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Simulation of resonance over-voltage during energization of high voltage power network

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Abstract

Under network equipment outage conditions, the system has to be restored to normal operating conditions as fast as possible to ensure the supply security and avoid prolonged interruption of power supply. In the development of the restoration strategy under different contingencies, a wide range of issues are needed to be studied. For different contingencies, it is important that appropriate approaches, tools and study models are selected and used to meet different objectives.

The extraordinary system conditions during restoration require special electromagnetic transient analysis with different system modelling methods and system parameters. All these are very different from those studies conducted for normal operating conditions. Field tests of various restoration arrangements also play an important role in calibrating the study models and parameters in order to verify the study results. With all these studies, CLP Power is able to establish practical and reliable system restoration plans.

Keywords: Temporary over-voltage; Resonance; Power system restoration; Insulation coordination; Power system simulation; Field tests

1. Introduction

CLP Power operates a vertically integrated electricity generation, transmission and distribution business to serve about 80% of the population in Hong Kong Special Administrative Region. The maximum local demand in 2004 was 6329 MW. The transmission and distribution network comprises more than 11,900 km of overhead line and cable with voltages ranging from 11 kV to 400 kV.

It is the key objective of CLP Power to provide a stable and reliable power supply to its customers. Under different situations, such as supply restoration after large disturbance, energization of various system equipment is required to restore the system to normal operating conditions as fast as possible in a safe and efficient manner.

However, as the network configurations under outage conditions are much different from the normal system running arrangements, the restoration plan of the network requires a detailed study in the planning stage to assess the feasibility and risk involved as well as to develop an optimal system restoration strategy.

The most direct way to assess the feasibility and risk of the restoration plan is to conduct field tests. However, apart from the high degree of risk anticipated, field tests require resources and network outages which may affect the supply reliability. It is also not practical to test all configurations and operating conditions in the restoration plan. Furthermore, in many cases field tests could not be conducted due to operational limitations.

Simulation study has the flexibility to model and analyse different network configurations and system conditions for the restoration plan. However, the accuracy of the models and hence the results are sometimes questionable. To solve this problem, CLP Power has adopted a hybrid approach to assess the feasibility and risk of the restoration plan by combining simulation study with field tests.

This paper describes the resonance over-voltages encountered during the energization of transformers in transmission systems and the use of simulation method for resonance analysis and formation of risk mitigation measures.

2. Study for power system restoration

The major objective of power system restoration study is to develop an optimal restoration strategy to ensure an efficient and reliable process of restoration of supply to the customers with the shortest time while maintaining the stability and security of

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the system and the safety of its related equipment during the restoration process.

The system characteristics and behaviour during the restoration process are highly non-linear and complex. The extraordinary system configurations and the operating conditions may result in system response beyond the scope of normal operations. Because there are many complex and different problems to be solved in the restoration study, it is more effective to break down the big problem into small ones and analyse them one by one with appropriate analysis tools.

A wide range of issues are needed to be studied at the planning stage to identify the risk associated with the system characteristics and performance under restoration conditions and to develop mitigation measures if required. Other than the capability of the generating plants and their auxiliary equipment for restoration, the most commonly performed studies are analyses focused on load flow, stability, voltage profile, system frequency and fault level studies which are also performed for normal operating conditions. For these studies, the modelling methods and the system parameters used in the restoration study are basically the same as that in the studies for normal system operating conditions.

However, with the extraordinary system configuration during restoration, the behaviour of the system is basically electromagnetic transient in nature and this requires some special electromagnetic transient analysis, and different system modelling methods and system parameter requirements. For example, for the analysis of the resonance over-voltage in restoration through transformers, it requires the modelling of the non-linear magnetizing characteristics of the transformers. It is therefore important to build appropriate models and use appropriate parameters according to the objectives of the studies.

3. Resonance over-voltage

A major concern during restoration is the resonance over-voltage occurred during the energization of a no-load transformer as shown in Fig. 1.

The root cause of resonance over-voltage is the unfavorable combination of the source impedance, the shunt capacitance of the energized circuits, the non-linear magnetizing characteristics of the energized transformer, inadequate damping of the system and the source voltage phase angle at the moment the transformer is energized.

Resonance over-voltage is not commonly known as it usually does not exist in normal operating condition. It is also not possible to identify its existence by common system analysis tools using linear models for system elements. Fig. 2 shows a typical waveform of resonance over-voltage recorded by site measurement.

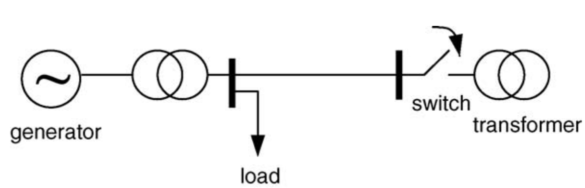

Fig. 1. Energizing a no-load transformer.

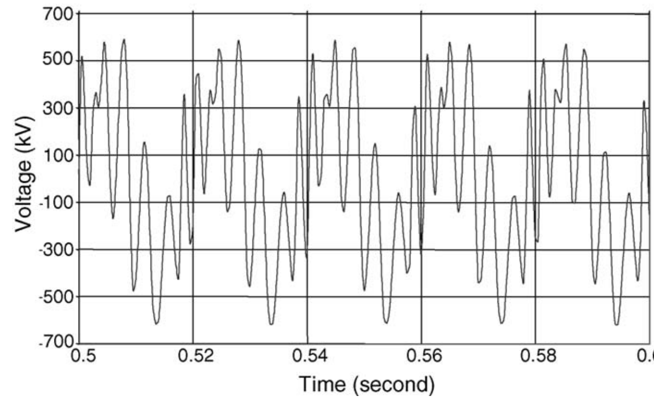

Fig. 2. Recorded waveform of resonance over-voltage.

Resonance over-voltage is a kind of sustained or poorly damped temporary over-voltage. The waveform shown in Fig. 2 contains a number of high frequency harmonic components which can be identified by a Fourier analysis. The Fourier analysis result (as shown in Fig. 3) indicates that the dominant harmonic voltages components of the voltage waveform are in the range of 250–300 Hz.

System equipment is usually designed to withstand a power frequency over-voltage of about 1.6 p.u. for 1 min. The equipment can withstand higher over-voltage if the duration of the over-voltage is shorter. However, the magnitude of resonance over-voltage may exceed 1.6 p.u. for a longer time if the resonance is poorly or not damped.

Furthermore, the protective devices in the system such as surge arresters will normally be activated before the resonance over-voltage reaches the equipment's over-voltage withstand limits. Also the over-voltage withstand capability of the equipment may deteriorate due to aging or other internal defects.

Therefore, sustained resonance over-voltage, even it is below the specified over-voltage withstand capability of system equipment, may damage the system equipment or result in tripping of some circuits during restoration process. Such situation is not desirable and the risk of resonance over-voltage should be minimized.

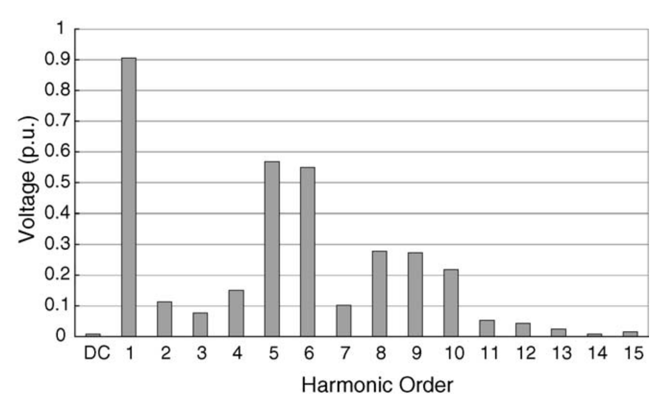

Fig. 3. Fourier analysis of resonance over-voltage in Fig. 2.