proaches can give results of large generality and accuracy. One of the models presented in the literature (that from K. H. Weck) and the model proposed in the paper allow to reach an accuracy generally much better than 10% for configurations without insulators.

Integration methods generally resulted in much lower accuracy.

All the models presented low accuracy for the configuration with insulators considered (*I*-type string without shielding electrodes) thus underlining the necessity of further studies. However larger accuracy of the evaluation methods is expected for actual configurations, also in presence of insulators, in all the cases for which the discharge does not directly involve the insulators (e.g. *V*-type string or *I* string with shielding electrodes).

Discussers: B. Hutzler, T. Shindo and T. Suzuki

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Computer Models for Complex Plant & System Based on Terminal Measurements

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Keywords: Equivalent, Circuit, Frecuency, Transformer, Motor, Fourier, Analysis, Transient, Voltage, Swithcing.

Summary

A method for obtaining models of complex plant and systems for use in transient voltage studies is described. The method is based upon determining the terminal impedance/frequency characteristics of the plant or system under study over a wide frequency range. These characteristics are obtained from measurements performed at sampled frequencies with a programmable impedance meter and microcomputer. A method for correcting results for measuring lead length errors is also described.

The method is shown to be applied to obtain models of single and three-phase transformers. These are validated comparing measured and calculated input impedances.

The impedance/frequency characteristics are used to calculate the transfer functions across any two terminals of the system. The response to any excitation is calculated first in the frequency domain as the product of the frequency spectra and the transfer functions, and second in the time domain by the inverse Fourier transformation.

This method is applied to calculate the second-pole-to-close switching transient generated in a breaker/cable/motor system. Again, measured and calculated results show excellent agreement.

Although some limitations of this method appear at frequencies of up to 10 KHz, it is generally applicable to all items of system plant and to systems.

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Network Reconfiguration in Distribution Systems for Loss Reduction and Load Balancing

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Distribution systems are normally operated as radial systems; however, configuration of the system can be changed (reconfigured) by changing the state of some sectionalizing switches, strategically placed on the line sections of the system. Especially with the introduction of remote control capability to the switches, on-line network reconfiguration become an important part of distribution automation. The network is reconfigured for two purposes: (i) to reduce the system power loss, (ii) to relieve the overloads in the network. The first problem is referred to as network reconfiguration for loss reduction and the second as load balancing.

In this paper, network reconfiguration for both loss reduction and load balancing are considered and general formulation and solution methods are proposed.

The problems are similar to each other and differ only in their objectives. Noting that the radiality constraints forces one to choose only *spanning tree* type topological configurations, the problems can be formulated as a *minimal spanning tree* problem of the following type. Given a graph, representing the network topology, find a spanning tree such that the objective function (power loss or load balanced index) is minimized while the following constraints are satisfied:

- voltage constraints,
- capacity constraints of lines, transformers,
- reliability constraints.

In network reconfiguration for loss reduction, the solution involves a search over relevant radial configurations. To aid the search, two different methods, with varying degree of accuracy, have been developed to estimate the new power flow in the system after a load transfer between two laterals, feeders, or substations. To represent the power flow in a radial distribution network, the methods utilize the following type recursive equations, called the *DistFlow branch equations* [1], which uses the real power, reactive power, and voltage magnitude at the sending end of a branch $-P_i, Q_i, V_i$ respectively to express the same quantities at the receiving end of the branch.

$$P_{i+1} = P_i - r_i \frac{P_i^2 + Q_i^2}{V_i^2} - P_{Li+1} \tag{1.i}$$

$$Q_{i+1} = Q_i - x_i \frac{P_i^2 + Q_i^2}{V_i^2} - Q_{Li+1} \tag{1.ii}$$

$$V_{i+1}^2 = V_i^2 - 2(r_i P_i + x_i Q_i) + (r_i^2 + x_i^2) \frac{P_i^2 + Q_i^2}{V_i^2} \tag{1.iii}$$

The methods are computationally attractive and in general give conservative estimates of loss reduction.

For load branching, the ratio of complex power at the sending end of a branch, S_i over its KVA capacity, S_i^{max} is used as a measure of how much that branch is loaded. The branch can be a transformer, a tie-line with a sectionalizing switch or simply a feeder section. Then the load balance index for the whole system is defined as follows.

$$c_b = \sum \left(\frac{S_i}{S_i^{max}} \right)^2 = \sum \frac{P_i^2 + Q_i^2}{S_i^{max\,2}} \tag{2}$$

This will be the objective function of load balancing.

Since the two problems are similar (they both require the same data (system parameters and load) and load flow calculation to evaluate the objectives for a given network topology), the search and power flow estimation methods developed for power loss reduction can also be used for load balancing.

The convergence behavior of the search method is tested and test results are presented. Although the method is heuristic, its convergence characteristics seems acceptable for practical purposes.

References

[1] M. E. Baran, and F. F. Wu, "Optimal Sizing of Capacitors Placed on a Radial Distribution System," *presented at IEEE PES Winter Meeting,* Feb. 1-6, 1988, paper no 88WM 064-8.

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Telephone Interference Criteria for HVDC Transmission Lines

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Summary

The telephone interference caused by a transmission line is primarily characterized by the equivalent line disturbance current defined as:

$$I_e = \sqrt{\sum_n (C_n \cdot I_n)^2}$$

where

C_n = C-message weighting factor for the n:th harmonic
I_n = residual line current of n:th harmonic

For many HVdc lines, particularly in North America, this current has been required to be <270 mA. During the last few years, however, values as low as 100 mA have even been specified by some utilities. Since the cost for installation of dc filters in the converter stations becomes high and very progressive if the equivalent line disturbance current has to be limited to less than about 1 A, it is very important that the specified value reflects the actual need from a telephone interference standpoint.

The object of the report is to identify the maximum tolerable equivalent disturbance current for transmission lines. This is done by means of a combination of calculations and measurements in which different key parameters are scanned and evaluated. Based on a general calculation of coupling impedance versus soil resistivity and frequency, specific data are defined for a typical "worst case" coupling between a HV line and a telephone system in a suburban area. Disturbance current criteria for a dc line are given in the report based on a maximum noise metallic voltage at a telephone set of 17 dBrnC (OdBrnC = 24.5 μV across 600 ohm) and a circuit balance of 60 dBrnC.

An important issue of the report is to give a comparison with corresponding disturbance currents of HVac lines, which are the result of totally different disturbance criteria successfully applied for decades. Moreover, the telephone interference requirements as identified in the IEEE Std 776-1987 for distribution lines are compared with calculated disturbance criteria for dc lines. The conclusions of the report are:

— An acceptable noise level for a state of the art telephone system should in most cases be obtained if the equivalent C-message weighted disturbance current (I_e) on a dc line is limited in the following range depending on the soil resistivity:

$$1.5 < I_e < 3 \text{ A at } \rho = 100 \text{ ohm} \cdot \text{m}$$

$$0.75 < I_e < 1.5 \text{ A at } \rho = 1000 \text{ ohm} \cdot \text{m}$$

— The threshold levels as defined in the IEE Std 776-1987 for distribution lines are comparable or less stringent than the criteria identified above.
— Measurements show that filter performance requirements, which for the ac side of converter stations have been successfully applied for decades correspond to ac line disturbance currents in the range of

$$1.5 < I_e < 3 \text{ A}$$

— Currently specified disturbance limitation criteria for dc lines are too stringent and not coordinated with corresponding criteria for distribution lines and HVac lines.

Discussers: A. Coutu, D. J. Lorden, K. A. Adamson and S. C. Kapoor

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Availability of Corona Cage for Predicting Audible Noise Generated from HVDC Transmission Line

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In DC transmission lines, corona current and audible noise (AN) generated from a conductor bundle for Gmax (the static maximum conductor surface gradient) depend greatly on the surrounding electrode configuration because of the difference in the effect of space charge generated by corona discharge. Even for the same Gmax, the corona current and AN generated differ owing to the electrode arrangement around the conductor bundle. Therefore, the method of predicting corona current and AN for AC lines which uses Gmax as the main variable is not applicable to DC lines.

This paper describes a prospect that a corona cage is available for predicting AN generated from HVDC transmission lines. In this approach, Fmax (the "true" maximum conductor surface gradient in the presence of space charge, obtained by the ion flow computation for the area surrounding the conductor bundle) is introduced as the main variable in order to evaluate the effect of space charge. It allows us to have standardized AN performance of a conductor bundle by using a corona cage based on the following assumption:

"If the surface condition of conductors and the weather conditions are the same, the corona current and AN generted from a conductor bundle are determined by Fmax, regardless of surrounding electrode arrangement."

This assumption has been verified for the following electrode configurations:

1) Between corona cages with different diameters for a 4 × 2.85 cm conductor bundle