A Special Ferro-resonance Phenomena on 3-phase 66kV VT-generation of 20Hz zero sequence continuous voltage

S. Nishiwaki, T. Nakamura, Y .Miyazaki

Abstract— When an one line grounding fault in a transmission line was removed, the insulation of the earthed voltage transformer(VT) broke down at the substation of a petroleum refinery which was provided with electric power from both an on-premises power generation plant and an outside power company. At this time, the abnormal 20 Hz zero sequence continuous voltage was recorded. Initially, the cause was not known, however it was found from an analysis using EMTP that this was a ferro-resonance phenomenon of the VT. This abnormal 20 Hz zero sequence continuous voltage could be reproduced by computation. It is thought that the main causes of the ferro-resonance were the existence of a single phase VT connected in addition to a 3-phase VT, and also the fact that the system became completely ungrounded neutral system after the one line grounding fault was removed.

Keywords: Ferro-resonance, Voltage transformer, 20Hz zero sequence continuous voltage, One line grounding fault, 3-phase circuit

I. INTRODUCTION

A 66kV voltage transformer (VT) was broken and a very special voltage waveform was recorded in an electric facility of a petroleum refinery. An abnormal 20 Hz zero sequence continuous voltage was recorded. At first, we did not understand their causes. By analysis with computation using EMTP, it was found the causes were ferro-resonance on 3-phase VT.

The petroleum refinery owns an electric power generation plant and is also supplied by an outside electric power company. When a ground fault at a transmission line of the electric power company was removed by the operation of a circuit breaker at a far substation of the electric power company, the ferro-resonance started. In the electric facility of the petroleum refinery, one phase VT was connected in addition to the 3-phase VT. It was found that this additional one phase VT was one of the causes of the ferro-resonance phenomena that we experienced.

By the open operation of the circuit breaker at the substation of the electric power company, the power transformer with neutral grounding resister (NGR) was removed, and the system became completely isolated neutral. It was found that this was also a cause of the ferro-resonance.

It was suggested that the continuous large excitation current flowed in the VT due to the iron core magnetic saturation with the ferro-resonance. The VT was broken by the over-heating in the winding.

There are many reports concerning the phenomena of ferro-resonance [1]. The phenomenon of ferro-resonance, which is well known with regard to the voltage transformer, is caused by a series circuit consisting of capacitor between the terminals of an open circuit breaker and a VT [2]. The phenomenon of ferro-resonance that occurs in a 3-phase transformer due to an open phase is also known [3] [4]. There is also an example of report concerning ferro-resonance of a VT under the similar system conditions reported in this paper below, that is, the condition in which the voltages of the three phases are applied normally in an ungrounded system [5]. In this example, the stray capacitance of the neutral point of the power source is the main cause of ferro-resonance. This is different from the example reported in this paper.

II. PHENOMENA THAT OCCUR IN A POWER SYSTEM

The situation when the generation of a 20 Hz zero sequence continuous voltage and VT burnout were experienced simultaneously is as follows. Figure 1 is the configuration of the power system at this time. The petroleum refinery which has its own power generation plant had been supplied with power from the power company's 66 kV transmission lines.

1) An accident of one line grounding fault occurred at point 'a' along the transmission line.
2) Circuit breaker 'b' of the substation Ass opened.
3) Circuit breaker 'c' of the petroleum refinery did not operate. Consequently, the system was energized by the output voltage of the power generation plant of the petroleum refinery.
4) The one line grounding fault disappeared naturally.
5) A 20 Hz zero sequence continuous voltage was

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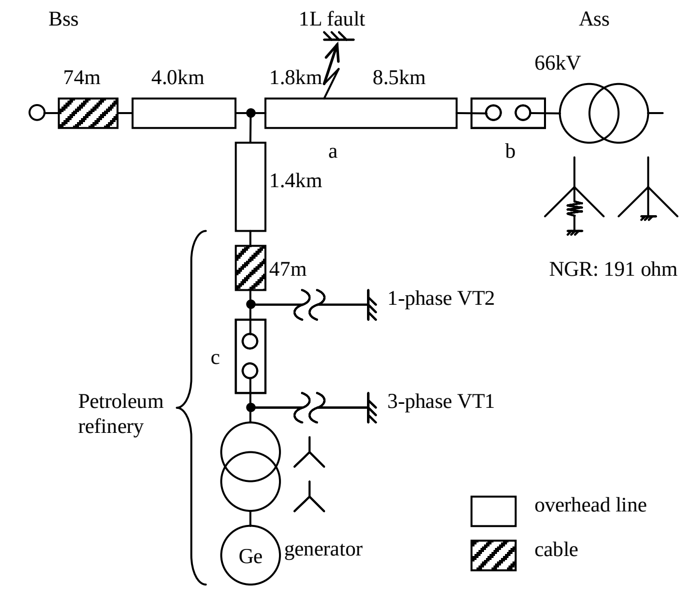


Fig. 1. Configuration of the power system where the ferro-resonance happed.

generated for several minutes.

6) The insulation of one phase of the 3-phase VT broke down.

A marten was found lying on the ground beneath the transmission line tower where the one line grounding fault occurred. It was presumed that the marten had climbed the transmission line tower, and touched an insulator, resulting in the grounding fault. It is thought that the disappearance of the one line grounding fault in item 4) above was the result of the marten falling off the tower. It is also conceivable that after circuit breaker 'b' opened, the system became completely ungrounded, reducing the grounding fault arc current, which in turn caused the arc to disappear naturally.

Figure 2 shows the voltage waveforms recorded at the petroleum refinery. It is considered that the one line grounding fault continues at time section 'a' in Fig. 2, because a 60 Hz zero sequence voltage appears in this time section. Upon entering time section 'b', the zero sequence voltage abruptly changes from 60 Hz to 20 Hz. At this time, distortion also appears on each line voltage of the three phases.

The insulation of the VT broke down after the phenomenon of section 'b' continued for several minutes.

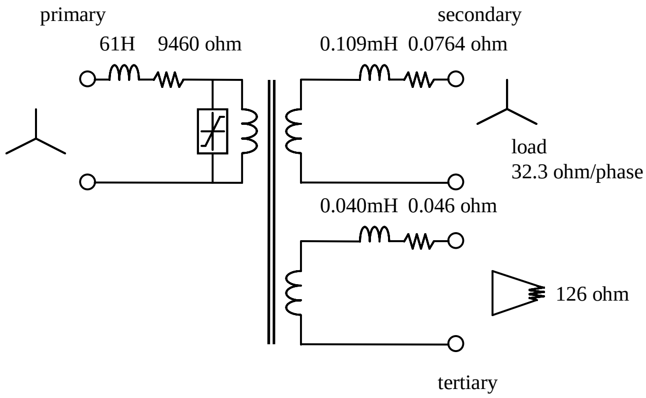
III. Reproducing the 20 Hz Zero Sequence Voltage by Computation

A. Computation Circuit

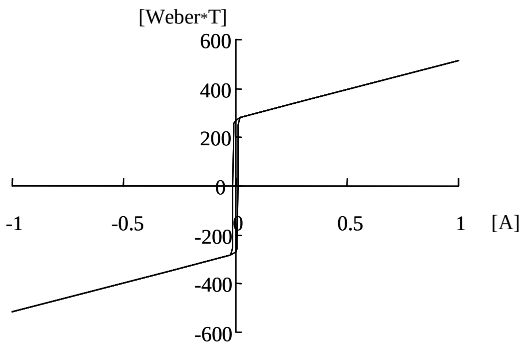
Initially, the recorded waveform of Fig. 2 could not be explained. By performing analysis using EMTP-ATP, it was found that the waveform was produced by magnetic saturation of the core of the VT, and was a ferro-resonance phenomenon.

Computation was performed by simulating the circuit of Fig. 1 in three phases. The modeling for each item of equipment is shown below.

1) 3-phase VT1 at the petroleum refinery



(a) equivalent circuit



(b) i- ϕ curve of iron core

Fig.3. Modeling of 3-phase VT1

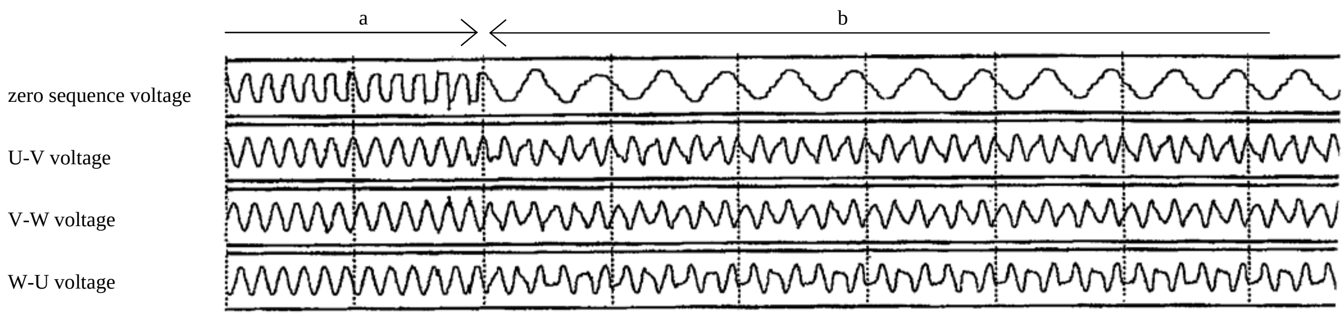


Fig.2. Voltage waveforms recorded in a petroleum refinery

2) 1-phase VT2 at the petroleum refinery

One phase of the VT1 of 1) above was used. The connection is at V phase.

3) 66 kV transmission line

A 3-phase untransposed transmission line constants was used. Computation of the constants was performed using the EMTP-ATP supporting program of Line Constants.

4) Cable

Simulation was performed using 200 pF/m.

5) Main transformer of the petroleum refinery

Neutral point of Y connection was not grounded.

6) Main transformer of Ass

Neutral point of Y connection was ground via a high resistance (191ohm).

B. Computation Results

The computation results are shown in Fig. 4. With reference to Fig. 4, an one line grounding fault is made to occur at time point 'a', the Ass circuit breaker is caused to open at time point 'b', and the one line grounding fault is removed at time point 'c' . In actual fact, the time from the operation of the circuit breaker at time point 'b' until the removal of the grounding fault at time point 'c' is longer period, but it is shortened in the computation.

The computed waveform of Fig. 4 (a) corresponds to the recorded waveform shown in Fig. 2. Simultaneous with the removal of the one line grounding fault at time point 'c' the zero sequence voltage changes from 60 Hz to 20 Hz. At this time, distortion appears on each line voltage of the three phases.

It can be seen that the computed waveform agrees well with the actually recorded waveforms that are shown in Fig. 2. It was possible to reproduce the occurrence of the 20 Hz zero sequence continuous voltage that actually occurred, by computation.

Figure 4 (b) shows the excitation currents at iron cores of 3-phase VT1. From time point 'c', core magnetic saturation currents starts to flow. The time point 'c' corresponds to the start of generation of the 20 Hz zero sequence voltage. It can be seen that the generation of the 20 Hz zero sequence voltage is due to ferro-resonance caused by magnetic saturation of the iron cores of the VT1. It is presumed that as a result of this continuous magnetic saturation current, the windings of the VT1 overheated, leading to a breakdown of the insulation of the VT1. Because the winding resistance of the VT is large, marked overheating occurs as a result of a continuous current of several A.

Figure 4 (c) is the voltages to ground at the 66kV terminals of the VT1. It can be seen that when ferro-resonance occurs, an overvoltage of about 2.2 pu occurs continuously. A 20 Hz zero sequence component is included in each phase voltage.

Figure 4 (a) shows the tertiary open delta and secondary voltages of 3-phase VT1. The waveforms in Fig. 2 as well are the waveforms observed on the tertiary open delta and secondary sides of the VT1. On the other hand, in the computation, the zero sequence voltage was tried to be calculated by adding the 3-phase terminal voltages to ground on the 66 kV side of the VT1. As a result, this voltage was found to be almost the same as the zero sequence voltage waveform of Fig. 4 (a). The calculated waveforms of the 3-phase 66 kV line voltages were also found to be almost identical to the observed line voltage waveforms of Fig.4 (a). From these facts, it is thought that even if the core magnetic saturation current shown in Fig. 4 (b) flows, output voltage waveforms of the tertiary open delta and secondary sides of the VT1 will be faithful to the 66 kV primary side voltage waveforms with high accuracy.

IV. Discussions

A. Effect of Single Phase VT

As shown in Fig. 1, a single phase VT2 was connected to the line side of the petroleum refinery in addition to the 3-phase VT1. This single phase VT2 was removed, and computation was performed. In this computation, the time point 'a' when the one line grounding fault occurred, time point 'b' when the circuit breaker at Ass operated, and time point 'c' when the grounding fault was removed agreed with the computation of Fig. 4. The waveforms resulting from the computation without the single phase VT2 are shown in Fig. 5. From Fig. 5, it was found that ferro-resonance did not occur.

In Fig.5, after the one line grounding fault is removed at time point 'c', magnetic saturation of the core occurs temporarily, and the excitation current in Fig. 5 (b) becomes large temporarily, but subsequently decays again. This core magnetic saturation temporary current is caused by the residual charge on the transmission line discharging through the VT. The zero sequence voltage in Fig. 5 (a) and the voltage to ground in Fig. 5 (c) fall along with the decay in the excitation current after time point 'c'.

The fact that ferro-resonance ceases to occur when the single phase VT2 is removed indicates that it is possible that an imbalance in the 3-phase circuit is one of the causes of ferro-resonance.

B. Effect of Neutral Grounding High Resistance

Computation was carried out under the condition where the neutral point of the main transformer at the petroleum refinery was grounded through a high resistance (191 ohm), and also under the same conditions as those used to obtain the waveforms of Fig. 4. As a result, the ferro-resonance did not occur.

As shown in Fig. 1, the neutral point of the main transformer at Ass was grounded through a high resistance. However, after the circuit breaker at Ass operates, the petroleum refinery system becomes completely ungrounded. Consequently, the neutral point potential can oscillate freely. It is thought that this is one of the causes of ferro-resonance.

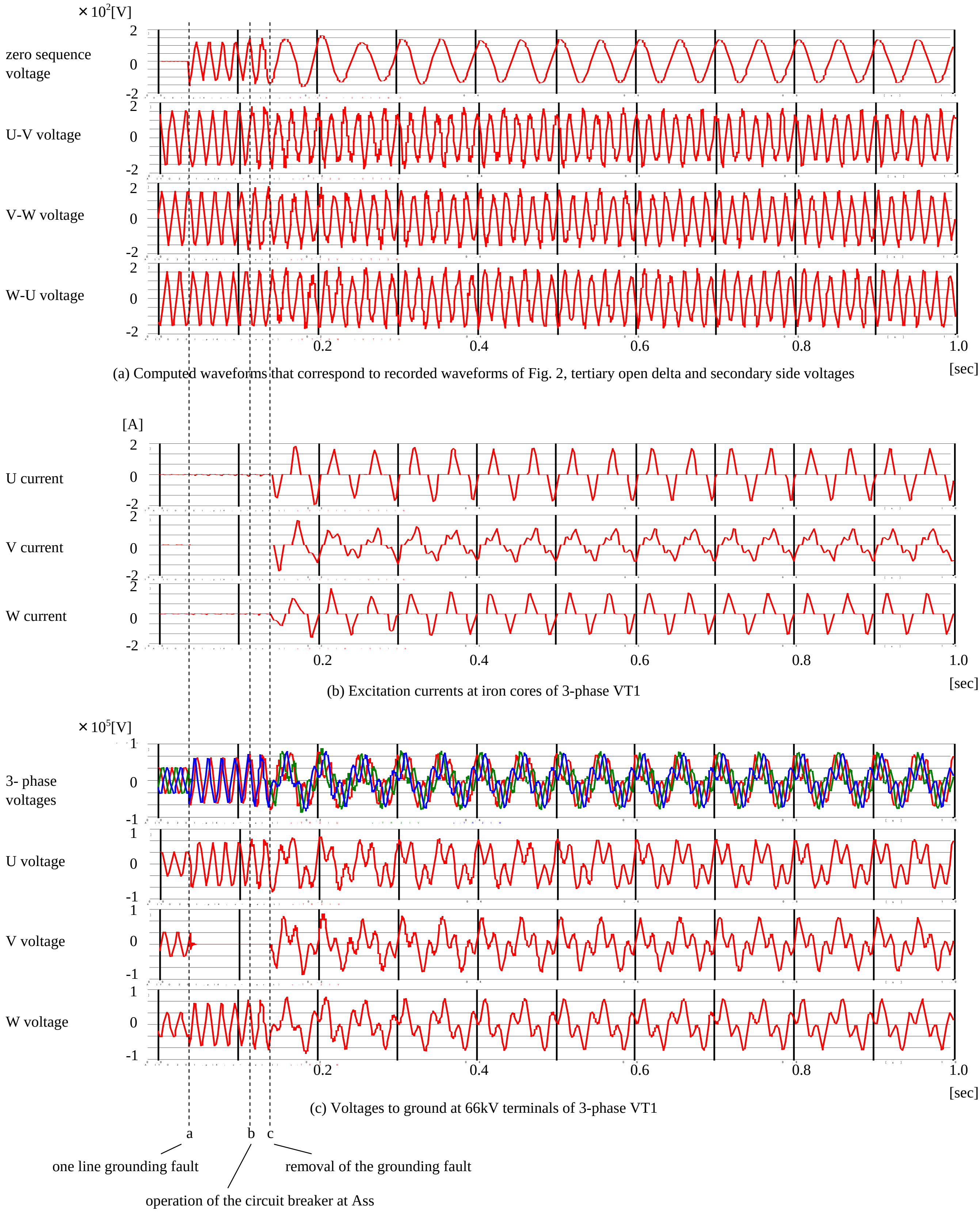
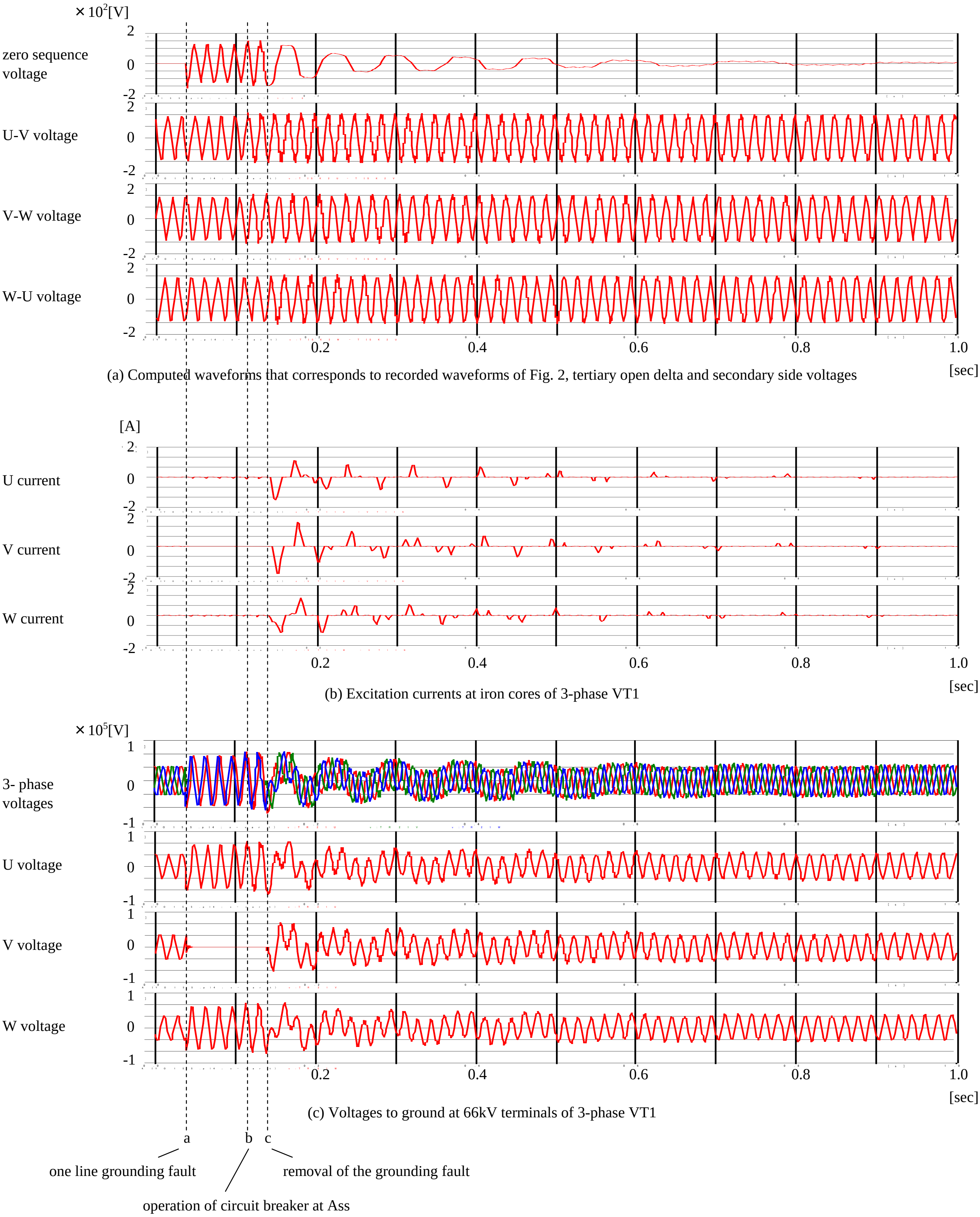


Fig. 4. Waveforms of ferro-resonance reproduced by the computation



(a) Computed waveforms that corresponds to recorded waveforms of Fig. 2, tertiary open delta and secondary side voltages

(b) Excitation currents at iron cores of 3-phase VT1

(c) Voltages to ground at 66kV terminals of 3-phase VT1

Fig. 5. Computed voltage waveforms without the single phase VT2, no generation of the ferro-resonance.

C. Effect of The Timing of Removal of The One Line Grounding Fault

In Fig. 4, when the computation was performed with changing time point 'c', which is the timing of removal of the one line grounding fault, ferro-resonance ceased to occur. It can be seen that the occurrence of ferro-resonance is affected by the initial conditions of the system.

D. Effect of The Load on The VT

When computation was performed after increasing the load on the VT secondary side, ferro-resonance ceased to occur.

V. CONCLUSION

It was possible to reproduce ferro-resonance in a 66 kV VT, which was actually happened in a field, by means of analysis using EMTP. It was possible to explain the recorded abnormal 20 Hz zero sequence continuous voltage and also the insulation breakdown of the VT. Ferro-resonance occurs under a variety of conditions. It is considered that the main causes of the ferro-resonance reported here are the existence of a single phase VT connected in addition to another 3-phase VT, and also the fact that the system became completely ungrounded after the one line grounding fault was removed.

VI. REFERENCES

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VII. BIOGRAPHIES

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