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THE ASSESSMENT OF FLICKER FROM GROUPS OF SUPERGRID CONNECTED ARC FURNACES

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INTRODUCTION

The following basic problems are encountered in the assessment of flicker from several installations connected at different locations:-

The technique for determining the flicker that may result at the point of common coupling (P.C.C.) from a single installation is well established and described in Engineering Recommendation P.7/2 [1] and its associated ACE report [2]. The technique for calculating the flicker that may result from several installations as described in the recommendation is a laborious process. Basically it involves reducing the network to an equivalent three node mesh which permits the flicker at one node to be referred to a second node. This process has to be repeated for all sources of flicker and nodes where flicker may be excessive. In some circumstances there may be nodes without directly connected arc furnace installations which must also be studied because of their proximity to several installations.

The difficulty in choosing the system conditions and fault levels that should be studied makes it desirable to assess the sensitivity of the results to fault level changes. The variation of flicker with the annual variation of fault level is, for a single installation, dependent upon only the variation of fault level at its own point of common coupling P.C.C. However, with several installations the variation of flicker is dependent upon the variation of fault level at the P.C.C's of all the installations. Assessment of this variation using the method described in P.7/2 is again a tedious process.

The statistical law given in P.7/2 for summing the flicker from a group of furnaces may not apply for all the conditions realised in practice and an assessment may need to be made of the effect of flicker variation for different statistical laws of combination. Again the repeated calculations for assessing this variation is tedious.

The effect of variations in severity factor need to be considered if the correct value is not generally known. Since the variation of flicker is proportional to severity factor assessment is made relatively simple if the same value of severity factor is used for all furnaces.

These aspects of the overall flicker level assessment have been examined to see if any techniques can be formulated for simplifying the task without introducing significant errors. Since there is always considerable uncertainty in the postulated conditions, e.g. furnace ratings and characteristics, system fault levels, etc., any small errors introduced by simple scaling factors may not have a significant effect on the final results.

ALTERNATIVE FLICKER ASSESSMENT TECHNIQUES

Calculation of Flicker

An alternative and less laborious procedure to that given in P.7/2 for establishing the effect of several installations is to make use of the harmonic penetration program HARP03 [3]. This program allows a network to be represented by the resistance, reactance and susceptance values of its branches and complex voltage and current sources may be applied at any node. The output data is the resulting voltage and current distribution in the network.

A short circuit study, with generator infeeds as sub-transient reactances for the appropriate condition of the national network may be reduced to the area of interest with the aid of the network reduction program DRIL04 [4].

This section of the network may then be represented in HARP and a current lagging by 90° can be injected at the appropriate node to simulate the furnace. The value of the injected current is set to represent the equivalent short circuit MVA of the furnace:-

I injected =

$$\frac{\text{furnace SC MVA}}{100\ \text{MVA}} \times 1 \text{ p.u. current}$$

where furnace SC MVA =

$$\frac{10^4}{\%X_s + \%X_t + \%X_f} \qquad -(1)$$

and $\%X_s$ = reactance of source (behind P.C.C.)

$\%X_t$ = reactance of transformers between P.C.C. and furnace bar

$\%X_f$ = reactance of furnace

(all % on 100 MVA)

Output data from the study gives the voltage change ($\Delta V\%$) at each node of interest. The process is then repeated for each of the other furnace installations. The flicker values ($\%Vf_g$) are then obtained by multiplying the voltage changes by the severity factor, i.e. :-

$\%Vf_g = k_s\% \Delta V =$

$$\frac{k_s \times \text{furnace SC MVA} \times 100}{\text{SC MVA at P.C.C.}} \quad - (2)$$

where k_s is defined as the severity factor in P.7/2.

Flicker values obtained in this manner will correspond to values calculated according to P.7/2 for a furnace acting alone. The flicker values at nodes other than the source P.C.C. will be the proportions of the source flicker transferred to these nodes.

The combined flicker at a P.C.C. resulting from the operation of three furnaces with P.C.C's 1, 2, and 3 is then calculated according to the nth root combination law:-

Combined flicker at P.C.C.1 =

$$\sqrt[n]{\%Vf_{g1}{}^n + vf_{g2}{}^n + vf_{g3}{}^n} \quad -(3)$$

where Vf_{g1} is local flicker

vf_{g2}, vf_{g3} are flicker contributions from remote P.C.C's 2 and 3

n can have values between 2 and 4 depending mainly on the assumed modes of operation of the furnaces.

Where there are a number of furnaces with a common supply their representation can be reduced to a single injection of current (90^o lag) of value corresponding to:-

equivalent S.C. MVA =

$$\sqrt[n]{\text{SC MVA}_1{}^n + \text{SC MVA}_2{}^n + \text{SC MVA}_3{}^n}$$

It is also worth noting that if a study is to be made with a different combination law it is only necessary to scale the results of the HARP study in the ratio of the equivalent short circuit MVA ratings for the installation as derived from the application of the two combination laws.

In addition to simplifying the basic assessment the technique makes it easier to determine the effect of different connections for new installations permitting an optimum scheme to be found. It is also easier to study the effect of outages and the relative merits of different compensator locations and parameters.

Choice of Fault Level

The results of any assessment are critically dependent upon the choice of system conditions and the corresponding fault levels. The Engineering Recommendation P.7/2 suggests that Winter minimum conditions should be examined as being representative of conditions during Spring and Autumn evenings when lighting is likely to be in use as opposed to the lighter Summer evenings. In practice, it is difficult to establish appropriate conditions with any accuracy and in marginal situations excessive flicker may result as conditions change. The existing calculation procedure makes it very difficult to assess all the potential conditions.

The flicker at the high voltage P.C.C. resulting from a single installation is inversely proportional to fault level at the P.C.C. for all normal variations of fault level throughout the year, since furnace short circuit MVA can be considered effectively constant for changes in system fault level. The source impedance ($\%X_s$) is at all times small compared with furnace impedance ($\%X_p$) and step-down transformer ($\%X_t$). See equations 1 and 2.

Accurate prediction of the effect of changes in fault level for several installations would require the adjustment of each contribution of flicker to its change in fault level. In practice the proportional changes in fault level are often similar between the different nodes and this suggests that a simple inverse relationship to fault level may be a sufficiently accurate guide for modifying the accurate results of the first assessment: the errors introduced being small compared with those inherent in the basic data.

Assessment of Effect of Using Different Laws for Combining Flicker

In combining the effect of several furnaces it can be shown that the technique described in P.7/2 amounts to a fourth root law:

$$Vf_g = \sqrt[4]{\Sigma\, Vf_{gn}{}^4}$$

More recently the validity of this law is being questioned and international opinion (see Figure 1) has varied from a square root to a fourth root law which implies that the combination law in P.7/2 is at the optimistic end of this range.

The flicker level produced by various combinations of furnace states may be assessed in a multi-furnace situation by making assumptions about the period of time each spends melting, refining, and off.

Figure 2 shows the results of such an assessment of flicker for 4 or 6 furnaces and the effect on the assessed flicker levels of using various combination laws. The results are based upon the following assumptions:

(a) Each furnace has an equal probability of being in one of three states.

  (1) Melting with a flicker level of 1 p.u.

  (2) Refining with a flicker level of 0.3 p.u.

  (3) Off with a flicker level of zero.

(b) The square root law is assumed to be valid for combining the individual flicker voltages (5).

(c) The furnaces are assumed to be electrically close together i.e., connected to a common P.C.C.

Figure 2 shows that for both 4 and 6 furnaces the level predicted by a 4th root law would be exceeded for 33% of time. Correspondingly the use of a 2nd root law gives a result that would never be exceeded. The 2.5th root law, for the assumed conditions, give results which are only exceeded between 2% to 4% of time and this is perhaps rather more realistic.

Whilst no firm conclusion can be drawn from this limited analysis it is considered that sufficient doubt exists concerning the validity of the fourth root law to make it worthwhile testing the sensitivity of the results by the use of a 2.5th root law.

SITE MEASUREMENTS

Engineering Recommendation P.7/2 describes the use of the E.R.A. flicker meter to establish the level of flicker at a point on the network due to existing installations. In practice it is difficult to establish meaningful results using this technique. A major problem is encountered in establishing typical and controlled conditions during the period of any test. Where several installations influence the results, their pattern of operations varies widely even to the extent of not operating at all. The information needed to establish conditions is not readily available from some steelworks. The other source of variation is the system condition which will depend on the time of year and day of measurement and this may be untypical. Even if the conditions can be established the measurement technique used requires a protracted period of test and the situation is likely to change during the test. The present instrument records the average flicker at 1 minute intervals and hence it must be operated for a long period to obtain a realistic estimate of the 1% cumulative probability level defined as the gauge point in P.7/2.

Consideration is being given to the design of an improved instrument (13)(14) which should simplify the data collection and assessment but many of the problems related to furnace and system conditions will still apply. Consideration is also being given to development of equipment for on line measurement of system impedance which would assist in assessing the interaction of the furnaces and the system for planning purposes.(15) This would also be used as an on line aid for operating at maximum power according to system conditions.

ACCEPTANCE OF FURNACE LOADS

It is normal policy to accept this type of load wherever possible but it becomes increasingly difficult to accept further installations as the number increases. The extent to which consideration is given to the effect of possible future installations is a matter of judgement for the supply authorities concerned. In considering a proposed installation it is important to realise, when assessing results based on future prediction of fault level, that these only provide a best estimate of future conditions. However if the recommended limits are exceeded on the most optimistic assessment of flicker, as defined in P.7/2, this suggests that compensation should be installed or an alternative location sought. This would involve discussion between the supply authority and their consumer to determine the optimum solution. It is perhaps worth noting that a number of smaller furnaces would result in less disturbance than a single large unit.

Correspondingly the case for immediate installation of compensation could hardly be justified if the estimated flicker only exceeded the limit when account was taken of lower fault levels and pessimistic combination laws. However, some contingency plan might need to be established such as provision of land space for a compensator.

Consideration might need to be given to defining the measures for containing flicker during the period between complaints being received and a compensator being put into service. If the recommended limits are only marginally exceeded this could probably be achieved by limiting the use of higher furnace taps or phasing operations between furnaces. Such restrictions would only need to apply during periods of low fault level.

COMPENSATION

System Compensation

In practice if flicker complaints arise it can sometimes be difficult to establish the source of the disturbance when several installations contribute to the flicker in the same area. It could be the result of a general growth of steel production or be due to the incremental effect of the most recent installations. When two developments occur in parallel it would be difficult to determine who should install compensation equipment and what degree of improvement would be required. One possible solution would be to call on several steelworks to install compensation equipment but whilst this may be equitable it might not be the most economic solution. For these reasons studies were made of the use of a supergrid connected compensator to improve flicker over a wide area.

This was done with the same computer program (HARP) by the injection of leading current. Results suggested that a compensator connected at the supergrid could achieve a bigger and more wide spread improvement than a similar sized compensator connected at one of the installations.

Compensation Design

The design of a compensator for connection at supergrid voltages would present more problems than one for 33 kV and it would be difficult with a saturable reactor to achieve the low slope reactance required to match system source reactance. Series capacitor slope correction would be required which would impair the speed of response and hence flicker performance. A step down transformer would probably be necessary and correction for its impedance would also be required which would further impair flicker performance. The thyristor switched reactor type of compensator can be controlled to provide the required MVAR injection but its flicker performance is limited by the delays inherent in this retrospectively acting system. Other problems with supergrid connected compensators could be encountered when outages occur. Nevertheless, the potential advantage of supergrid connection suggests that further studies of this possible alternative may be worthwhile. In the meantime, the only available technique for reducing flicker is with compensators connected to individual steelworks 33 kV busbars.

CONCLUSIONS

(i) In the case of complex multi-furnace installations the use of the network analysis program HARPO3 provides a less tedious means of assessing flicker.

(ii) If an initial assessment, based on Winter minimum fault levels and a 4th root combination law for combining furnaces, exceeds the recommended limit in P.7/2 an alternative connection arrangement or the use of a compensator should be considered. Alternatively consideration could be given to restriction on the use of the higher furnace tap positions or for guarantees on the phased operation of the furnaces.

(iii) If the results are within the P.7/2 flicker limit then it may be advisable to repeat the study with more pessimistic fault levels, e.g. Spring/Autumn estimates and a 2.5th root combination law. If this exceeds the recommended limit some provision may need to be made to cater for any subsequent problems. This could take the form of a plan of restricted use of taps or phasing of furnace operations or the provision of a compensator. If with the pessimistic assumptions the limits are not exceeded then no provision or contingency plan should be required.

(iv) When several potential schemes arise in parallel there will ultimately be a limit to the capacity of the system for this type of load and consumers could be encouraged to install a larger number of smaller furnaces rather than a few large ones.

(v) The confidence that may be placed on system flicker measurements is limited unless controlled conditions can be achieved for the period of test.

ACKNOWLEDGEMENT

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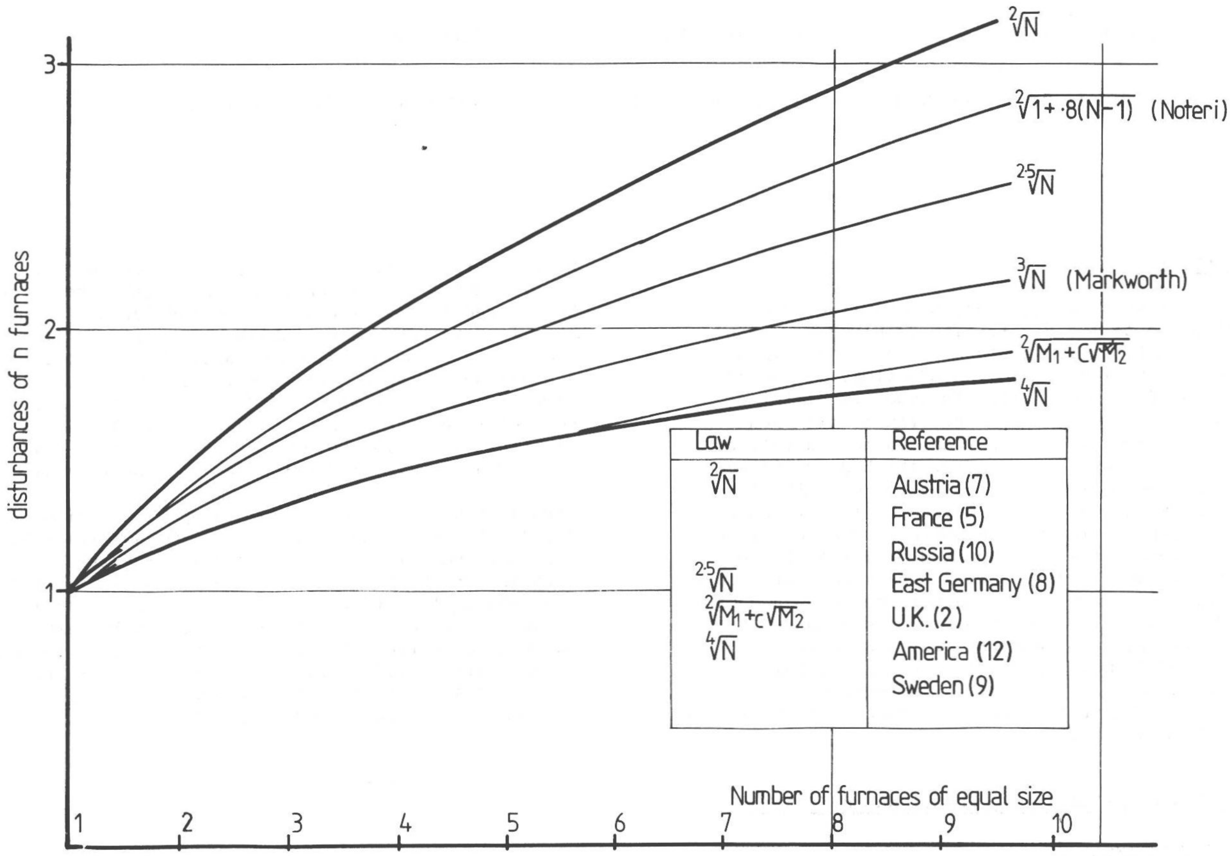

Figure 1 Combined disturbances of multi-furnace installations

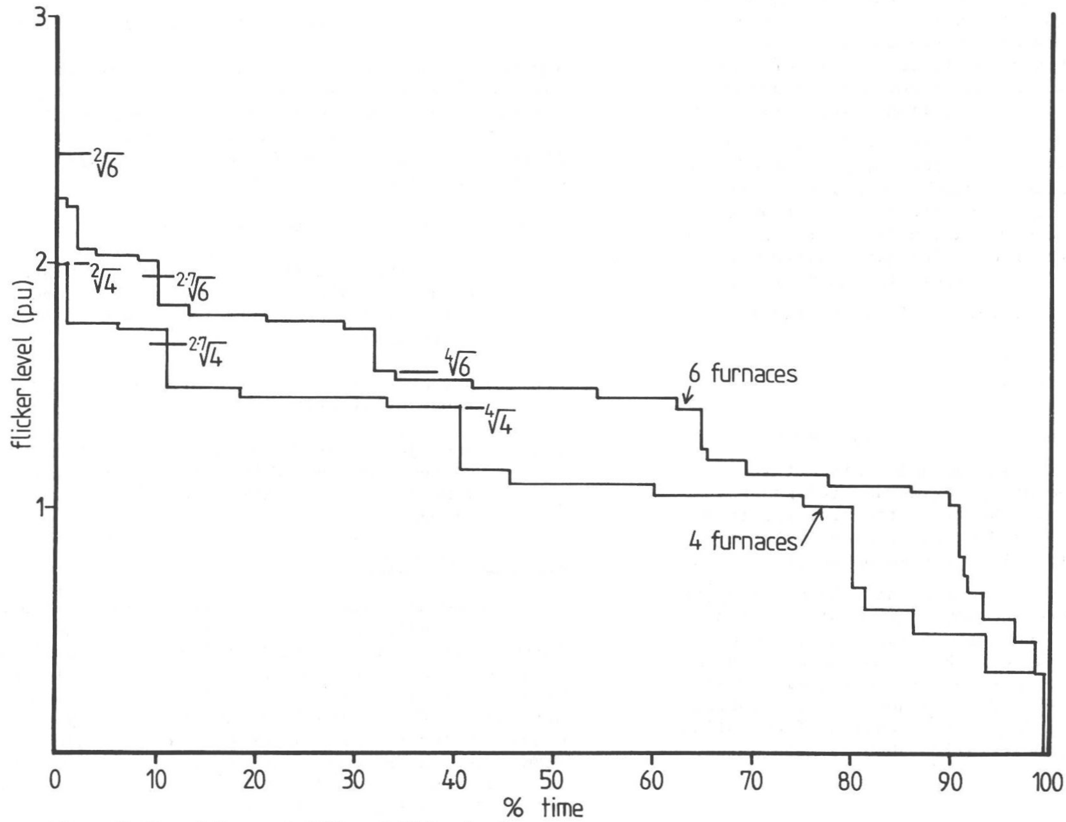

Figure 2 Cumulative probability of flicker level

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