Scientific Research

Fault Analysis and Modeling for the High Voltage Electric Power Metering System

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Abstract: A network fault model for the high voltage electric power metering system is proposed in this paper. Firstly, the closed relations between short circuit of the primary/ secondary side of CT and the network impedance are drawn from the circuit parameter analysis of the metering system under the different loads. Secondly, an auxiliary circuit is designed, used to detect the impedance changes from which the fault model is derived. Finally, Simulations are performed on the model to demonstrate the efficiency of the fault detection model.

Keywords: high voltage electric power metering system; current transformer; fault analysis; modeling

1 Introduction

High voltage electric power metering system is composed of current transformer、voltage transformer、three-phase electric energy meter and leads which are used to connect transformers with three-phase electric energy meter. Faults taking place in any one of these components will bring metering inaccuracy, so much as palsy of the whole high voltage metering system. During the recent years，many scholars or technicians analyzed and calculated some faults which can lead to metering inaccuracy[1−3]. These faults include one phase or between phases short circuit of circuit loop and opposing connection of current transformer and so on. These researches have a common point, that is we have known and analyzed some fault happened. However, we want to know real time the type of metering system fault in practice. So model building is a necessary factor of update detection, which can make sure real time the type of metering system fault. Based on this idea, taking the short circuit of the primary/secondary side of CT for example, in the paper we found the model which can detect fault by the change of circuit parameter.

2 Fault Analysis

A principle diagram of the high voltage electric power metering system is shown in figure 1. “1”and “2” denote two metering unit of three-phase electric energy meter respectively. “TV1”and “TV2” denote voltage transformer. “TA1”and “TA2” denote current transformer. I_A and I_C represent current of phase A and phase C respectively. However I_a and I_c stand for secondary current of phase A and phase C. For convenience we consider that metering system and the whole supply as a network, and we expect to describe the change of metering system by changing the network impedance when the load changes or the system fault occurs. So we research the impedances, which are network impedances and taken at P and Q, changing with load and the fault occurs. That is, we find the relation of the change of network impedance and fault. For convenience, we reduced load to secondary circuit[4]. Equivalent circuit diagram and equivalent impedance diagram are shown respectively in figure 2 and figure 3.

Deriving from the working principle of current transformer and equivalent circuit, we can get

$$Z_{A12} = n^2 \times Z_L \quad (1)$$

$$Z_{C12} = n^2 \times Z_L \quad (2)$$

Where n denotes transformation ratio of current transformer Z_L refers to the equivalence impedance between A-phase and B-phase or between B-phase and C-phase. Based on figure 2 and figure 3, we can get network impedance Z_i :

$$Z_i = \frac{\left(Z_B + n^2 Z_L\right)^2}{2(Z_B + n^2 Z_L)} = \frac{Z_B + n^2 Z_L}{2} \quad (3)$$

When short circuit of the primary side of CT occurs, this corresponds to having a resistance named R_D between M and N in figure 1:

$$Z_{A12} = n^2 \times \frac{Z_L \cdot R_D}{Z_L + R_D} \quad (4)$$

$$Z_{C12} = n^2 \times Z_L \quad (5)$$

The network impedance taken at the point P and Q in this case is:

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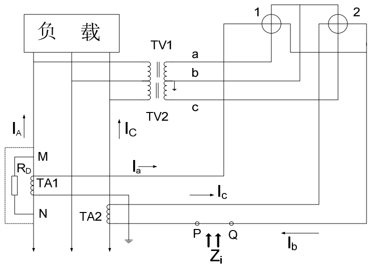

Figure 1. The interconnection principle diagram of high-voltage electric power metering system

$$Z_i' = \frac{\left(Z_B + \dfrac{n^2 Z_L R_D}{Z_L + R_D}\right)\left(Z_B + n^2 Z_L\right)}{2Z_B + \dfrac{n^2 Z_L R_D}{Z_L + R_D} + n^2 Z_L} \qquad (6)$$

When short circuit of the secondary side of CT occurs, this corresponds to having a resistance named R_D between two sides TA1 in figure 1:

$$Z_{A12} = n^2 \times \frac{Z_L \cdot R_D}{n^2 Z_L + R_D} \qquad (4')$$

$$Z_{C12} = n^2 \times Z_L \qquad (5')$$

The network impedance taken at the point P and Q in this case is:

$$Z_i'' = \frac{\left(Z_B + \dfrac{n^2 Z_L R_D}{n^2 Z_L + R_D}\right)\left(Z_B + n^2 Z_L\right)}{2Z_B + \dfrac{n^2 Z_L R_D}{n^2 Z_L + R_D} + n^2 Z_L} \qquad (6')$$

Now we will take an example to show that with different loads, change of the network impedance when the metering system works well or short circuit of the primary side of CT happens.

Assuming that the effective value of network voltage is 10KV, the rated load is 500KVA, and the power factor is 0.9 under rated load operating. The power factor increases with load decreasing [5]. So for convenience we can consider load impedance as resistance. The impedance of the copper lead as short-circuit line is $R_D = 1.275 \times 10^{-3}\Omega$. The active drop of current coil of the three phase electric meter is $0.1 \sim 0.5V$ commonly, which impedance of coil is Z_B=$(0.01 \sim 0.1)\Omega$. In this paper we choose $Z_B = 0.05\Omega$.

So $|Z_L| = \frac{U^2}{P} = \frac{\left(10\times10^3\right)^2}{500\times10^3} = 200\Omega$ with rated load. When the load is 50 percent of rated load, that is $|Z_L| = 400\Omega$. As well as the load is 10 percent of rated load, that is $|Z_L| = 2000\Omega$. A maximum current value is $I_m = \frac{U}{|Z_L|} = \frac{10\times10^3 V}{200\Omega} = 50A$, and the range of rated secondary current is $0 \sim 5A$. Therefore we choose transformation ratio $n = 10$.

Using the above parameters in formula (3), yields the impedance Z_i 1) When rated load, one has $Z_i = 1\times10^4\Omega$, 2) If load is 50% rated load, one has $Z_i = 2\times10^4\Omega$,3)However load is 10% rated load, one has $Z_i = 1\times10^5\Omega$. $Z_i' \approx Z_B + n^2 R_D = 0.1775\Omega$ Z_i''= $\approx Z_B + R_D \approx 0.05\Omega$

Deprived from the above calculation: when the load changes from rated load to 10% rated load, impedance Z_i taken at the point P, Q changes only one order of magnitude; however, the network impedance decreases sharply when short circuit of the primary/secondary side of CT occurs, it will change 4~5 orders of magnitude or even more, compared with common condition. So we can judge whether short circuit of the primary side of CT occurs or not through change of the network impedance. We conclude that the two faults can be detection by the same means. So we take the example of short circuit of the primary side of CT.

3 Fault Modeling

For network impedance is not easy to measure directly, we put a measuring current transformer TA3 with transformation ratio n_2 between P and Q, which is shown in figure 4, Where $\dot{u}_B$ stands for a standard voltage source with frequency f_2 and internal resistance R_i , And R , Z_i separately stands for a standard resistance and the equivalent impedance of the network when the system works well, however it changes into Z_i' when system fault occurs.

According to figure 4, we can compute the detection signal:

$$\dot{u} = \frac{\dot{u}_B}{R + R_i + n_2^2 Z_i} \times n_2^2 Z_i \qquad (7)$$

The detection signal under fault is:

$$\dot{u}' = \frac{\dot{u}_B}{R + R_i + n_2^2 Z_i'} \times n_2^2 Z_i' \qquad (8)$$

We choose $\dot{u}_B = 10\angle 0^\circ V$, $f_2 = 50KHZ$, $R_i = 50\Omega$, and R can be chosen by the above parameters. If

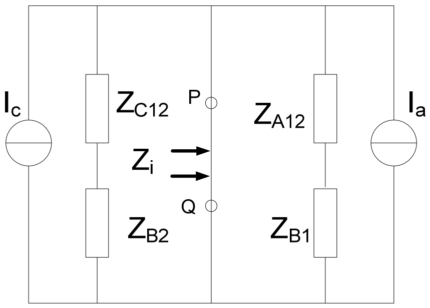

Figure 2. The equivalent circuit diagram of high voltage electric power metering system

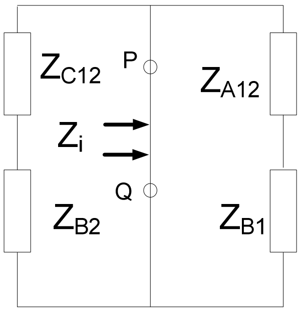

Figure 3. Equivalence impedance diagrams

Z_{C12} is the equivalence load of between B-phase and C-phase when Z_L are transformed to secondary; Z_{B1} and Z_{B2} are the current coil impedance of electric meter, used to Z_L when computing; Z_{A12} is the equivalence load of between A-phase and B-phase when Z_L are transformed to secondary.

$R >> n_2^2 Z_i$ and $R >> R_i$, we can get $u \to 0$ by equations (7) and (8), but it is difficult to judge whether $u \to 0$ is caused by the change of load or fault.

$$\dot{u}' = \frac{\dot{u}_B}{R + R_i + n_2^2 Z_i'} \times n_2^2 Z_i' \tag{8}$$

We choose $\dot{u}_B = 10\angle 0^\circ V$, $f_2 = 50KHZ$, $R_i = 50\Omega$, and R can be chosen by the above parameters. If $R >> n_2^2 Z_i$ and $R >> R_i$, we can get $u \to 0$ by equations (7) and (8), but it is difficult to judge whether $u \to 0$ is caused by the change of load or fault.

Equations (7) and (8) are the detection signals under standard power supply effect whether fault occurs or not. Actually, metering system undergoes the network voltage effect besides standard power supply, that is, the detection signal is the effect of the above two signals. Standard power supply falls into high frequency signal, while the network voltage belongs to power-frequency signal. So the effect of the network voltage can be filtered by a high-pass filter, we can get the fault detecting model of the metering system as follows:

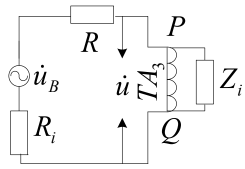

Figure 4. Fault detection circuit

$$Z_i' = \frac{\left(Z_B + \frac{n^2 Z_L R_D}{Z_L + R_D}\right)\left(Z_B + n^2 Z_L\right)}{2Z_B + \frac{n^2 Z_L R_D}{Z_L + R_D} + n^2 Z_L} \tag{9}$$

$$\dot{u}' = \frac{\dot{u}_B}{R + R_i + n_2^2 Z_i'} \times n_2^2 Z_i' \tag{10}$$

4 Simulation Study

4.1 Simulation Environment

In this paper, we choose a load of two-shift operation for studying. The practical load curve is irregular generally, for the simple description, we describe the load curve as $p(k) = |500000\sin(t)| + 10000$, as shown in figure 5. A constant is added so that the load curve can describe the fact more accurately, because there is little 0 load in factory, they always need some electric consumption.

4.2 Simulation Result

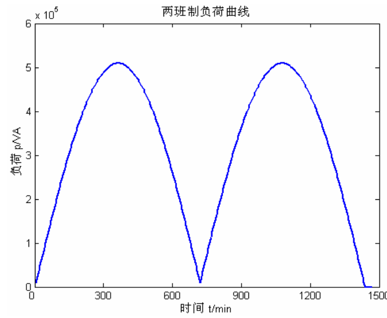

Figure 5. The load curve of two-shift operation

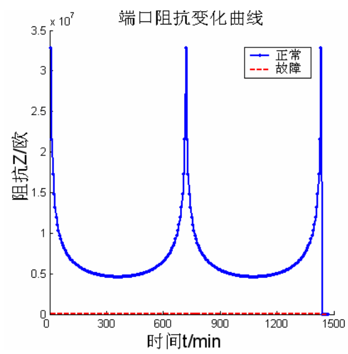

Figure 6. The change curve of network impedance

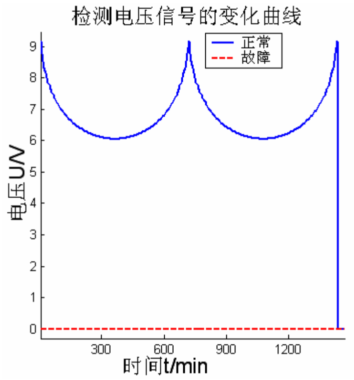

Figure 7. The change curve of detection voltage

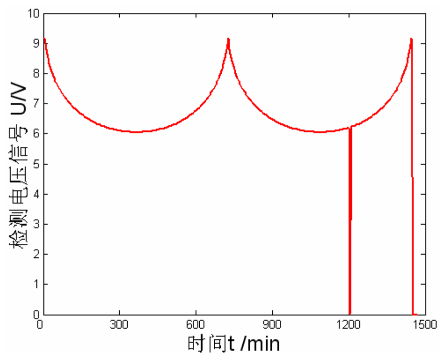

Figure 8. Current transformer has a short circuit at some o'clock

4.3 Results Analysis

Figure 6 shows the simulation curve of the network impedance changing with load under the system running well or some fault occurs. From the diagram we can see that the range of variation is about $0.5\times10^{7}\sim3.3\times10^{7}\Omega$, whatever the load changes, as long as short circuit of the primary side of CT doesn't occur, the network impedance will fall to some very little value, but it doesn't approach 0. Once short circuit of the primary side of CT occurs, the network impedance will approach 0. From figure 7 we can see clearly that the range of the detection signal u is about $6\sim9.1V$ under the system running well, but the signal goes almost 0 when the short circuit of the primary side of CT occurs. That is to say, if the detection signal changes into 0 suddenly, we can say that there is a short circuit of the primary side happening on some current transformer, which can be seen clearly from figure 8, and we can judge that current transformer has a short circuit at 20 o'clock according to the abrupt change of detection voltage.

5 Conclusions

We come to the conclusion that there are close relations between the network impedance and short circuit of the primary side of CT, which are drawn by analyzing the circuit parameters of the metering system. Based on the conclusion, an auxiliary circuit is designed and a fault detection model is built. Simulations performed on the model demonstrate the efficiency. The model can also be used for reference to detect some other faults, for example, one phase or between phases short circuit of circuit loop, opposing connection of current transformer , one phase disconnect of secondary circuit of voltage transformer etc, they need to be studied further for the future.

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