A Novel Power-frequency Variation Protection Strategy Based on System Setting Impedance

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ABSTRACT

By analyzing the protection principle of power-frequency variation and the influence of the current transformer saturation, this paper proposes a novel protection strategy based on power-frequency variation of the maximum and minimum setting impedance of the system to cope with the transformer saturation. Typical saturation cases of transmission line are analyzed and the simulation results based on PSCAD indicate that the proposed strategy could guarantee the correct operation of protection, which maintains the original operation characteristics of power-frequency variation protection.

KEYWORDS

System impedance, power-frequency variation, current transformer, saturation.

INTRODUCTION

The problem of electromagnetic transformer saturation has been one of the most important research points in the field of relay protection for a long time [1, 2]. When the saturation occurs, the sampling current of the second side of transformer will be distorted leading to the disoperation of protection based on current value. There has been some research results about the identification of transformer saturation, For example, the harmonic component of sampling current is considered to identify the transformer saturation [3], but this method is vulnerable to the harmonic of system fault current. The virtual impedance calculated by voltage and current signal is proposed to determine whether the saturation occurs [4]. But this method is limited by the reasonability of impedance model, and complex calculation is needed. Some other methods lack the feasibility in practical application.
The power-frequency variable protection is of high accuracy and fast operation speed compared to traditional distance protection [5]. However, there still exists some problems such as the influence of transformer saturation. In this paper, a protection strategy based on system setting impedance is proposed to eliminate the influence of current transformer saturation. The system impedance under fault condition is replaced with the impedance under maximum and minimum system operation mode, which is combined with traditional power-frequency variation protection criterion. The new criterion could identify the fault accurately to guarantee the correct operation of protection.

OPERATION CHARACTERISTIC OF POWER-FREQUENCY VARIATION AND THE INFLUENCE OF CURRENT TRANSFORMER SATURATION

Suppose $\Delta \hat{U}$ and $\Delta \hat{i}$ are the power-frequency components of $\Delta U$ and $\Delta I$, the operation voltage of power-frequency variation impedance relay $\Delta U_{op}$ is calculated as:

$$
\Delta U_{op} = \Delta \hat{U} - \Delta \hat{i} Z_{set} = -\Delta \hat{i} Z_s - \Delta \hat{i} Z_{set} = -\Delta \hat{i} (Z_{set} + Z_s)
$$

(1)

Where $Z_{set}$ and $Z_s$ are the setting and system impedance, $\Delta \hat{U}$ and $\Delta \hat{i}$ are the power-frequency voltage and current where the protection relay is installed. In practical application, the product of a reliability coefficient $k_{rel}$ and the rated voltage $U_n$ is set as protection operation threshold, and is calculated as:

$$
\Delta U_{opm} = k_{rel} U_n
$$

(2)

However, the current transformer saturation can lead to the decrease of current amplitude. In formula (1), when the saturation of current transformer corresponding to impedance relay occurs, the amplitude of $\Delta \hat{i}$ will decrease. Because the setting impedance $Z_{set}$ is constant, the amplitude of $\Delta \hat{i} \times Z_{set}$ will decrease, and the amplitude of $\Delta U_{op}$ will decrease accordingly.
As shown in Fig. 1, when the saturation of current transformer occurs, the amplitude of $\Delta U_{op}$ will decrease and tend to $\Delta U$ with the increase of saturation degree. In this process, the practical amplitude of $\Delta U_{op}$ is $\Delta U_{op}$, the practical protection scope changes to c, while the fault occurs at b and the initial protection setting scope is a. If $\Delta U_{op} < \Delta U_{op}'$, it can be seen that $c < b < a$. In this case, the practical protection scope will reduce caused by transformer saturation, and the practical location of the fault cannot be covered. Therefore, power-frequency variation protection will fail to operate.

**POWER-FREQUENCY VARIATION PROTECTION STRATEGY**

Suppose that the external fault $F_2$ and $F_3$ will not lead to the saturation of current transformer installed at M side, and only when the internal fault $F_1$ occurs and $MF_1 / MN < 0.1$, the saturation of current transformer will occur. The protection scope $MF_1$ is called the saturation risk scope.

In order to avoid the wrong protection decision of power-frequency protection when transformer saturation occurs, a strategy based on system setting impedance is proposed. For the traditional power-frequency protection, formula (1) could be rewritten as:

$$\Delta U_{op} = \Delta U - \Delta I Z_{set} = \Delta U - (-\Delta U / Z_{set})Z_{set}$$

(3)

Where the maximum and minimum of system setting impedance $Z_{set}$ are denoted as $Z_{max}$ and $Z_{min}$, which correspond to the maximum and minimum system operation mode respectively, and

$$-\Delta U / Z_{max} \leq -\Delta U / Z \leq -\Delta U / Z_{min}$$

(4)

New criterion (3) indicates that when $Z_{set}$ is replaced by $Z_{max}$, the amplitude of $\Delta I$ will decrease, which is equivalent to the saturation of current transformer, and the protection scope will also decrease; when $Z_{set}$ is replaced by $Z_{min}$, the amplitude of $\Delta I$ will increase, which is inverse to the saturation of current transformer, and the protection scope will also increase.

As shown in Fig. 3, $l_1$ is the total length of protected line, $l_2$ is the setting protection scope of protected line, and $l_3$ is the aforementioned saturation risk scope set as $l_3 = 0.1l_1$. Suppose that the fault point X is located within saturation risk scope $Ma$, and the system impedance is set as $Z_{real}$. According to the traditional
power-frequency variation criterion, transformer saturation could lead to the decrease of the amplitude of $\Delta \gamma$, and the protection will fail to operate.

If $Z_s = Z_{\text{min}} \leq Z_{\text{rel}}$, then there will be $|\Delta \hat{U}/Z_{\text{rel}}| \leq |\Delta \hat{U}/Z_{\text{min}}|$. Different from the transformer saturation, the protection scope will expand to Me, and protection will operate reliably. On the contrary, if $Z_s = Z_{\text{max}} \geq Z_{\text{rel}}$, then there will be $|\Delta \hat{U}/Z_{\text{max}}| \leq |\Delta \hat{U}/Z_{\text{rel}}|$, which corresponds to the transformer saturation, and the protection scope will reduce to Md. In general, system impedance under different operation mode is not that distinguished, so it can still be satisfied that $M_X < M_a < M_d$, and the protection will operate reliably.

Suppose that the fault point X is located within the scope a with no transformer saturation. The traditional power-frequency variation protection will operate reliably. If $Z_s = Z_{\text{min}} \leq Z_{\text{rel}}$, the protection scope will expand and protection will also operate reliably. However, when $Z_s = Z_{\text{max}} \geq Z_{\text{rel}}$, the protection scope will reduce to Md. Apparently, if XQ tend to be 0, there will be $M_X > M_d$, and the protection will fail to operate.

Suppose that the fault point X is located within the scope QN out of protection setting scope. Similarly, the traditional power-frequency variation protection will operate reliably. If $Z_s = Z_{\text{max}} \geq Z_{\text{rel}}$, the protection scope will reduce to Md. However, if $Z_s = Z_{\text{min}} \leq Z_{\text{rel}}$, the protection scope will expand to Me. Obviously, there could be $M_Q < M_X < M_e$, and the protection will misoperate.

In conclusion, the process of power-frequency variation protection strategy based on system setting impedance is as follows: (1) calculate the system parameters and the maximum and minimum system impedance $Z_{\text{max}}$ and $Z_{\text{min}}$; (2) calculate system setting impedance according to formula (1) and formula (3) when $Z_s = Z_{\text{max}}$ and $Z_s = Z_{\text{min}}$, the setting result (operation or non-operation) is calculated as R1, R2 and R3 respectively; (3) if R2 equals to R3, which means the fault point occurs close to My side where impedance relay protection is installed, the protection setting result is reliable based on criterion (3), and protection operates according to R2 or R3; (4) if R2 and R3 are not equal, which means the fault point occurs close to the terminal of protection setting scope, the transformer saturation is unlikely to occur, and the protection eventually operates according to R1.

**SIMULATION**

A model of a 220kV transmission line with total length L of 200km is built in PSCAD, as shown in Fig. 2. The protection operation threshold is set as $\Delta U_{\text{opm}} = 0.97U_n / \sqrt{3} = 123kV$ where $U_n$ represents the 220kV line voltage. In the simulation, the variation amplitude of system impedance is set as $\pm 50\%$, the simulation duration is set as 2s, and the fault is set as metallic phase-A-to-ground at 1s.
Figure 3. Power-frequency variation protection scope.

Figure 4. Different setting calculation result comparison.

(1) Suppose that the fault point is located at $MF = 0.05L$ and the extreme transformer saturation occurs after the fault. Based on protection setting calculation, the variation of $|\Delta U_{op}|$ is shown in Fig. 4(a). It can be seen that the protection will fail to operate according to the setting value based on current, but the protection will operate reliably according to the setting result based on $Z_{max}$ and $Z_{min}$. According to proposed strategy, the calculation results of R2 and R3 are both equal to operation. Therefore, the protection makes the right decision.

(2) Suppose that the fault point is located at $MF = 0.8L$ and there is no transformer saturation. Based on protection setting calculation, the variation of $|\Delta U_{op}|$ is shown in Fig. 4(b). According to proposed strategy, the calculation results of R2 and R3 are not equal. Therefore, the setting result R1 based on the current should be adopted, and the protection will operate.

(3) Suppose that the fault point is located at $MF = 0.95L$ out of the protection scope and there is no transformer saturation. The variation of $|\Delta U_{op}|$ is shown in Fig. 4(c). Similarly, the calculation results of R2 and R3 are not equal. Therefore, the setting result R1 based on the current should be adopted, and the protection will not operate. Therefore, the protection makes the right decision.
SUMMARY

For the protection principle of traditional power-frequency variation, according to the analysis of the influence of current transformer saturation, this paper proposes an improved protection strategy based on system setting impedance to deal with transformer saturation. The model of 220kV transmission line built in PSCAD verifies the feasibility of the proposed strategy.

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