Development of large-capacity multiple-phase rectifier model for industrial use by utilizing EMTP

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Abstract

With the recent higher-voltage and larger-capacity design of power semiconductors, a large capacity design of power converters has become possible and its range of application is widening in the power systems, industrial fields, etc. As a result of wide diffusion of power converters, on the other hand, voltage distortions due to increased harmonic current enlarge,thereby causing serious problems in the power systems. As a method of remedying these harmonic problems, a multiple phase design of power converters is generally known. As the number of phases increases to 24, 36 and 48, there arise several facets which do not go with the practical system with theoretical verifications only. So, we developed a multiple phase rectifier model (1) resorting to general-purpose transient-phenomenon tool EMTP (2) making full use of the simulation technique by computer and will introduce here instances of harmonic problem analysis and load current feedback control incidental to DC short circuit.

Keywords: power systems, industrial facility, harmonic, multiple phase rectifier, harmonic filter, EMTP, DC short circuit, feedback control.

1. Introduction

The progress of power electronics technique capable of freely converting or controlling the electric energy gives considerable influences over small to large capacity power converters. Ever-increasing harmonic generated by different devices raise voltage distortions of power systems.

As typical harmonic suppression method on large capacity power converters, the following countermeasures can be enumerated.

- Countermeasures on power converter

Multiple phase design, high frequency PWM design, etc. for power converters which are harmonic sources.

- Countermeasures on harmonic filter

Harmonic generated by the power converter are absorbed by active filters or LC filters to prevent them from being conveyed to the supply side.

Practically, many power converter systems share multiple phase design and use of harmonic filters because studies are made from the view point of both harmonic suppression method and cost.

So, as a harmonic suppression method for large-capacity multiple-phase rectifier systems,we reduce the harmonic content by combination of several transformers so as to take into account the phase shift angle and also harmonic filter. Fig. 1.1 shows a simple system configuration..

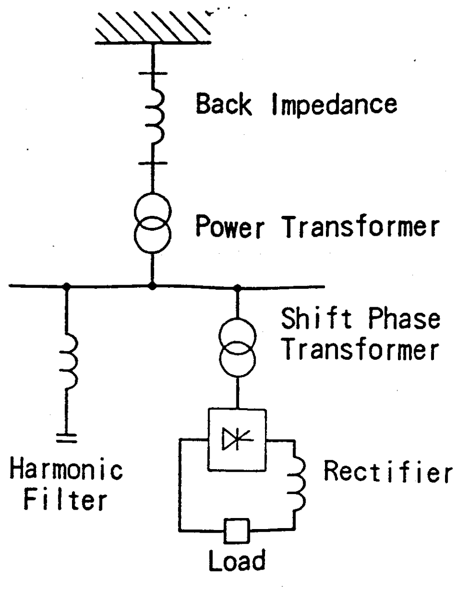


Fig. 1.1 simple system configuration

The harmonic content of theoretically can be lowered theoretically but cannot completely be suppressed of the real system because of unbalance of 3 phase source voltage and dispersion of control angle (α angle). As we proceed to settle these problems, we were obliged to recognize the importance of simulation technique resorting to computer. So, we used a transient phenomenon analyzing tool(EMTP) for analysis.

The present paper introduces concrete examples while describing the development of multiple phase rectifier model resorting to EMTP.

2. Development of multiple phase rectifier model

In multiple phase rectifier modeling, we performed a multiple phase rectification with the aid of the harmonic composition method [3] where AC side harmonic components are expressed in terms of vector. Fig. 2.1 exemplifies a compositon of harmonic vectors for 24 phases. In this case, we require 2 transformers capable of changing the shift angle ($\pm\theta = \pm 7.5$) of 12 phase rectifier transformer (Δ／Y, Δ／Δ).

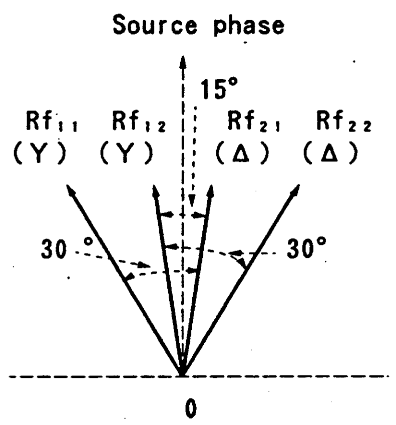


Fig 2.1 Composition of harmonic Vector

So, more than 10 years ago, A parent company to us developed (transformers with phase shift windings) as transformers capable of changing the phase shift angle. Fig. 2.2 shows the transformer winding and core structure. Taking advantage aforementioned technique, we developed the said model using EMTP.

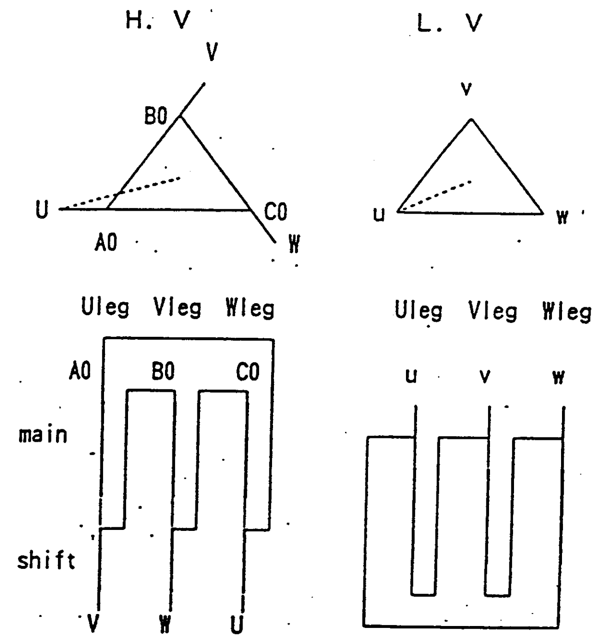


Fig. 2.2 Transformer winding and core structure

Based on the vector diagram (Fig. 2.3) for transformer with phase shift windings, relation (2.1) for the high voltage winding voltage including the phase shift angle is obtained as follows.

$$e_1 = 2/\sqrt{3}\, E \sin\theta$$

$$e_2 = \{ \sin(60-\theta)/(\sqrt{3}/2)\}\, E - e_1 \qquad (2.1)$$

E : Rated voltage
θ : Phase shift angle (deg)
e_1, e_2: Winding voltages

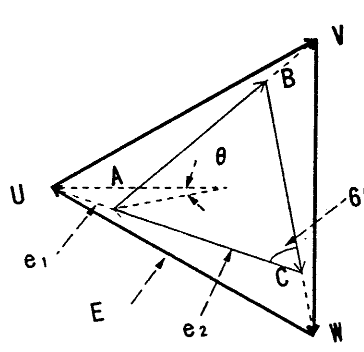


Fig. 2.3 Harmonic vectors

Expression (2.1) reveals that a transformer model with phase shift windings is available by combining windings built in EMTP (unit phase winding transformer model). As a result, a digital simulation for run status of multiple phase rectifier model has become possible.

3. Simulation using multiple phase rectifier model

The multiple phase rectifier model is 3 phase bridge circuit model of basically multiple pulse design. Here, let us outline the 3 phase bridge circuit and explain the analyses on the parallel 24 phase rectifier model.

3.1 Outline of 3 phase bridge circuit

The circuit uses DCL(DC reactor) to smoothen DC side current ripples. The AC side current has a square waveform and, therefore, ignoring the commutation overlap angle, harmonic components in the AC side current are expressed by,

$$I = \frac{2\sqrt{3}}{\pi} Id\,[\sin\omega t \pm \frac{1}{5}\sin 5\omega t \mp \frac{1}{7}\sin 7\omega t - \frac{1}{11}\sin 11\omega t + \text{-----}\,] \quad (3.1)$$

From expression (3.1), the order and maximum theoretical value of harmonic generated by 3 phase bridge circuit are given by:

$$n = mp \pm 1 \qquad In = I_1/n \qquad (3.2)$$

I_1 : RMS value of fundamental frequency

p : Harmonic order

Conventionally, harmonic generated by a multiple phase rectifier were calculated by expression (3.2) and the harmonic were offset to reduce them. On actual models, theoretical verification if often impossible (generation of non-theoretical harmonic, unbalanced theoretical harmonic, etc.)

3.2 Analysis by parallel 24 phase rectifier model

This section will exemplify analyses on parallel 24 phase rectifier model consisting of two 12 phase rectifiers concretely. This modeling is often retained recently for power systems converters as represented by HVDC, industrial power facilities (electrochemical rectifiers, DC arc furnace rectifiers), etc. Refer to Fig.3.1 Application example of harmonic problems and load current feedback control incidental to DC short circuit will be enumerated.

3.2.1 Application example of harmonic problems

(1) Voltage distortions incidental to balance and unbalance and influence of harmonic content on current.

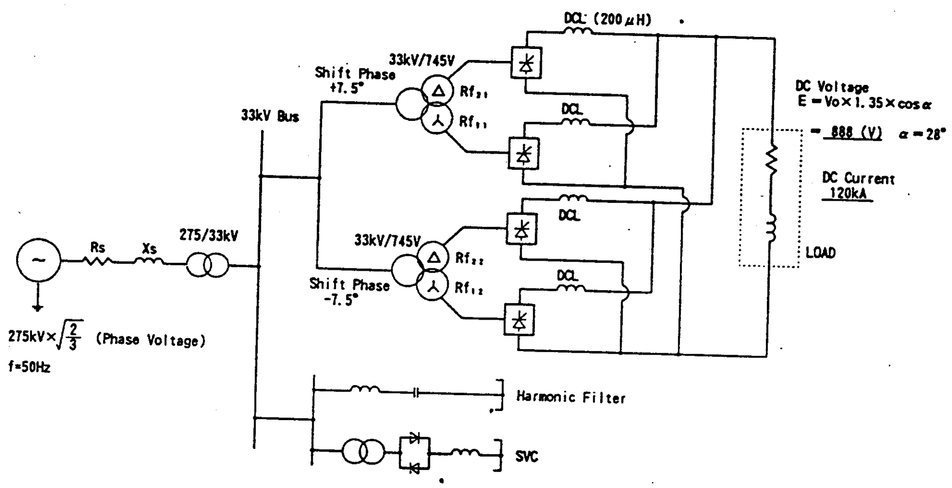


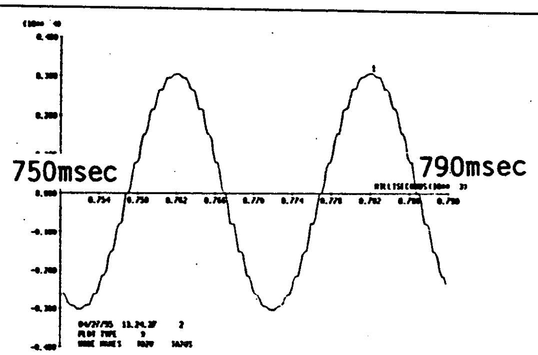
Fig 3.1 Parallel 24 phase rectifier model

The harmonic current for symmetrical 24 phase consisting of four 6 phase rectifiers and for asymmetrical 18 phases with a rectifier tripped can quantitatively be determined from the harmonic content and simulation waveform. The simulating conditions:

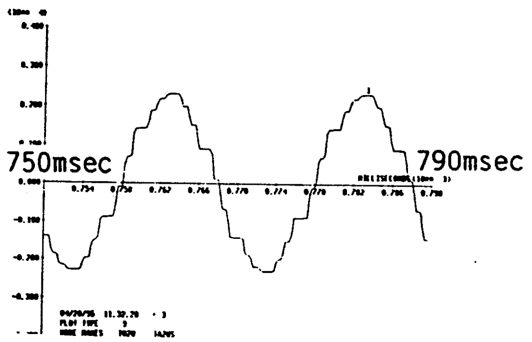
- Control angle: 28 (deg) constant
- Harmonic filter present
- Overlap angle ignored

Fig. 3.2 shows simulation waveform for 24 phase current I_{24}(u phase) on load side for symmetrical 24 phase run and asymmetrical 18 phase run and 33 kV bus phase voltage (u phase). Fig. 3.3 gives bar graph comparisons of harmonic contents of their waveform subjected to FFT. Asymmetrical 18 phase run quantitatively reveal voltage and current harmonic components which are absent for symmetrical 24 phase run. There are simply theoretical verification methods but dynamic verification methods taking the entire system into account are not found so often even in scientific documents.

(2) Verification of voltage distortion suppressing effects according to whether harmonic filter is present or not while harmonic suppressing effects are expected from the harmonic.

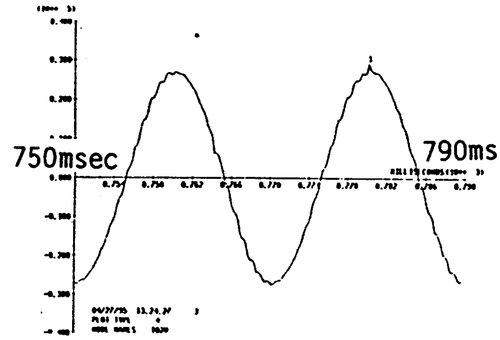


(a) symmetrical

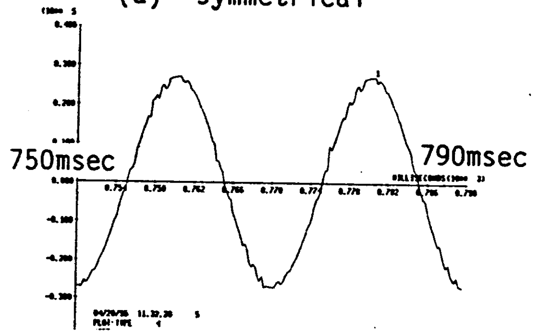


(b) asymmetrical (18 phase)

(1) load side 24 phase current



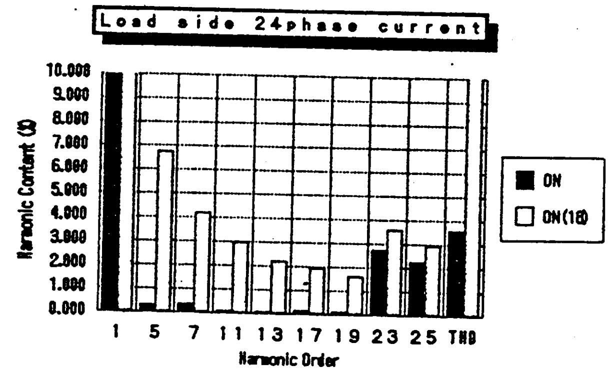
(a) symmetrical



(b) asymmetrical (18 phase)

(2) 33KV phase voltage

Fig 3.2 Simulation wavefrom



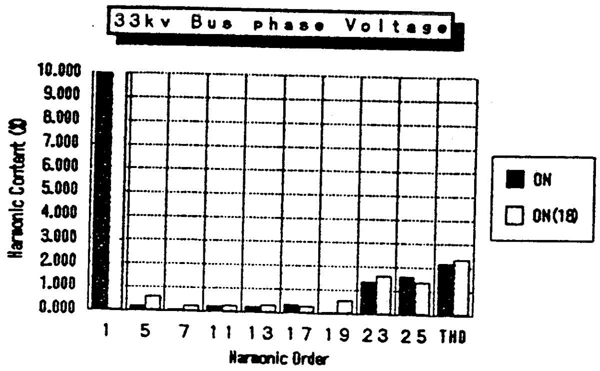


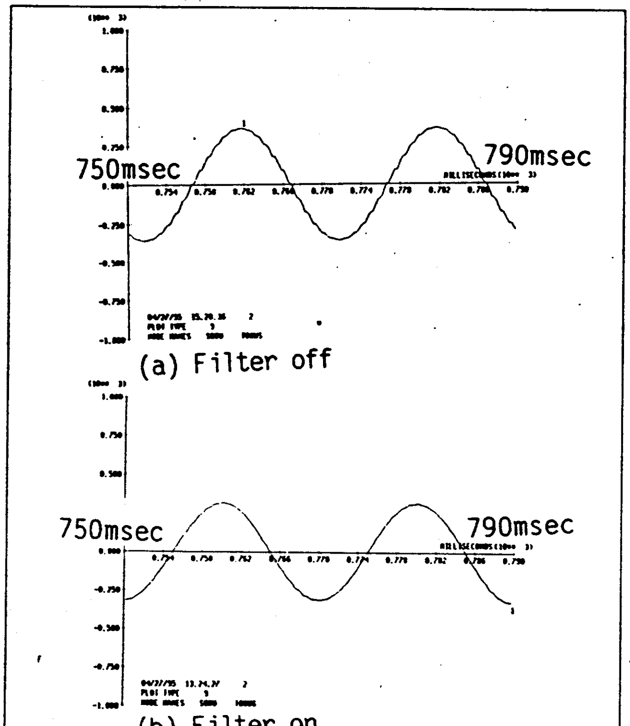
Fig 3.3 Comparative graph for harmonics contents symmetrical, asymmetrical (18 phase)

filter, a wrong design its characteristics may enlarge the harmonic. As their verification methods, harmonic analyzing programs have been developed by many enterprises. Most of them are routine calculations of single phase and allow to give only limited quantitative determinations. To check the effects of harmonic filter, we developed a multiple phase rectifier model. Thus, we can estimate and quantitatively determine voltege distortions by harmonic. The simulating conditions:

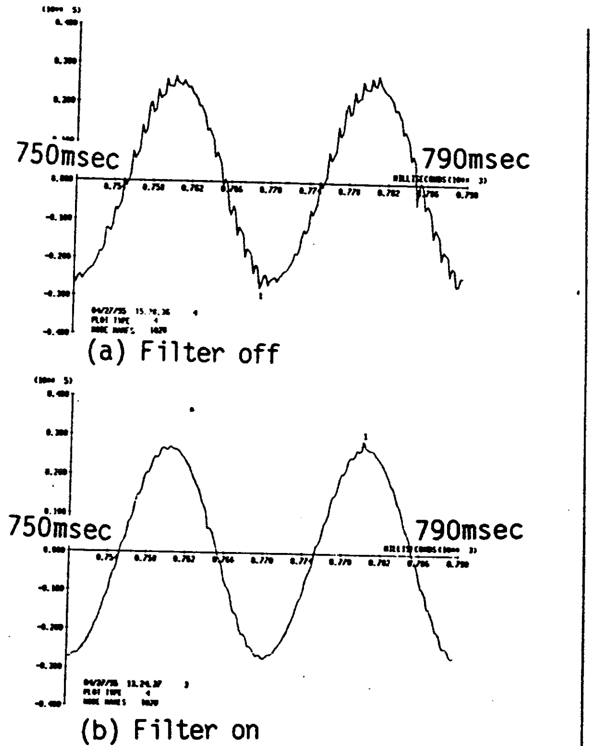
- Control angle: 28 (deg) constant
- Harmonic filter present or absent
- Overlap angle ignored

Fig. 3.4 shows simulation waveform for 24 phase current $I_{\cdot 24}$ (u phase) and 33 kV bus phase voltage (u phase) on the line side with and without harmonic filter at symmetrical 24 phase run. Fig. 3.5 is a bar graph for comparing their harmonic content after subjecting them to FFT. The results show that the harmonic current coming form 24 phase rectifier is absorbed by the harmonic filter and that 33 kV bus voltage distortions are suppressed.

These years, an optimum filter design method is disclosed with the harmonic filter cost taken into account. However, we have to finally design harmonic filters which cope with most adverse asymmetrical run given in (1) and think that a transient simulation technique is necessary.

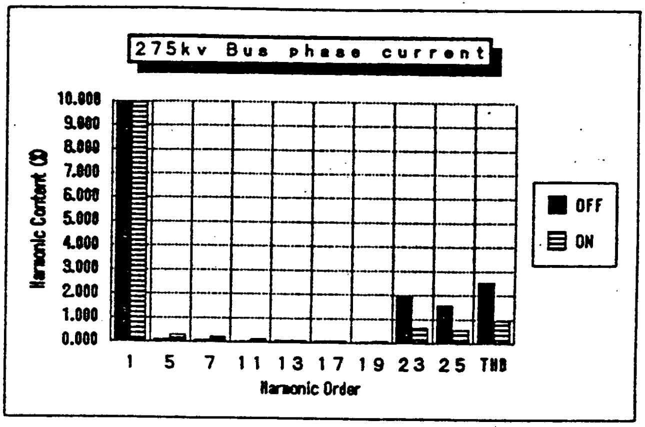


(1) system side 24 phase current



(2) 33KV phase voltage

Fig 3.4 Simulation wavefrom



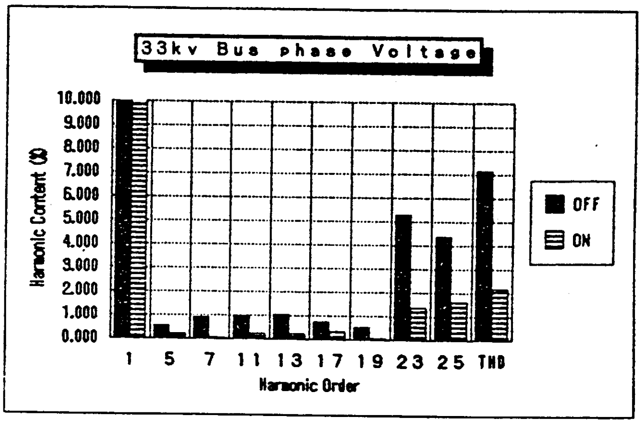


Fig 3.5 Comparative graph for harmonics contents (Filter ON, OFF)

3.2.2 Control of constant load current incidental to DC short circuit

Out of industrial power facilities, DC arc furnace and other multiple phase rectifier systems where a short circuit is produced on DC side are employed from time to time recently. So, we gave a load current feedback control (Fig. 3.6) by means of TACS of EMTP in 6 phase rectifier of the model in Fig. 3.1 and examined whether the load current was quickly suppressed or not when DC short circuit on the rectifier side was produced as a disturbance.

The simulating conditions are:

- Control angle: 28 (deg) constant
- Harmonic filter present
- DCL time constant 135 (msec)
- System side power factor 1.0

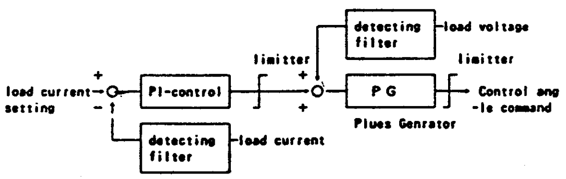
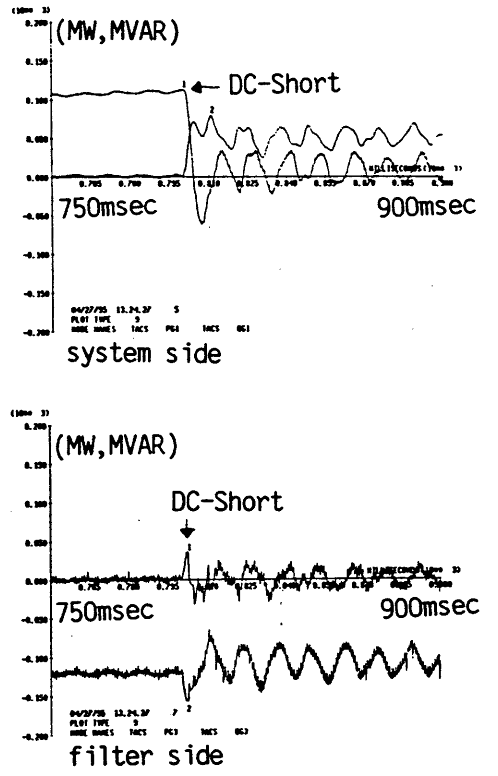


Fig 3.6 Load current feedback control by TACS

As simulation waveform , Fig. 3.7 shows line side and multiple phase rectifier side and harmonic filter's active and reactive powers and rectifier load current.

The wave forms reveal that the load current resumes the set value approximately 10 msec after the short circuit occurrence.

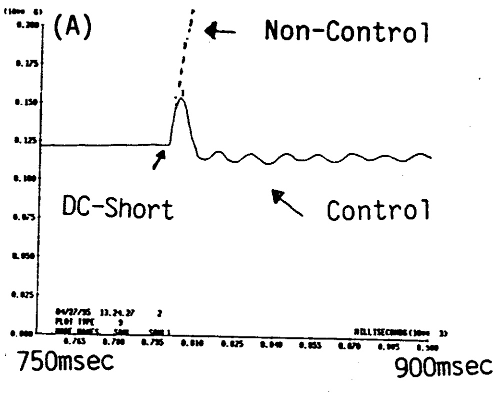


(2) active power , reactive power
Fig. 3.7 Simulation waveform

4. Conclusions

This time, we developed a multiple phase rectifier model using EMTP. This simulation technique is useful for predictive diagnosis for various design techniques.

Ther remain some questions on up to where the calculation accuracy of model created with EMTP is satisfied. As future problems, we will compare the data with measured one making full use of EMTP modeling technique to prove it physically.



(1) DC current

5. Acknowledgments

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