2007년도 대한전기학회 하계학술대회 논문집 2007. 7. 18 - 20

주파수 의존 등가회로의 전자기 과도 현상 시뮬레이션

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Frequency Dependend Network Equivalents to Electromagnetic Transient Simulation

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Abstract - The complexity of modern power systems often makes it impractical to model it in its entirety for electromagnetic transient studies. Therefore areas outside the immediate area of interest must be represented by some form of Frequency Dependent Network Equivalent (FDNE). The advantage of using z-domain fitting is that it can be directly implemented in a digital simulation program without any loss of accuracy. Fitting in the s-domain always requires ``discretizing" a continuous system and the inherent approximations. This paper presents z-domain rational function formulation and demonstrates the use of it for the assessment of the transient response of the Lower South Island of New Zealand.

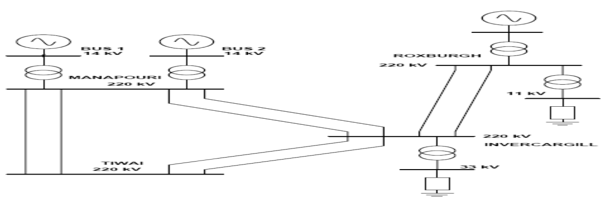
1. Introduction

Although time domain techniques, such as used in EMTP and PSCAD/EMTDC packages, can accurately perform analysis of power system transients, detailed representation of a large complex power system will entail a prohibitive amount of computation. Hence there is a need to have equivalents which adequately represent the areas outside the immediate area of interest. These are called Frequency Dependent Network Equivalents (FDNE) as the requirement to adequately represent the transient behaviour means it must mimic the frequency response of the system in represents. Therefore conventional equivalents based on the fundamental frequency short circuit level are inadequate for representing the external networks behaviour when simulating transients, due to the presence of other frequency components.

This paper demonstrates the accuracy achievable for transient analysis of a practical system by applying the enhanced FDNE to the Lower South Island of New Zealand. One of the objectives of this paper is to provide a benchmark for this type of work. The Lower South Island was an actual system and all the input data, such as line geometry, transformer parameters...etc, is available in published literature[1-2]. The inclusion of all the FDNE coefficients allows the transient response of this FDNE to be assessed easily and compared with those generated by other methods.

2. Derivation of Frequency Response

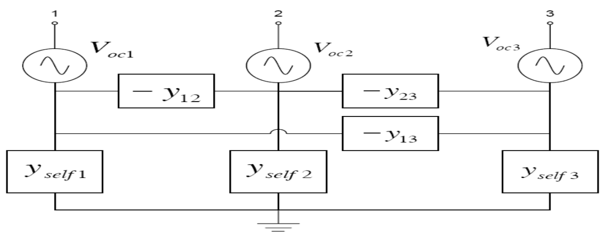
The development of a frequency dependent network equivalent (FDNE) requires knowledge of the frequency response of the system to be represented. The modelling of the frequency dependence of overhead lines and cables is well advanced in electromagnetic transient packages, but this is not the case with other system components; for instance the standard models of generators, transformers and loads do not represent the increase in resistance (and slight reduction in inductance) associated with skin effect. Therefore the use of a frequency domain program will give a frequency response closer to reality. However, if the FDNE is developed from the frequency response obtained from a frequency domain program its accuracy can only be assessed by corresponding measurements in the real system, which is not a practical proposition. Hence for verification purposes, the approach taken in this paper is the derivation of the frequency response from the less accurate time domain simulation, as this allows the complete time domain model to be used as the benchmark. The New Zealand Lower South Island shown in Fig. 1. is used as a test system with a resistive load connected to the Tiwai bus and fault is applied to phase C.



<Fig. 1> Test System

3. Structure Of The Frequency Dependent Network Equivalents

The three-phase system equivalent of the test system will be of the form shown in Fig. 2, where each frequency dependent block is represented by a rational function.



<Fig. 2> Three-phase FDNE

3.1 Obtaining the Rational Function from Frequency Response

Each term is represented by a rational function of the form.

$$H(z) = \frac{a_0 + a_1 z^{-1} + a_2 z^{-2} + \cdots + a_m z^{-m}}{b_0 + b_1 z^{-1} + b_2 z^{-2} + \cdots + b_m z^{-m}} \tag{1}$$

3.2 Implementation in Time Domain

From eqn, (1)

$$\begin{aligned} i(n\Delta t) &= a_0 v(n\Delta t) + a_1 v(n\Delta t - \Delta t) + a_2 v(n\Delta t - 2\Delta t) \\ &+ \cdots + a_m v(n\Delta t - m\Delta t) + b_1 i(n\Delta t - \Delta t) \\ &+ b_1 v(n\Delta t - 2\Delta t) + \cdots + b_m i(n\Delta t - m\Delta t) \end{aligned} \tag{2}$$

Hence in discrete time:

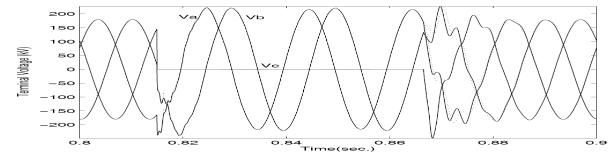
$$i(n\Delta t) = G_{equiv} \cdot v(n\Delta t) + I_{History} \tag{3}$$

여기서 $G_{equiv} = a_0$

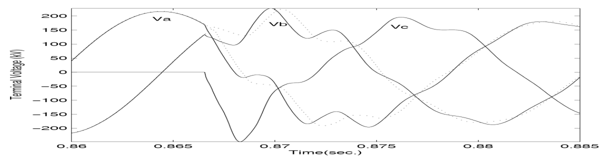
$$\begin{aligned} I_{History} &= a_1 v(n\Delta t - \Delta t) + a_2 v(n\Delta t - 2\Delta t) \\ &+ \cdots + a_2 v(n\Delta t - m\Delta t) + b_1 i(n\Delta t - \Delta t) \\ &+ b_2 i(n\Delta t - 2\Delta t) + \cdots + b_m i(n\Delta t - m\Delta t) \end{aligned} \tag{4}$$

4. Simulation

The simulations performed using PSCAD/EMTDC, consist of a single-phase fault represented by a 0.001 Ω resistance, applied to phase C at 0.815 s and removed after 0.05 s. The comparison of the Full system and FDNE (using a frequency range of 5-1250 Hz for fitting) solutions is displayed in Fig. 3. The period immediately after fault inception (expanded in Fig. 4) is practically identical in both cases, while slight differences are noticeable after fault removal.

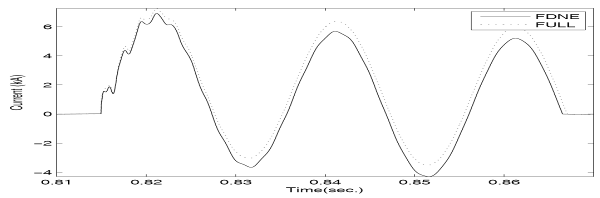


<Fig. 3> Comparison of transient assessed using full system and FNDE representation, solid-full system, dotted-FNDE

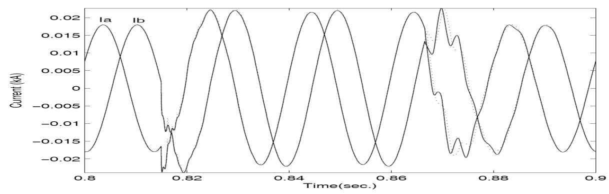


<Fig. 4> Fault removal, solid-full system, dotted-FNDE

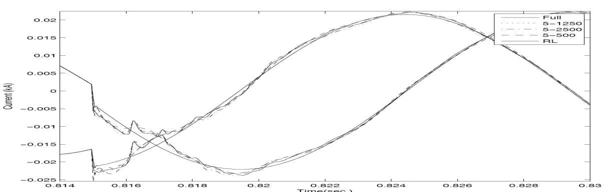
The phase currents are shown in Fig. 5 ~ Fig. 7. Close inspection of these shows that the FDNE equivalent mimics the full system well; however, there is a low frequency component that causes a growing phase lag in the voltage during the fault period. This means that when the fault is removed there is a slight discrepancy in the voltage between the Full and FDNE solutions which accounts for the slight differences in the transient on fault removal. This phase difference vanishes within approximately 0.25 s of fault removal.



<Fig. 5> Current in faulted phase (phase C), solid-full system, dotted-FNDE



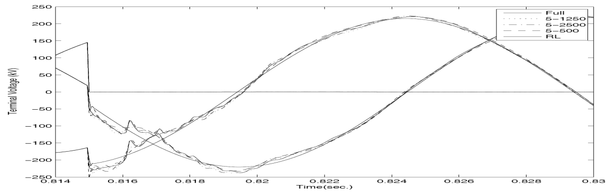
<Fig. 6> Current in unfaulted phases (phase A and B), solid-full system, dotted-FNDE



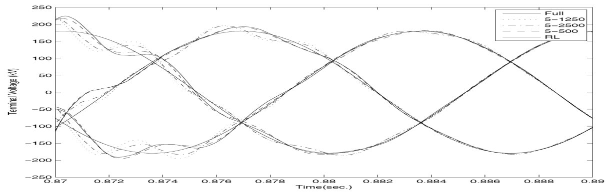
<Fig. 7> Expanded view of current in unfaulted phases (phase A and B), dotted-FNDE

Fig. 8 and Fig. 9 show an expanded view of the terminal voltage on fault application and removal. All, except the 50 Hz based RL equivalent, give a good representation of the full system with the main error at fault removal due to the phase shift.

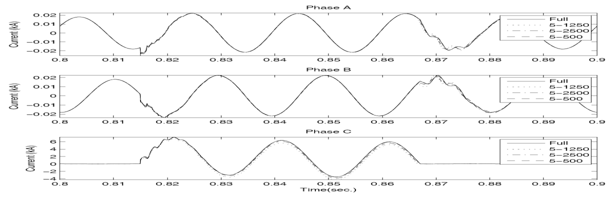
Fig. 10 shows the same comparison for current (without the RL equivalent). Careful inspection of the current error, displayed in Fig. 11, shows that the greater the frequency range used for the fitting, the smaller the initial error; however, after 0.02 s all equivalents, even the 50 Hz based RL equivalent, give the same error. This error is due to the low frequency component causing the phase shift. Inspection of the error in the terminal voltage is very similar to the current error.



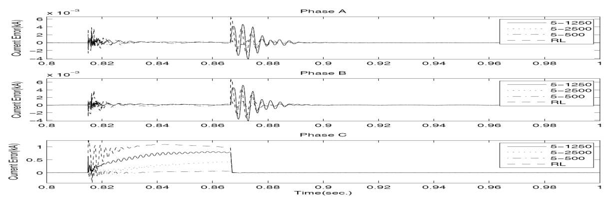
<Fig. 8> Comparison of terminal voltage for fault application



<Fig. 9> Comparison of terminal voltage for fault removal



<Fig. 10> Comparison of current waveforms



<Fig. 10> Comparison of current error

5. Conclusion

The weighted least-squares fitting of a z-domain rational function has been formulated and its application to the development of a frequency dependent network equivalent of a practical system has been demonstrated. Full information of the derived FDNE has been given, allowing the transient response of this FDNE to be easily assessed and compared to other FDNEs developed for the same test system.

The effect of frequency range used to develop the FDNE has been shown and compared to an RL equivalent based on fundamental frequency information.. Although the frequency range determines the error in the first cycle after a disturbance, after this period the phase shift from a low frequency component dominates. All the equivalents give the same error after 0.04 s. There is a need to improve the fit below 50 Hz in order to remove this phase shift.

[References]

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