Postprint of a New Adaptive Transformer Loading Rate Algorithm for Power Grid Monitoring Systems

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Abstract

In the centralized monitoring mode of power grids, the traditional load rate calculation method employed for transformer load rate monitoring is subject to the correctness of telemetry sampling from medium- and low-voltage side switches. This paper leverages network topology analysis from the dispatching technical support system, introduces switch status parameters and main transformer status parameters, and proposes an adaptive load rate algorithm for main transformers. Simulation verification demonstrates that the proposed method can accurately reflect transformer load rate while remaining unaffected by the correctness of telemetry sampling from medium- and low-voltage side switches, which holds significant importance for scientific dispatching and refined monitoring.

Full Text

A New Adaptive Load Rate Algorithm for Transformers in Power Grid Monitoring Systems

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Abstract

Under the centralized monitoring model for power grids, traditional transformer load rate calculation methods are affected by the accuracy of telemetry sampling from medium- and low-voltage side circuit breakers. This paper proposes a new adaptive load rate algorithm for main transformers by leveraging network topology analysis from the dispatching technical support system and introducing switch state parameters and main transformer state parameters. Simulation verification demonstrates that this method correctly reflects transformer load rates without being influenced by telemetry sampling errors on the medium- and low-voltage sides. The approach is significant for scientific dispatching and refined monitoring.

Keywords: Power grid monitoring, Load rate, Adaptive

1 Introduction

As power grid operations continue to expand, the integration of dispatching and monitoring has entered a new phase [1-3]. Power grid monitoring constitutes a critical component of the "Grand Operation" system, encompassing not only basic grid operation surveillance but also signal analysis and processing [4-8], remote switching operations, accident handling, new equipment commissioning and acceptance, online monitoring of transmission equipment status, and industrial video-assisted surveillance [9-12]. These evolving responsibilities present new challenges for monitoring operators and demand higher intelligence in information screening and processing.

Transformer load rate monitoring represents a key focus in daily grid surveillance. However, the reliability of traditional load rate calculations is constrained by field equipment reliability, including sampling devices, measurement and control units, remote terminal units, and dispatching data networks. Under heavy monitoring workloads, mismatched or erroneous real-time data caused by equipment anomalies often go unnoticed. This is particularly critical during peak summer load periods, when accurate main transformer load rates are essential for monitoring power supply reliability. Incorrect telemetry data (e.g., reduced magnitude values) can cause heavily loaded transformers to display artificially low load rates, leading monitoring personnel to overlook actual overload conditions, delay necessary actions, and potentially cause transformer tripping or damage to critical equipment.

The adaptive transformer load rate algorithm proposed in this paper can obtain correct main transformer load rates even when medium- and low-voltage side circuit breaker telemetry values are incorrect. By comparing results with traditional calculations, the algorithm reveals hidden telemetry defects, providing crucial evidence for defect elimination.

The D5000 intelligent dispatching technical support system, adopted by all dispatching agencies of the State Grid Corporation, elevates traditional switch- and measurement-oriented monitoring to comprehensive equipment status monitoring by integrating real-time field data with grid models and topology connections. This system provides dispatchers and monitoring personnel with device-based information such as unit startup/shutdown, line energization/outage, line overload, high-voltage reactor switching, static compensator switching, transformer energization/outage or charging, transformer overload, and busbar energization/outage. The functional structure of the D5000 system is shown in Figure 1 [Figure 1: see original paper].

For the internal bridge connection substation illustrated in Figure 2 [Figure 2: see original paper], traditional three-winding transformer load rate calculation obtains the apparent power by summing active and reactive telemetry values from the medium- and low-voltage sides. This algorithm excludes transformer losses, as they constitute a small proportion of the total apparent power and have minimal impact on load rate calculations for real-time monitoring applications.

2 Traditional Main Transformer Load Rate Calculation

In the D5000 system, the load rate for the #1 main transformer in Figure 2 is calculated as:

$$(\%) = (P \; + P \;)^2 + (Q \; + Q \;)^2$$

The load rate for the #2 main transformer is:

$$(\%) = (P \; + P \;)^2 + (Q \; + Q \;)^2$$

As evident from Figure 2 and the equations above, the reliability of the #1 transformer load rate directly depends on the accuracy of P , P , Q , and Q telemetry sampling. Once telemetry sampling anomalies or data freezing occur at the medium- or low-voltage side circuit breakers, the #1 main transformer load rate becomes unreliable. Under the centralized monitoring model for regional grids, secondary equipment quality varies significantly across county-level 110kV substations, with some equipment severely aged, leading to frequent telemetry device anomalies. Since telemetry sampling abnormalities do not trigger corresponding light indicators or alarm messages, and given the large number of monitored substations, monitoring personnel cannot promptly detect telemetry defects, creating hidden hazards for potential accidents.

3 Adaptive Load Rate Calculation Method for Transformers

As shown in Figure 3 [Figure 3: see original paper], the 110kV Longxing substation in the Shijiazhuang area uses an internal bridge connection with three voltage levels: 110kV, 35kV, and 10kV. The apparent power of incoming line 1 is S , incoming line 2 is S , the 110kV Bus Section 1 voltage is U , the 110kV Bus Section 2 voltage is U , and the sectional breaker a1 apparent power is S .

For internal bridge connection substations, the 110kV side operating modes are listed in Table 1 . The modes include: (a) normal operation, (b) single main transformer 1, (c) single main transformer 2, (d) single line 1, (e) single line 2, (f) single line with single main transformer 11, (g) single line with single main transformer 12, (h) single line with single main transformer 21, and (i) single line with single main transformer 22.

Table 1 State Parameters for Internal Bridge Connection

The apparent powers S # and S # of the two main transformers under different operating modes can be derived from the 110kV side parameters:

Introduce the power flow matrix: S = [S S]

The switch state matrix is: A = [A A A]

The main transformer state matrix is: B = [B # B #]

Where the switch state parameter is: A = 1 (switch i-j is closed)
A = 0 (switch i-j is open)

The main transformer state parameter is: B # = 1 (main transformer i# is in service)
B # = 0 (main transformer i# is out of service)

The sectional breaker a1 apparent power is: S = U I

Let S = S + S . The main transformer apparent power calculation formulas for different operating modes are:

For normal operation, single main transformer, and single line with single main transformer modes: S # = B #S + (1 - B #)S
S # = B #S + (1 - B #)S

For single line mode: S # = S - S
S # = S

For single line mode (alternative configuration): S # = S
S # = S - S

For single line with single main transformer modes: S # = S , S # = 0
S # = 0, S # = S
S # = S , S # = 0
S # = 0, S # = S

This analysis demonstrates that substation operating mode identification constitutes a critical component of the adaptive load rate algorithm. The D5000 dispatching technical support system performs network topology analysis to obtain circuit breaker status information and determine the current substation operating mode. Based on the identified mode, the algorithm automatically selects the appropriate load rate calculation formula. The flowchart of the adaptive load rate algorithm is shown in Figure 4 [Figure 4: see original paper].

4 Case Study

This paper uses the 110kV Fucun substation in the Shijiazhuang power grid as a simulation model. The substation employs an internal bridge connection with two main transformers, each rated at 50 MV·A. The 110kV incoming lines are the Zhongfu Line 166 and the Zhonggao 1 Line T-connection 167, which supply 110kV Bus Sections 2 and 3 respectively. Under normal operation, the sectional breakers 102, 302, and 502 are in hot standby. Figure 5 [Figure 5: see original paper] shows a simplified one-line diagram of the Fucun substation in the D5000 system.

When the 110kV Zhongfu line is under maintenance, the Zhonggao 1 Line T-connection 167 supplies both #2 and #3 main transformers, with breaker 102 in service. The 313 breaker for #3 main transformer exhibits sampling anomalies, causing mismatches between the total telemetry values of the 35kV Section 3 bus branches and the 313 breaker telemetry values.

Using the traditional load rate calculation method: $P = P + P$
$Q = Q + Q$
$(\%) = \sqrt{}(P^2 + Q^2) / S\_N$

Using the adaptive load rate algorithm, automatic identification of the substation operating mode through Figure 4 yields: $\Delta P = P \quad A + P (A - A)$
$\Delta Q = Q \quad A + Q (A - A)$
$^- (\%) = \sqrt{}(\Delta P^2 + \Delta Q^2) / S\_N$

The comparison between the two load rate algorithms is presented in Table 2 .

Table 2 Comparison of Two Load Rate Algorithms

#3 Main Transformer Load Rate (%)	Traditional Algorithm	Adaptive Algorithm

Table 2 demonstrates that when medium- and low-voltage side breaker sampling anomalies occur, the traditional algorithm fails to accurately reflect the main transformer loading condition. Particularly during heavy loading, it cannot satisfy overload alarm requirements. The #3 main transformer is approaching full load and requires load transfer measures, yet the traditional method shows severely underestimated values, preventing overload alarm messages from appearing in the monitoring system and affecting the timing of dispatch load transfers. The adaptive algorithm, through comparative calculations using 110kV side breaker telemetry values, accurately reflects the main transformer apparent power condition, providing crucial support for load monitoring and power flow control with reliability and adaptability.

When all substation sampling devices operate normally, the Fucun substation telemetry data is shown in Figure 6 [Figure 6: see original paper]. The #3 main transformer load rates calculated by both methods are compared in Table 3 .

Table 3 Comparison of Two Load Rate Algorithms (Normal Operation)

#3 Main Transformer Load Rate (%)	Traditional Algorithm	Adaptive Algorithm

Under normal sampling conditions, the traditional and adaptive load rate algorithms produce results that differ only by the transformer loss value, which has minimal impact on the outcome. Both methods yield similar results and correctly reflect the main transformer load rate.

5 Conclusion

This paper analyzes the limitations of traditional transformer load rate calculation methods in power grid monitoring systems. Based on a comprehensive summary of internal bridge substation operating modes, the paper introduces switch and main transformer state parameters and develops a systematic adaptive load rate calculation methodology with a clear algorithm flow. Simulation verification confirms the reliability and adaptability of the proposed method.

In practical power grid monitoring applications, the traditional and adaptive load rate calculation methods should be combined. The traditional method' s alarm displays and load rate limit violation windows should be retained, while an additional adaptive main transformer load rate monitoring platform should be implemented. By automatically comparing results from both methods, a visual comparative display platform can be created. This approach not only improves the efficiency of main transformer overload monitoring but also facilitates easier detection of telemetry sampling anomalies on medium- and low-voltage sides, providing valuable reference data for future equipment defect elimination.

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