with the sag.

Tension monitoring device is one of a direct method device. Tension of the conductors are measured using tension monitoring device that is installed at the towers through determine the sag of the overhead conductor [47]. From the data of conductor tension, conductor temperature is able to be computed and later on the transmission line ampacity can be subsequently derived once the temperature value is obtained by using IEEE 738 standard.

The tension monitor's significant merit of monitoring line tension is that it considers the net total effects of external loading onto the line. The drawback of a direct line monitor is that the transmission lines are required to be modify during maintenance and installations therefore causes power outage [47]. Measuring the line sag is another way to measure line tension. The advantage of sag monitor over tension monitor is that it does not need to be install on the transmission line whereas the tension monitor that required to install on the transmission line. The advantage of sag monitor system is that it does not interrupt power transmission line for the maintenance and installation of the sag monitor. Multiple laser beams are installed at lower part of transmission line point to monitor several lowest points of the conductors. The transmission line sag is determined through these laser beams.

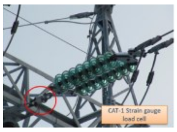
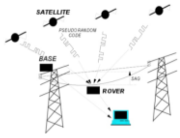
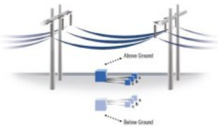
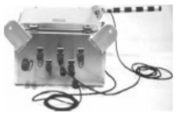
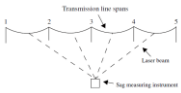
Table I: List of indirect method devices

Device	Function/characteristic

Sensor for weather monitoring 	The weather monitoring system consists of sensors for ambient air temperature ,solar radiation intensity, wind angle, wind speed, and etc. The device are typically mounted on a transmission tower.
Thermal rate/Conductor replica 	The Thermalrate system is used to evaluate weather conditions. This system does not required modification of power lines, and the evaluation results are used on the actual conductor. They are installed near to the actual conductor.

Besides sag monitoring, monitoring of conductor operating temperature is part of the direct monitoring method. Based on IEEE and CIGRE standards, conductor temperature is required for the heat balance equation. Therefore, a temperature monitoring system is installed to work along with weather measurement sensors. According to Davis, installing of meteorological sensors and conductor temperature sensor at critical locations along the power lines is required for DTR system to measure the conductor temperature and monitor the weather conditions [39]. Some example of conductor temperature monitoring system conventional thermal sensors are thermistor, real-time spot measurement devices and thermocouple. Non-contact thermal sensors and infrared based thermal sensor are also available where sensors pick up conductor temperature when conductor is energized [48]. Integrating fibre optic distributed temperature sensor (FODTS) inside the core of the power is another new way of conductor temperature measurement method. Instead of fixed at one point only, the integrated fibre optic thermal sensors distributed along the line by using a optical time-domain reflectometry (OTDR) technique to measure the temperature therefore integrating fibre optic temperature sensor are more accurate. On top of that, the measurement information can be send to the control centre using this same fibre optic cable. With such advantage, the work for communication tools installation and investment can be avoided. Table II below shows some of the direct means of measurements sensors.

Table II: List of direct method devices

Device	Functions/characteristics
Power doughnut 	This self powered power doughnuts can be easily installed by clamping it into line to use for determine conductor sag, conductor temperature, ground voltage and conductor inclination to determine line tension. The device are powered directly by the energized conductor's electromagnetic field
Power line sensor 	This device is also self powered as power doughnut. Principally, usage of this device is to measure conductor temperature, and however, it measures sag and weather conditions with an additional integrated sensor.
CAT1 	The CAT-1 load cells are mounted on the dead-end structure of a power line to measure the tension of the line suspension section. The sag on the suspension section spans is determined by the conductor tension once the installed equipment is calibrated. DLR is determined based on IEEE and optionally the CIGRE methods
Inclination monitor 	The angle between the conductor and its horizontal position is measured to indicate sag.
Global positioning system (GPS) 	Measure conductor sag using differential GPS technology.
Resistive wire	The electromagnetic field generated current in a high resistance grounded wire is measured to determine the sag of the conductor where resistive meter is installed nearby.
Video Sagometer 	It is typically install on the conductors' supporting tower to provide a conductor sag measurement based on video based information.
Promethean devises RT-TLM 	The sensor is placed underground below the monitored line to estimate the ampacity. However, the exact location of the sensor unit is not critical (within 100 ft. from the cable span nadir). Ampacity estimation of the equipment is consistent with the IEEE Standard 738-1993.
Tension monitor 	The tension of the conductor are measured by the device and converts it to its temperature. The combined effect of wind, solar heating and ambient air temperature are used to measure the conductor tension
Laser meter 	lowest point of the conductor is pointed by laser beam to measure the sagging level.
Ampacimon 	Ampacimon smart sensor module is attached directly to an overhead power line anywhere on the span. It analyses conductor vibrations and identifies the fundamental frequencies of the span. The sag can be determined from it alongside gravity (constant) being the only additional parameter that may be needed.

2.3.3. Comparison between Direct and Indirect Method

A direct method such as weather monitoring is easier to install, cheaper to maintain and does not require unique calibration due to its simplicity. The indirect method is very reliable for low load-lines. However, the weather monitoring method is less accurate to represent the condition of the entire power line because the power line has multiple spans that cut across a few areas with different weather conditions. Compared to weather monitoring, sag or tension monitoring can be more accurate in representing the entire power line condition as sag of the line considers the whole power line condition. A direct method such as sag monitoring requires field data for analysis to determine the transmission line ampacity. The Sag monitoring method may project significant errors when a line is lowly loaded due to a minimal sag on the transmission line. In comparison, the direct method seems more accurate as it measures the actual condition of the transmission line to determine the line capacity, while the indirect method determine the transmission line capacity base on surrounding data and the assumption relationship between surrounding condition and line capacity.

2.4. Challenges for Dynamic Thermal Rating

2.4.1. Transmission Line Selection for Dynamic Thermal Rating

Lightly loaded lines are hard to measure accurately by monitoring systems making dynamic thermal rating useless in lightly loaded lines. Dynamic thermal rating is usually implemented on historically proven congested lines. Another selection criteria for dynamic thermal rating is the length of the transmission line. Due to the nature of long transmission lines are limited mainly by voltage limit, and short transmissions are limited mainly by thermal limit, the dynamic thermal rating is implemented on shorter transmission lines rather than a long transmission line [49].

2.4.2. Identifying Critical Spans

Along the length of the line, Conductor temperature varies due to variations of the wind. Transmission line ampacity is determined based on the line segment that receives the slightest cooling. This line-span with the slightest cooling is referred to as a critical span. Within a transmission line, there can be few critical spans [36]. Therefore, determining how many devices are required and where to monitor all crucial line spans is a big challenge for dynamic thermal rating system implementation. The effective wind speed at each line-span is the primary consideration for installing monitoring devices on the transmission line.

2.4.3. Reliability of Dynamic Thermal Rating

As promising as a dynamic thermal rating system is, there are challenges in the reliability of dynamic thermal rating performance. Firstly, varying weather makes it hard to determine the weather condition accurately. For example, it is hard to model during low wind conditions. The second challenge to dynamic thermal rating reliability is device inaccuracy and model inaccuracy. Examples of model inaccuracy are mathematic rating model error, conductor data error, topological data error and non-linear behavior of conductor. Thirdly, the dynamic thermal rating instrument itself or the communication system may malfunction, causing a problem in dynamic thermal rating system reliability. Even with the functioning dynamic thermal rating instruments, error of sampling interval setting may cause an error in the dynamic thermal rating system. Lastly, an insufficient number of measurements along a long line also risks an unreliable dynamic thermal rating system.

Some of the solutions to improve dynamic thermal rating system reliability are installing multiple combined monitoring and verification systems such as sag with clearance monitoring system, weather station combined with video sagometer and live weather data for weather forecast data. With the combination of multiple monitoring systems, the error of dynamic thermal rating systems can be minimized to improve its reliability. Another way to improve the dynamic thermal rating reliability is through modelling of the measurement uncertainties. Fuzzy logic, mathematically modelling, and neural networks are examples of modelling that have been implemented to increase the reliability of dynamic thermal rating systems [50].

2.4.4. Integration of Dynamic Thermal Rating System into System Operation

Even though utilities can benefit from a dynamic thermal rating system, the volatile nature of dynamic rating and challenging to predict rating make utilities slow in adopting dynamic thermal rating system. Many utilities do not accept the challenges of dynamic thermal rating systems because most of them are concerned more about the safety and reliability of power systems rather than economic benefits by reducing line congestion. Utilities are more likely to follow the conservative static thermal rating for the line and construct new infrastructure to reduce line congestion than apply the dynamic thermal rating system to reduce congestion because utilities can pass the infrastructure cost through electricity tariff to the demand side. Thus, utilities are less motivated to remove the constraint of line congestion with a dynamic thermal rating system. Besides, utility lack of interest in adopting dynamic thermal rating into their system is due to lack of effective load reduction method to handle occasional unfavorable periods. Lastly, the difficulty in quantifying the financial benefits of dynamic thermal rating due to the highly volatile nature of line congestion makes it harder for the utility side to adopt the dynamic thermal rating system.

2.5. Comparison between IEEE and CIGRE Standards

2.5.1. IEEE vs CIGRE Joule Heating

There is a distinction between the joule heating effects of homogeneous and non-homogeneous conductor in the CIGRE standard. This distinction is not recognised in the IEEE standard although it is mentioned that there is a need to do this.The IEEE standard the recognized skin effects of non-homogeneous conductor but not in the CIGRE standard. The reduction in joule heating due to the absence of skin effect can range in between 0% and 3% depending on the the ampacity rating being evaluated and number of wire layers.

2.5.2. IEEE vs CIGRE Solar Heating

The relative position of the sun and the conductor are the major factors that influence solar heating. On the other hand, the solar declination (height of the sun depending on the day of the year), hour angle (position of the sun depending on day time) and latitude of the line make up the relative position. Until January 2007, the IEEE standard 738 relies on tabulated values presented for solar heating. Specific days of a year (June 10 and July 3), hours of a day (10 am, 12noon and 2 pm) are use to determine the tabular values, and this tabular values are for the earth's northern hemisphere application. These conditions restricted the application of the IEEE standard 738 only to those location in the region of the northern hemisphere of the earth. Up till the date of January 2007, CIGRE standard offers more flexibility for determination of solar heating calculation. Due to the IEEE standard limitation, the IEEE committee change its standard by using new approach to replaces tabular values with formulas commensurate with the CIGRE standard flexibility. Nonetheless, the differences in the methodologies used for CIGRE and IEEE standard 738 for solar heating calculation remain obvious.

On top of direct solar radiation consideration, IEEE standard 738 makes adjustments to the intensity of solar based on the ambient atmospheric conditions. Industrial or clear atmosphere are the two condition that being considered by IEEE standard 738. Industrial atmospheric conditions will have lesser solar intensity than clear conditions due to the air pollutants and particles. On the other side, CIGRE standard takes more parameters into consideration such as: diffuse radiation, direct radiation and reflected radiation. Even though CIGRE does not consider air quality but CIGRE considers different types of ground surfaces effects, which greatly influence the reflected radiation calculation. Due CIGRE method required solar meters that are hard to maintain and high cost of solar meters, an alternative solar heating calculation is offered by CIGRE.

Both IEEE and CIGRE standards agree that the increase in the altitude above sea level causes solar intensity to increase. However, there is a little difference between the IEEE and CIGRE standards when considering solar heating. IEEE standard assume same increment throughout the yearly season. On the other hand, CIGRE standard usually gives 10% to 15% higher solar heating than the IEEE standard.

2.5.3. IEEE vs CIGRE Convective Cooling

Either CIGRE or IEEE standards, the convective cooling is differentiated into without wind or by wind.

On the other hand, CIGRE standard only uses a single formula for calculating either natural or forced convection cooling. To differentiate these two types of convective cooling, different formulas and techniques as mentioned in section2.5.3.3 is used to varied the Nusselt number. In forced convection, high wind speed ($>0.5m/s$) will have high Nusselt number, and low Nusset numbers are used for wind speed ($<0.5m/s$) scenario as shown previously.

2.5.4. IEEE vs CIGRE Radiative Cooling

The CIGRE and IEEE standards determine the radiative cooling by using formula. Both the CIGRE and IEEE standards have quite similar radiative cooling value even they are calculated with different formula because radiative cooling only contribute to a small parts of the total heat loss.

3. Conclusion

This paper has reviewed the technology of DR and DTR system for enhancing the reliability and operation of power system. The study can serve as a platform from which prospective power system researchers can read and catch up on the knowledge of the two mentioned technologies. Development updates of the two state-of-the-arts are also presented.

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