Investigation on the Probability of Ferroresonance Phenomenon Occurrence in Distribution Voltage Transformers Using ATP Simulation

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Abstract. Ferroresonance is a complex non-linear electrical phenomenon that can make thermal and dielectric problems to the electric power equipment. Ferroresonance causes overcurrents and overvoltages which is dangerous for electrical equipment. In this paper, ferroresonance investigation will be carried out for the 33kV/110V VT at PMU Kota Kemuning, Malaysia using ATP-EMTP simulation. Different preconditions of ferroresonance modes were simulated to ascertain possible ferroresonance conditions in reality compare with simulated values. The effect of changing the values of series capacitor is considered. The purpose of this series of simulations is to determine the range of the series capacitance value within which the ferroresonance is likely to occur.

Keywords: Ferroresonance, EMTP, Voltage Transformers, Over-voltages, Overcurrents.

1 Introduction

The term 'ferroresonance' has appeared in publications dating as far back as the 1920s, and it refers to all oscillating phenomena occurring in an electrical circuit which contains a non-linear inductor, a capacitor and a voltage source [1, 7]. The first step in understanding the ferroresonance phenomenon is to begin with the 'resonant' condition. Resonance can be explained by using a simple RLC circuit as shown in Figure 1.

This linear circuit is resonanting when at some given source of frequency the inductive (X_L) and capacitive (X_C) reactance cancel each other out. These impedance

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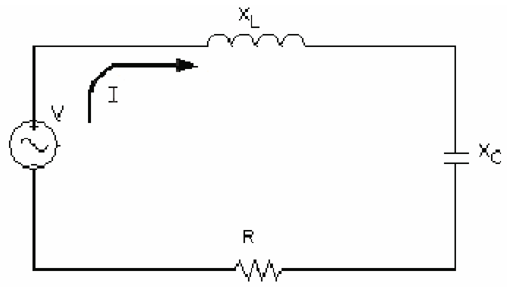

Fig. 1 RLC circuit for explaining ferroresonance

values can be predicted and change the with frequency. The current (I) in the circuit depends on the resistance (R). If this resistance is small, then the current can become very large in the RLC circuit. If the inductor in Figure 1 is replaced by an iron cored non-linear inductor, the exact values of voltage and current cannot be predicted as in a linear model. The inductance becomes nonlinear due to saturation of flux in the iron core. The understanding that ferromagnetic material saturates is very important. Ferromagnetic material has a property of causing an increase to the magnetic flux density, and therefore magnetic induction [3, 5, 6].

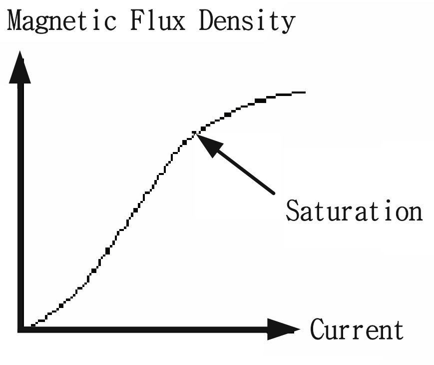

Fig. 2 Magnetization curve

As the current is increased, so does the magnetic flux density until a certain point where the slope is no longer linear, and an increase in current leads to smaller and smaller increases in magnetic flux density. This is called the saturation point. Figure 2 shows the relationship between magnetic flux density and current. As the current increases in a ferromagnetic coil, after the saturation point the inductance of the coil changes very quickly. This causes the current to take on very dangerously high values. It is these high currents that make ferroresonance very damaging. Most transformers have cores made from ferromagnetic material. This is why ferroresonance is a concern for transformer operation [2, 4].

2 Simulation Model

TNB(Tenaga Nasional Berhad, Malaysia) Transmission has had several failures of 33kV voltage transformers (VT) in the system. The simplified single line diagram for the 132/33 kV PMU Kota Kemuning is shown in Figure 3. The Engineering Services Department TNB Transmission Division reported that at 00:45 hour, PMU Kota Kemuning 3T0 (Fig. 3) tripped due to the explosion of 33 kV red phase VT. The equipment detail is shown in Table 1.

Table 1 VT detailed specifications

VT Type	UP 3311
From	V50
Accuracy Class	0.5
Primary Voltage	33/3
Secondary Voltage	110/3
Rated output	100 VA
Standard	BS 3941
Insulation Level	36/70/170 kV
Number of phase	1
Frequency	50 Hz
V.F	1.2 Cont 1.9 30 SEC

It was also reported that there were cracks on the VT and parts of it had chipped off. All three VT fuses of 33kV Incomer at the Double Busbar Switchgear had opened circuited and the screw cap contact surface with the termination bars was badly pitted.

The system arrangement shown in Figure 3 can be effectively reduced to an equivalent ferroresonant circuit as shown in Figure 4.

The sinusoidal supply voltage (e) is coupled to the VT through a series capacitor Cseries. The VT's high voltage winding shunt capacitance to ground can greatly contribute to the value of C_{shunt}. The resistor R is basically made up of the VT's equivalent magnetizing branch resistance (core loss resistance). The nonlinear inductor is represented by a nonlinear flux linkage (λ) versus current (i) curve (Fig. 4).

3 Simulation of Capacitance Precondition

The simulated circuit in ATP is shown in Figure 5. The switch can represent the circuit breaker or the disconnection of the fuse due to its operation. After the circuit breaker or the fuse opens, it is proposed that the supply voltage can still be coupled to the VT through equivalent series capacitance, C_{series}.

The voltage transformer was modeled as a nonlinear inductor in parallel with a resistance in the magnetizing branch (Rc). The circuit opening is represented by a time controlled switch. The values of all circuit components in Figure 5 were

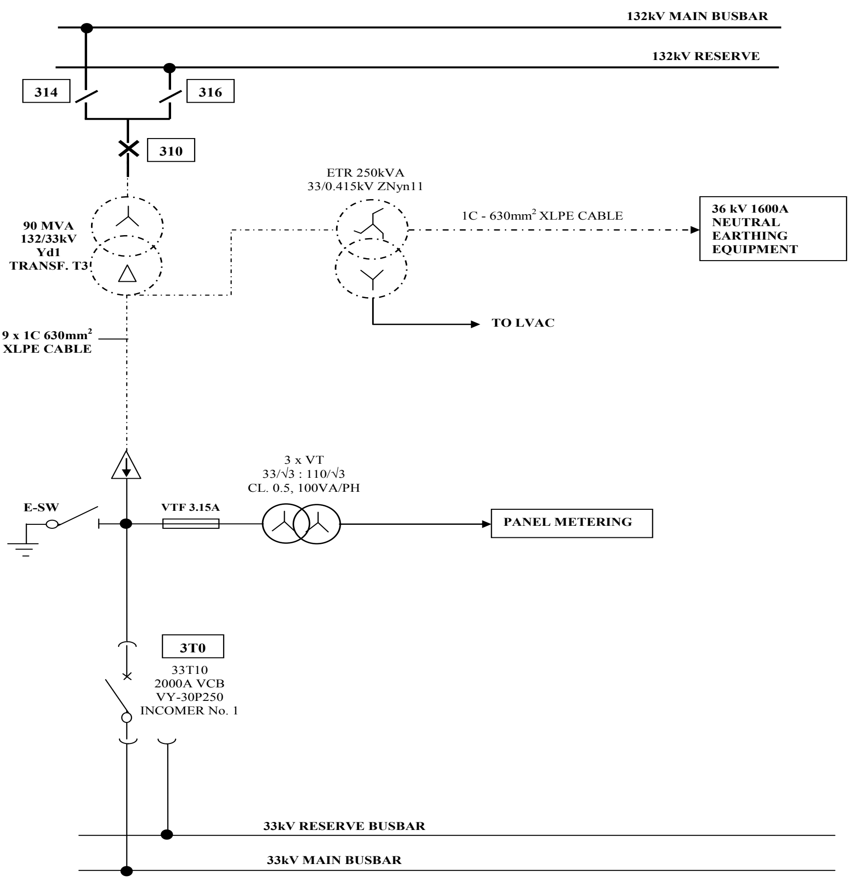

Fig. 3 Single line diagram of the substation

Fig. 4 Reduced equivalent ferroresonant circuit

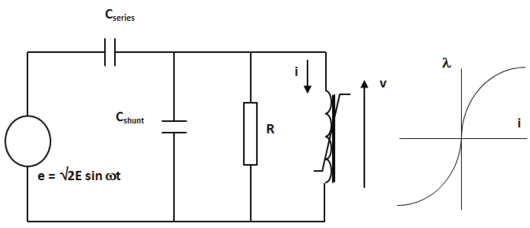

Fig. 5 The ATP simulated reduced equivalent ferroresonant circuit

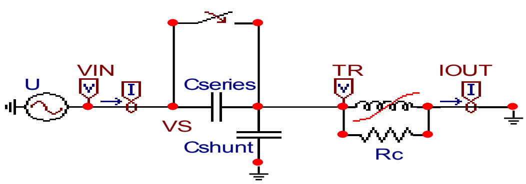

Table 2 Circuit Components Values

Parameter	Measured value
CHV-gnd	97.4 pF
DF of CHV-gnd	51.88 %
CHV-LV	640.7 pF
DF of CHV-LV	0.938 %
CLV-gnd	328.7 pF
DF of CLV-gnd	7.462 %
Rc	16.9 MΩ (calculated from open circuit test data)

Table 3 The effect of changing the value of series capacitor

Cseries (pF)	Peak Voltage at Transformer(kV) (before) (after)	Peak Current at Transformer(mA) (before) (after)	Frequency of System (Hz) (before) (after)	Ferroresonance Occur
8000	(26.944) (27.941)	(4.136) (3.947)	(50)(50)	NO
4000	(26.943) (28.895)	(4.137) (4.483)	(50)(50)	NO
2000	(26.943) (32.884)	(4.137) (5.612)	(50)(50)	NO
1500	(26.943) (35.297)	(4.135) (5.951)	(50)(50)	Yes
1000	(26.943) (52.429)	(4.136) (47.166)	(50)(50)	Yes
500	(26.944) (44.228)	(4.136) (20.813)	(50)(50)	Yes
350	(26.943) (41.609)	(4.137) (9.143)	(50)(50)	Yes
200	(26.943) (24.275)	(4.137) (3.548)	(50)(50)	NO
100	(26.943) (8.846)	(4.134) (1.245)	(50)(50)	NO
50	(26.943) (3.035)	(4.135) (5.561)	(50)(50)	NO

determined based on as far as possible the actual parameters. The following values in Table 2 were obtained from measurements made on the VT.

The simulation was carried out with a fixed value of shunt capacitor (C_{shunt}) at 97.4 pF and the value of resistance in magnetizing branch (Rc) at 16.9 MΩ. The circuit was supplied by AC source peak voltage of 26.94 kV with 50 Hz frequency. The time controlled switch was closed at 0 sec and disconnected after 0.25 sec. Table 3 shows the effect of variation in the series capacitor values. The peak voltage and the peak current at the VT were recorded before and after the switch operation. The time from 0 sec until 0.25 sec was considered as the before switch opening, and the remaining time was considered as after. The output waveforms for 1000 pF series capacitor where ferroresonance has occurred is shown in Figure 6. Figure 7 and Figure 8 show the output waveforms for 100 pF and 2000 pF series capacitor value where ferroresonance has not occurred.

It is clear from Figure 8 which shows that ferroresonance does not occur at 2000 pF of series capacitor although there is a small changes in the measured voltage and current of the system around disconnected time.

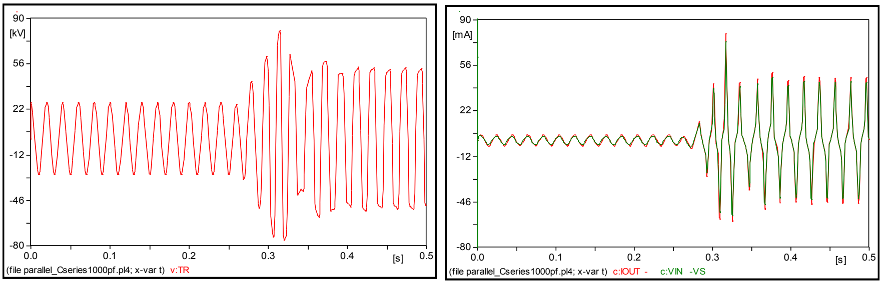

Fig. 6 The output waveform for 1000 pF series capacitor

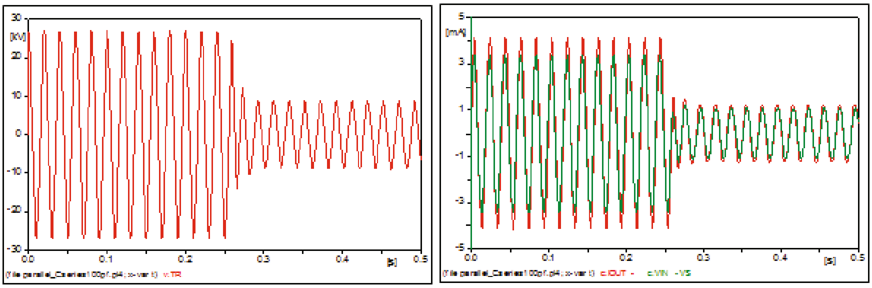

Fig. 7 The output waveform for 100 pF series capacitor

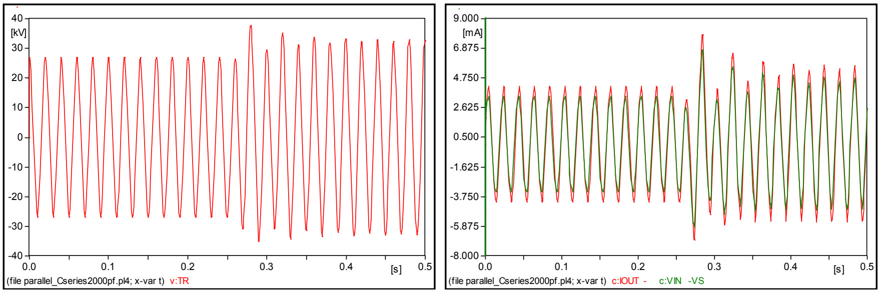

Fig. 8 The effect of changing series capacitor value for parallel RLC circuit by fixed the value of C_{shunt} at 97.4 pF and the value of Rc at 16.9 MΩ. C_{series} of 2000 pF

4 Conclusion

From the simulations it can be concluded that the value of series capacitor should be in the range of about 400 pF to 1400 pF (for 3-times magnification) in order for the ferroresonance to occur. As mentioned earlier, if the ferroresonance occurs due to a switching operation to disconnect the supply from the VT, the possible sources of this capacitor are the intercable capacitance, the busbar-VT capacitance, the opened circuit breaker capacitance, or the opened fuse capacitance. It can be said that, this range of values of series capacitance is relatively large compared to physically realised values. Therefore it can be concluded that once the VT is disconnected from the supply, there is no possibility of ferroresonance to occur since the supply voltage pre-condition cannot be physically met. In the simulation with C_{series} variation, it was found that there is no possibility of ferroresonance to occur due to disconnection of supply from the VT. This is due to the very high value of the series capacitance which is required.

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