Messwandler-Symposium

Am 10. März 1976 fand in Zürich unter der Leitung von Dr. A. Goldstein, Baden, ein SEV-Symposium über Messwandler statt. Die Entwicklung der Messwandlertechnik der letzten Jahre ist gekennzeichnet durch höhere Netzspannungen, strengere Anforderungen an das transiente Verhalten infolge wachsender Netzleistungen, genauere Erfassung des dielektrischen Verhaltens der Isolation sowie durch Ansätze in Richtung nichtkonventioneller Messwertübertragung. Der nachfolgende Aufsatz ist eine gekürzte Fassung des Symposiums-Aufsatzes von F.E. Holder. Anschliessend folgt eine Zusammenfassung der Aufsätze und Diskussionsbeiträge. Der ausführliche Symposiumsband mit allen Aufsätzen kann beim Administrativen Sekretariat des SEV zum Preis von Fr. 40.– (plus Portospesen) bezogen werden.

Measurement Transformers for Power Networks – a User View [1])

By F. E. Holder

Consideration is given to some of the relevant network phenomena affecting the demands made of measurement transformers of 'conventional' type commonly in use. Their performance under steady-state operating conditions as well as abnormal network are relevant factors, but it is also important to consider them as primary plant whose behaviour may have an effect on the primary network. In assigning a performance specification to measurement transformers account must be taken of practical operating experience which may suggest a less onerous specification than theoretical 'worst case' conditions would imply.

Einige wichtige Netzerscheinungen werden aufgeführt, welche die Anforderungen an Messwandler der üblichen «konventionellen» Bauart bestimmen. Massgebende Faktoren sind das Verhalten der Wandler im stationären Betrieb sowie bei gestörten Netzbedingungen. Daneben ist es wichtig, die Wandler auch als Primärapparate zu betrachten, deren Verhalten sich auf das Hochspannungsnetz auswirken kann. Beim Entwurf eines Pflichtenheftes für Messwandler sollen praktische Erfahrungen berücksichtigt werden, die möglicherweise eine weniger teure Lösung zulassen als dies der theoretische «Schlimmstfall» erlauben würde.

L'auteur décrit quelques phénomènes importants dans les réseaux qui déterminent les exigences à poser aux transformateurs de mesure (TM) usuels du type «conventionnel». Le comportement des TM en service stationnaire et en service dérangé sont des facteurs déterminants, mais il est tout aussi important de considérer les TM comme appareils primaires dont le comportement se répercute dans le réseau à haute tension. Lorsqu'on établit une spécification technique pour les TM, il importe de tenir compte des expériences pratiques qui peuvent conduire à une spécification moins onéreuse que les conditions théoriques extrêmes ne l'impliqueraient.

1. Introduction

This paper is concerned with conventional electro-magnetic current transformers and voltage transformers as well as capacitor voltage transformers in respect of both steady-state and transient performance in relation to their common usage on electrical power networks.

As generator unit sizes have increased, so their inertia constants have decreased. At the same time, both the geographical and electrical transmission distances have increased. The combined effect has been to reduce the stability margins of networks compared with earlier power systems. Furthermore, the DC time constant of the electrical loop between the generating source and a given 'fault point' on the network has tended to increase significantly leading to consideration of switchgear duties [1; 2] [2]). These factors have resulted in the need for faster response of some measurement equipments (example protection relaying) and closer examination of the measurement transformer requirements.

2. Relevant Network Phenomena affecting Measurement Transformers

Performance required of measurement transformers during power network short-circuit may be related to a rapid autoreclose cycle as follows:

2.1 Pre-response state of measuring equipment
2.2 Response to initial fault transient, and during the critical decision period of the relay
2.3 Behaviour during the latter part of the fault period, that is, post decision but pre-fault clearance
2.4 Response subsequent to fault removal
2.5 Response to fault transient during the critical decision period of second fault
2.6 Behaviour during latter part second fault period
2.7 Behaviour during final de-energisation of the faulted element

Routine switching operations may be significant under the following circumstances:

2.8 Energisation of an open-ended transmission line on which there is a significant trapped charge voltage
2.9 Energisation of a transmission circuit (line or cable connected), to which an inductive load is connected at the remote terminal (example: reactor or transformer or combination of both)
2.10 De-energisation of a circuit of the type described in 2.9
2.11 Sudden removal of a power source from an element or group of elements containing reactance and capacitance, to which there may also be connected rotating electrical plant
2.12 Interconnection of two elements each of which may be energised from differing supply sources (example: a poor synchronising when connecting a generator to an operational network)

3. Measurement Transformers considered as Primary Plant

It goes without saying that any measurement transformer whose primary winding is directly connected to an electrical power network must be assigned an appropriate insulation level. Further, the apparatus must be capable of withstanding transient phenomena without thermal distress or mechanical damage.

If an insulation failure occurs within a measurement transformer used to supply protection relaying, the consequences are very serious. Some Users favour 'Discharge' testing but there are some problems when the insulating materials used within a single assembly differ significantly in their inherent characteristics.

Current transformers (CTs) and capacitive voltage transformers (CVTs) rarely have any significant effect on the overall

[1]) Abstract of the Paper presented at the SEV Symposium on Measurement Transformers, March 10, 1976.

[2]) References at the end of the paper.

performance of the network. An electro-magnetic voltage transformer (EMVT), on the other hand, can reduce switching overvoltages on a long transmission line because it is able to drain the 'trapped-charge' when the circuit is disconnected from the main power network.

The User must consider whether this advantage is commercially justified bearing in mind that modern circuit breakers for extremely high voltage (EHV) are equipped with preclosing resistors which, in effect, rapidly discharge the line prior to the main contacts of the circuit breaker closing.

4. Performance under Steady-state Operating Condition

Broadly speaking, transformers which are used to energise energy measurement meters, instruments and slow acting control systems are required to maintain defined accuracy limits over a restricted operating range of voltage and frequency. Accuracy classes, well defined in National and International Standards [3; 4], may also be subject to particular User or statutory limits.

Some Users favour conjunctive testing of the transformers and measuring equipment, especially for energy measurement. Such tests are somewhat expensive but may be judged to be necessary for particular operational or contractual reasons.

Whilst accuracy of output during abnormal network conditions is not relevant, subsequent performance should not be impaired nor should the measurands presented to connected equipment be such as may cause damage.

5. Response to Abnormal Network Conditions

Transient response is particularly relevant to high-speed protection relaying (20 ms or less).

5.1 *Voltage Transformers (VTs)*

The dynamic response of an EMVT when a short-circuit is applied to a primary network is inherently adequate for presently available fast response analogue relay systems, irrespective of the point-on-wave of the voltage cycle when the fault occurs. The windings do, of course, posses capacitive coupling between turns and between layers, and high frequency oscillations can occur both during de-energisation and energisation. Such oscillations are usually small in magnitude, are heavily damped and thus do not play a significant part in the VT performance as seen by the relays.

The CVT is the more commonly used source of reference voltage on EHV transmission networks and has transient response limitations which must be recognised. The subject has been discussed in detail elsewhere, and it is sufficient here to state that the User may need to assess the relative performance characteristics of different CVT designs and relate these to particular protection relaying schemes [5...7].

Key factors for the relay are time deviation between primary and secondary voltage collapse to zero, transient overshoot of the secondary output voltage, and time for the secondary output oscillatory voltage to decay to a value which has negligible effect on the performance of the particular relay under consideration.

5.2 *Current Transformers*

Conventionally, CTs for protection relaying are expected to satisfy defined accuracy conditions when rated burden is connected to the secondary terminals and the primary applied sinusoidal current is that multiple of rated current appropriate to the accuracy limit factor (ALF). It has long been realised [8] that when the current in a given fault loop on a power network contains a significant DC component which decays exponentially with a time constant dictated by the network parameters ($T_1 = L/R$), the flux swing within the CT core is many times greater than the value necessary to reproduce the sinusoidal component of short-circuit current (fig. 1) [9].

For a previously de-magnetised closed-cored CT, the dimensioning necessary approximates to ($\omega T_1 + 1$) times that value which would be necessary to avoid saturation in the presence of a symmetrical sinusoidal current. Furthermore, modern core materials can retain a significant proportion (K_R) of the saturation flux for long periods; typically K_R will be in excess of 80% of the 'saturation flux'.

Thus if we consider the autoreclose cycle quoted in sections 2.1...2.7 above and assume that the CT is subjected to two consecutive energisations each of which is fully offset of the same polarity and whose effects are cumulative in respect of the pre-response state of the CT core, then the dimensioning necessary to avoid any saturation during the prescribed duty cycle may be written:

$$\text{Total Dimensioning Factor } K_{TD} \approx \frac{1}{1-K_R}\,(2\,\omega\,T_1+1) \quad (1)$$

Substituting typical numerical values of $K_R = 0.5$ and $T_1 = 0.1$ s will show that the core must have a cross-sectional area 128 times that value which would be necessary to avoid saturation in the presence of the symmetrical short-circuit current only, all other parameters being substantially similar.

In practice, experience has shown that such extreme over-dimensioning is not justified. The statistical probability of two consecutive fully offset faults of the same polarity occurring on an operational network is extremely low. The probability of

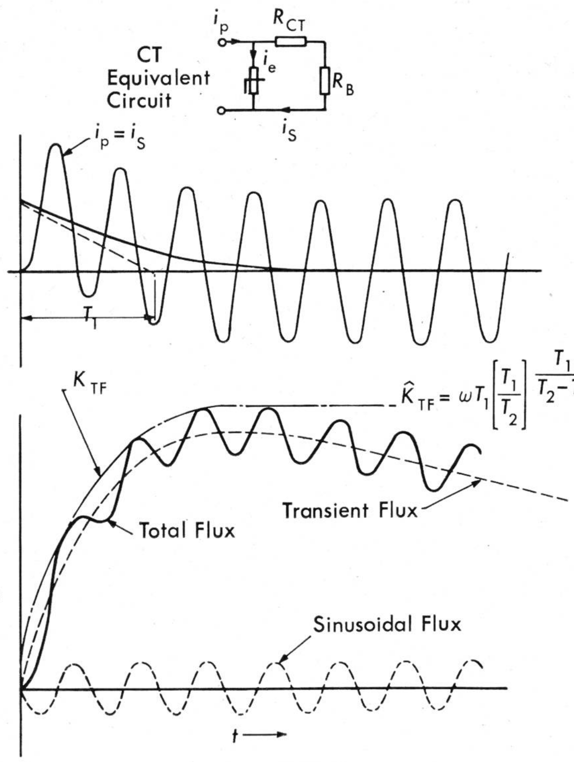

Fig. 1 Effects of DC component of primary fault current on flux demands made on CT core

remanent flux in the CT core being of similar polarity is at least an order lower still.

In many cases, the decision period of the relaying scheme is significantly less than the decay period of the DC component of fault current. Thus, transient saturation may be permissible after a defined time and thereby permit the use of a smaller CT.

Nevertheless, somewhat higher time constants are being encountered on large networks (of the order of 0.5 s at the terminals of large turbo-generators) [10] and further consideration is being given to the introduction of small controlled airgaps into the CT cores. Working Group 14 of the IEC TC 38 was formed to study the problem and consider a possible specification.

The general equation for the transient dimensioning factor (K_{TF}) representative of a single energisation of the CT whose core was previously de-magnetised may be written [9]:

$$K_{TF} = 1 + \frac{\omega T_1 \cdot T_2}{T_2 - T_1} \left(e^{-t/T_2} - e^{-t/T_1}\right) \qquad (2)$$

wherein the time to be chosen depends on the decision time of the protective relays connected to the CT.

It will be observed that the secondary circuit time constant (T_2) is a significant factor in determining the transient dimensioning necessary and it is convenient to consider three designs of CT designated X, Y and Z as follows:

Type X: a conventional closed-cored CT having a value for T_2 of the order of some s and an inherent remanence factor K_R of the order of 0.8 or greater.

Type Y: a similar CT equipped with small 'anti-remanence' gaps in the core and having a secondary circuit time constant T_2 of the order 200...300 ms and K_R less than 0.1.

Type Z: a so-called linearised design, having a value $T_2 \approx 60$ ms and negligible remanent flux.

Inevitably, advantages which accrue in respect of a reduction in dimensioning for type Y and Z designs must be set against the increase in 'error' in the measurands presented to the relaying equipment and assessed in relation to the total scheme.

5.3 *VT and CT Performance Considered Conjunctively*

Dual input processors may determine the product, the quotient or the phase angle relationship between voltages and currents. Distance impedance measuring protection relay systems are most significantly affected by CVT transient response and CT behaviour. From a purely analytical point of view it will be seen that CT dimensioning can be minimised if the decision time of the relay is very short [11]. Conversely, the accuracy of measurement and the directional response of the relay are both very dependent upon the CVT transient response and a longer decision time is desirable for reasons of security [12].

The User must take account of both factors when considering the overall performance of a particular scheme. Conjunctive testing is very desirable but is both expensive and difficult if the CVT is to be accurately modelled. Nevertheless, there have been considerable advances in testing techniques.

6. Overall Philosophy Leading to Application Specification

A dilemma which frequently faces the User applications engineer is to achieve a balance between capital outlay and 'idealised' technical objectives.

For example, to provide separate voltage transformers for earthing [13], protection relaying, instrumentation and metering functions would be very costly. On the other hand, a compromise specification may satisfy all the functional requirements within acceptable limits and permit one voltage transformer to be used.

7. Unexpected Events or Unusual Phenomena

The comments made so far have been concerned largely with electrical behaviour and natural phenomena which are well recognised and may be expected on any power network throughout the world but may differ slightly as a result of local conditions.

Individual Users have had unanticipated experiences involving phenomena for which no account was taken in equipment design. Geo-magnetic storms [14] which occur in parts of the northern hemisphere, coincident with sun-spot activity, have resulted in significant low frequency currents being induced in the networks concerned, leading to transformer saturation as well as relay malfunction.

Detailed changes in equipment design may equally result in unexpected responses. For example, the replacement of single-break oil circuit breakers by multiple-break small oil volume units equipped with shunt connected voltage control capacitors may result in series resonant oscillation with the magnetising inductance of a VT. This may occur when an already open circuit breaker is being isolated for maintenance purposes.

No doubt there are many other examples arising from changes in types of materials or modifications to the methods of fabrication. Increasing use of automatic control techniques, applied to the operation of power networks, makes it especially important that observed unusual phenomena are widely reported as soon as possible.

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