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Research on the influence of live replacement for transformers on the distribution grid and its optimization method

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Abstract. Live replacement of transformers could realize a more convenient way for overhaul and maintenance for this importance equipment in distribution networks. However, a series of harmful impact of transient process may be introduced into the transformer itself and the power distribution system, which would affect accurate measurement and stable operation of the grid. A PSCAD-based simulation model of live replacement for transformers is presented in this paper, and the corresponding method of optimization is also proposed. The scheme presented here is proved to realize live replacement on site, which is significant for improving the level of live maintenance automation and reliability of power distribution systems.

1. Introduction
Transformers are important equipment for measurement and relay protection in power systems. Once transformers are installed in power grid, measuring circuits can be isolated from high-voltage grid and the data of voltage and current can be easily captured by low-range meters. However, maintenance or replacement of transformers have to be operated when power is off, thus influencing reliability of distribution networks and reducing the automation level of live maintenance.

A series of harmful impact of transient process may be introduced into the transformer itself and the power distribution systems by live replacement, including saturation, ferromagnetic resonance and harmonic increase, which could reduce reliability and even influence normal operation of distribution networks. Besides, ferromagnetic resonance is commonly regarded as the main reason for branch fault [1].

Transient process in the circumstance of power system failures has been studied by researchers with the help of simulation software [2-5]. In this paper, a PSCAD-based simulation model of live replacement for transformers is proposed to study transient impact of the process, and the corresponding optimization method is also presented.

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2. Simulaiton model

2.1. Current transformer

Electromagnetic current transformers (Hereinafter referred to as CT) are commonly used in power systems; which primary side is magnetically connected to the secondary side. Different modeling method of CTs can be used based on core magnetization process. In simulation software, there are three kinds of models for CTs:

1) Model 1: Static model based on basic excitation curve;
2) Model 2: Dynamic model based on dynamic magnetization characteristics;
3) Model 3: Nonlinear time domain equivalent circuit model, including Lucas Model and J-A Model [6].

When using Lucas Model, all the nonlinear factors of transformers are listed separately and added up together using mathematic expressions. In the equivalent circuit of Lucas Model, several nonlinear circuit components are used to represent these nonlinear factors [7]; J-A Model is based on the ferromagnetic material phenomenological theory proposed by David Jiles and D. L. Atherton in 1984[8,9], and a set of nonlinear equations are used in this model to approximately simulate core magnetization characteristics under different circumstances.

Among the three kinds models above, nonlinear time domain equivalent circuit model is more commonly used for its accuracy and good time-frequency characteristics. In PSCAD software, the Lucas Model and J-A Model are represented by different built-in components. J-A Model is used for simulation in this paper.

When transient current flows on the primary side of CTs, a great amount of aperiodic current components could result in saturation of core and produce distortion current on the secondary side [10]. In severe cases, misoperation of relay protection devices could occur for the reasons above.

2.2. Potential transformer

V/V connection, as shown in Fig.1, is a typical wiring method for two potential transformers (Hereinafter referred to as PT), which is widely used for 6 to 10 kV power distribution equipments in substations to measure line voltages in three-phase three-wire systems.

The core of the transformer is regarded as nonlinear inductance, the value of which could decrease when two-phase or three-phase ground voltage increases in the transient process thus resonating with the capacitance to ground. Resonant overvoltage which threatens the normal operation of power systems could be produced in the process above [11].

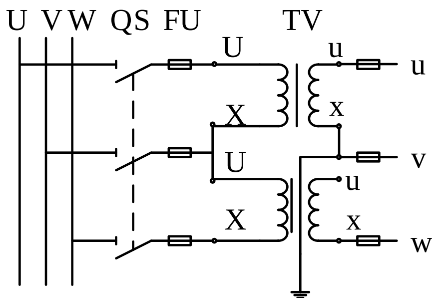

Figure 1. Schematic of V/V connection of potential transformers.

2.3. Simulation model of live replacement for transformers

A simulation model of 35kV/10kV substation and transmission line is built in PSCAD software. In this model, a three-phase voltage source is connected to the 35kV side, and models of overhead transmission line and fixed load are connected to the 10kV side.

According to GB50613-2010, 10 kV distribution system is a non-direct ground neutral system, thus resistance ground method is used in the model. According to the theory above, a PSCAD-based simulation model of live replacement for transformers is shown in Fig.2.

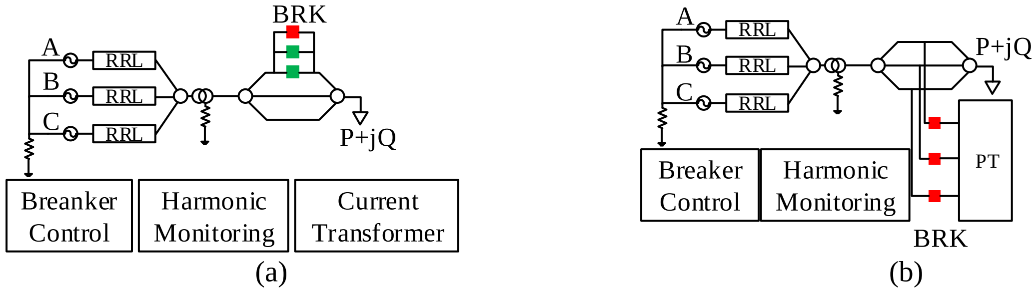

Figure 2. Schematic diagram of live replacement model of transformers.

3. Results and analysis

3.1. Simulation results of live replacement for CT

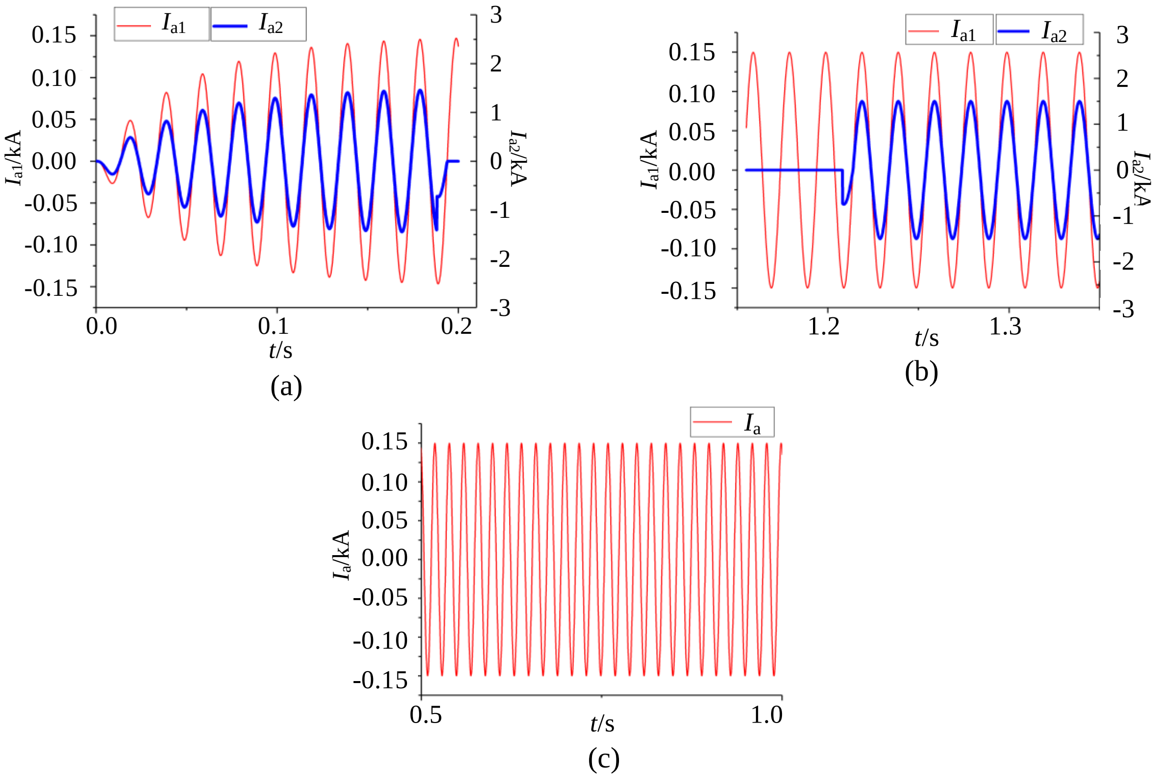

Figure 3. Simulating waveform of the current transformer.

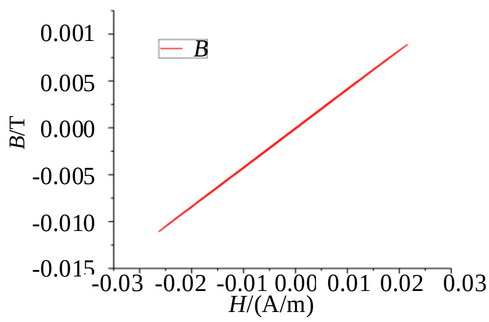

Figure 4. B-H curve of the current transformer.

The CT is set to be disconnected from the grid around 0.2s, and reconnected to the grid around 1.2s. Simulating waveforms of the CT and the distribution network are shown in Fig.3. B-H curve of it is shown in Fig.4.The content of harmonic voltage on the primary side of the system during the simulation is listed in Table 1.

Table 1. Harmonic voltage content of CT

	Before disconnection	After disconnection	After reconnection
2nd harmonic	0.331%	0.242%	<0.01%
3th harmonic	0.153%	0.137%	<0.01%
4th harmonic	0.010%	0.098%	<0.01%
5th harmonic	0.076%	0.077%	<0.01%
6th harmonic	0.061%	0.065%	<0.01%
7th harmonic	0.052%	0.057%	<0.01%

It can be seen from the results that the process of live replacement will not saturate CTs and has limited impact on the distribution network. According to the National Standard GB/T 14549-93, content rate of odd and even harmonic in phase voltages should be less than 3.2% and 1.6% respectively. Conclusions can be drawn from the results that live replacement of CTs satisfies the requirements of power quality in the power system.

3.2. Simulation results of live replacement for potential transformer

The PT is set to be disconnected from the grid around 0.5s, and reconnected to the grid around 1.0s. Simulating waveforms of the PT and distribution network are shown in Fig.5. B-H curve of it is shown in Fig.6. The content of harmonic voltage on the primary side of the system during the simulation process is listed in Table 2.

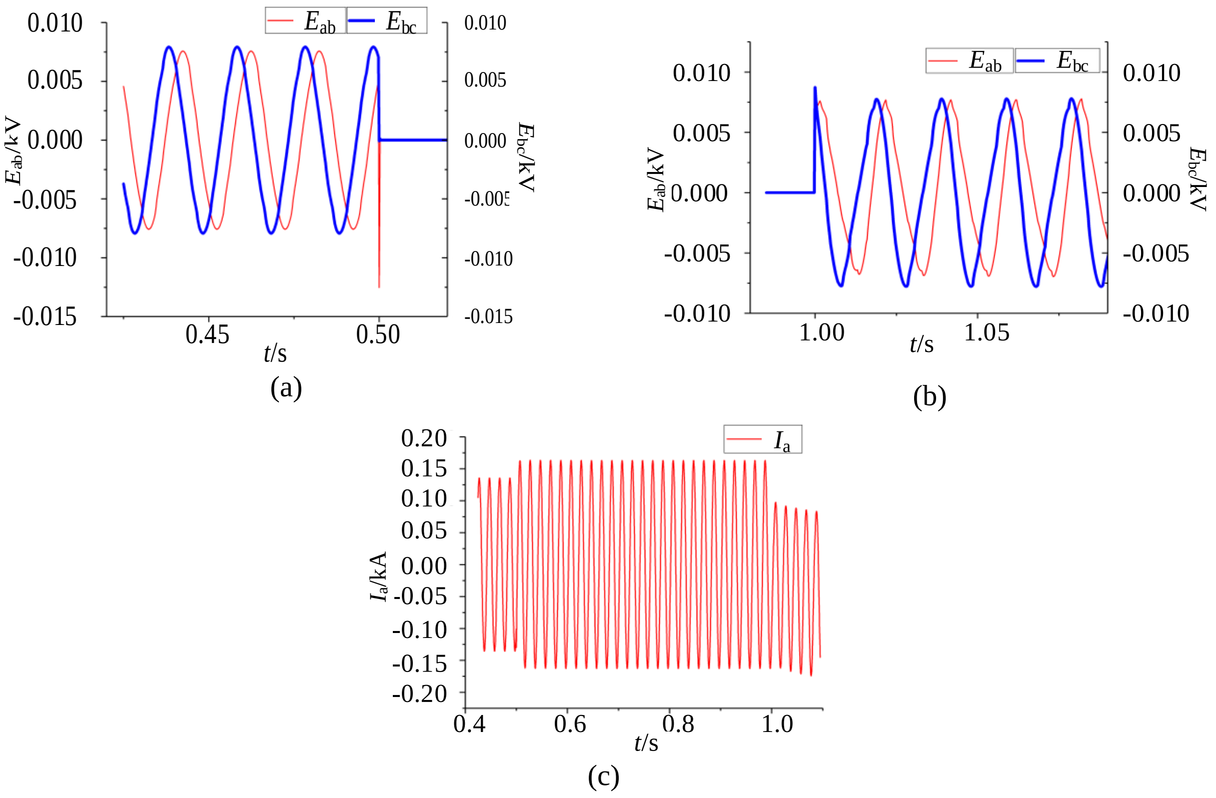

Figure 5. Simulating waveform of the potential transformer.

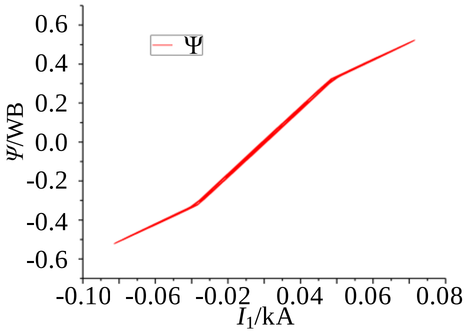

Figure 6. B-H curve of the potential transformer.

Table 2. Harmonic voltage content of the PT

	Before disconnection	After disconnection	After reconnection
2nd harmonic	0.01%	<0.01%	8.00%
3th harmonic	4.43%	<0.01%	3.55%
4th harmonic	<0.01%	<0.01%	0.56%
5th harmonic	0.11%	<0.01%	0.11%
6th harmonic	<0.01%	<0.01%	0.15%
7th harmonic	1.23%	<0.01%	1.02%

It can be seen from the results that the process of live replacement could saturate the PT, thus producing the phenomenon of ferromagnetic resonance, and has some impact on the distribution network. When the transformer is disconnected from the grid, the value of E_{ab} instantaneously reaches 1.66 times larger than its peak value, and when the transformer is reconnected, the value of E_{bc} reaches 1.13 times larger than its peak value. Besides, the content of harmonic on the primary side of the system increases dramatically. Conclusions can be drawn from the results that live replacement of PTs does not satisfy the requirements of power quality and could cause overvoltage in the power system.

4. Optimization method of live replacement for transformers

4.1. Design of optimization method

According to the simulation results above, the transient process of live replacement for PTs could have some impact on the distribution network, thus optimization scheme for it needs to be designed properly.

For the reason that the primary side of electromagnetic PTs is inductive, the transient process of them could lead to ferromagnetic resonance when connecting to the grid directly. In order to suppress the transient resonance state of the PT, a damping component is proposed to be connected on its primary sides. When reconnecting the transformer, the damping branch is connected to the primary side of it immediately and the branch will be shorted by a breaker subsequently; when disconnecting the transformer, the breaker opens and the damping branch is again connected. A PT with a damping component on its primary side is shown below in Fig.7.

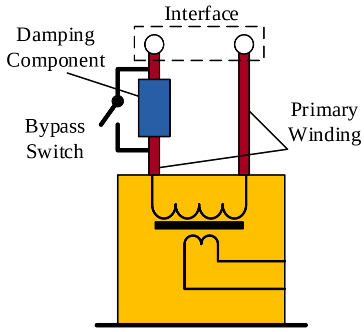

Figure 7. Schematic diagram of a PTwith a damping component.

4.2. Simulation of optimization method

A simulation model with a damping circuit module based on the optimization method mentioned above is built in PSCAD. In the damping circuit module, values of operation time of the breakers have to be set properly in order to suppress the transient process. In this simulation, the PT is set to be disconnected from the grid around 0.5s, and reconnected to the grid around 1.0s. Simulating waveforms of the PT are shown in Fig.8.

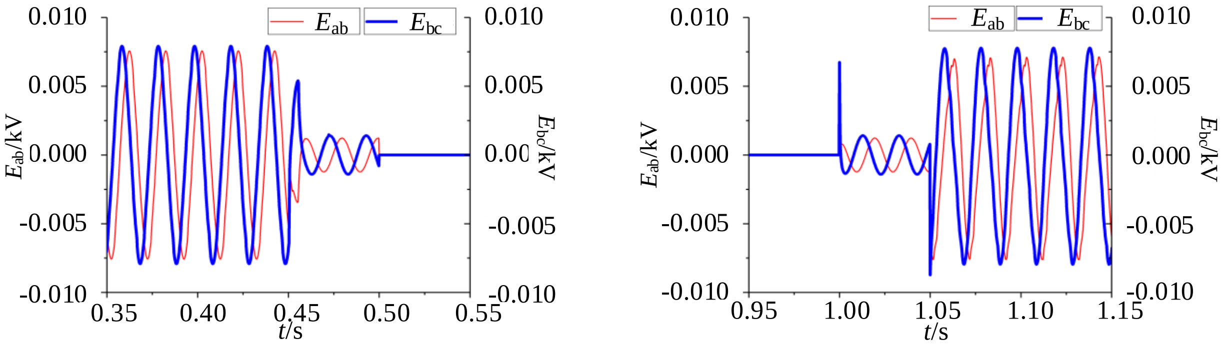

Figure 8. Simulating waveform of the potential transformer.

It can be seen from the results above that the optimization method could apparently decrease the content of harmonic in the power system and suppress overvoltage at the moment of replacement, thus improving stability and power quality of the power system.

5. Conclusions

In order to study the transient impact induced by live replacement of transformers and improve the automation level of equipment operation on site, a PSCAD-based simulation model is proposed in this paper. Several conclusions drawn from the results are listed below:

(a) Live replacement of CTs will not saturate the equipment itself and has limited impact on the distribution network, which satisfies the requirements of power quality power systems;

(b) Live replacement of PTs could saturate the equipment itself, thus producing the phenomenon of ferromagnetic resonance, and has some impact on the distribution network, which dissatisfies the requirements of power quality in power systems;

(c) An optimization scheme is proposed in chapter 4, where a damping component is installed on the primary of the PT. Simulation results reveals that the method could apparently decrease the content of harmonic voltage in the power system and suppress overvoltage, thus improving stability and power quality of power systems.

6. Reference

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