SEISMIC QUALIFICATION OF ELECTRICAL EQUIPMENT FOR SUBSTATIONS

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SUMMARY

Electrical equipment for substations are usually badly damaged by earthquakes: a reliable seismic design and proper qualification tests are therefore necessary. The seismic qualification poses, however, in most cases, very involved problems related to a) the increasing size and complexity (both structural and mechanical) of the equipment; b) the interaction of the equipment with its supporting structure, and c) the interaction, through cables or other connections, between different pieces of equipment in a substation.

This paper deals with the hybrid (experimental-analytical) techniques set up at ISMES in the last few years for the seismic qualification of electrical equipment for substations, with the aim of accounting for the above mentioned problems.

TESTS OF LARGE SIZED AND COMPLEX EQUIPMENT

Owing to the modern trend toward very high voltage transmission lines, the electrical equipment for substations tend to become very large and heavy. The usual procedure of carrying out qualification on a shaking table in such cases cannot be easily applied, because large vibrating platforms with the required performances (for example frequency range up to 30 Hz) are not available and also because the dynamic reaction forces of the structure under test tend to modify the motion applied to the table, which cannot be easily controlled. To avoid these drawbacks, ISMES has developed a qualification procedure by means of concentrated forces delivered by electrohydraulic actuators directly applied in one or more points of the equipment. The qualification tests of the Magrini circuit breaker type SF6-362 MHM (fig.1) give an example of the application of this procedure.
A first series of tests at low excitation level allows the dynamic properties of the structure (natural frequencies f, damping ζ, modal shapes ϕ) to be detected. As is well known, these properties can be determined from the transfer functions $H(\omega)$ between the response and any kind of excitation. On the basis of these experimental results and of the qualification requirements, the characteristics of the exciting forces (application points, intensity, phase lags) which produce on the structure under test the same ef-

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fects (accelerations, displacements) as generated by the base excitation, are determined according to the following considerations. In the frequency domain, the displacement of the i-th point of a n degree-of-freedom system undergoing a sinusoidal base acceleration a(t) is given by:

$$X_i(\omega) = \sum_1^n{}_k \; R_A^k(\omega) = -A_b \sum_1^n{}_k \, \phi_i^k C_A^k \, H^k(\omega)$$

where the participation coefficient is: $C_A^k = \sum_1^n{}_r \; m_r \phi_r^k \,/\, \sum_1^n{}_r \; m_r (\phi_r^k)^2$

In case of sinusoidal excitation by concentrated forces F_r, the displacement is:

$$X_i(\omega) = \sum_1^n{}_k \; R_F^k(\omega) = \sum_1^n{}_k \; \phi_i^k \, c_F^k \, H^k(\omega)$$

the participation coefficient being now: $c_F^k = \sum_1^n{}_r \; \phi_r^k F_r \,/\, \sum_1^n{}_r \; F_r (\phi_r^k)^2$

The equivalence is thus achieved if $R_A^k(\omega) = R_F^k(\omega)$ that is by a system of n

forces F_r such as $\sum_1^n{}_r \; \phi_r^k F_r = -A_b \sum_1^n{}_r \; \phi_r^k m_r \qquad (k = 1, n)$

The qualification proper can now be carried out either analytically, by computing the displacements and stresses induced by the forces previously determined, or experimentally, by applying the exciting forces F_r directly to the equipment, using computer controlled electrohydraulic actuators (1). Since only the lowest modes are usually of interest, a system of two to three forces is sufficient for satisfactory qualification.

The experimental approach is preferable since it takes into account possible non-linear effects which are disregarded if analytical qualification is carried out: in this case the displacements and stresses are overestimated. It is worth mentioning that, owing to the possibility of carrying out the testing of the equipment at the manufacturer's works, the method here presented is time saving and can be cheaper than the usual tests on the shaking table.

QUALIFICATION OF COMPLEX EQUIPMENT BY COUPLING OF VARIOUS PARTS

Electrical equipment for substations are installed on metallic supporting frames (fig.2), which usually are neither designed nor built by the manufacturer of the equipment. It follows that the same equipment may be mounted on different supports; this would require seismic qualification for each type of support, since the dynamic behaviour of the system strongly depends on the dynamic characteristics of the support. A typical example is given in fig.3, which shows the response curves of the electric part alone of center break disconnector type DR 245 KV shown in fig.2 and of the same mounted on a supporting frame. For such cases, ISMES has set up a hybrid (experimental-analytical) procedure that requires the qualification of the electrical part only and the measurement, during the tests (which are carried out via shaking table, or via concentrated forces) of the forces, bending moments and torques - as a function of the exciting frequency - transmitted by the equipment to the supporting points. The measurements are made by means of load cells, the basic scheme of which is illustrated in fig. 4.

The knowledge of these quantities allows the response of the support (usually a rather simple structure) to be computed. Once the motion of the points connecting the equipment to the support is known, it is possible, by means of analytical procedures (2), (3) to couple the two sub-systems, and to compute the response of the assembled system in terms of displacements and stresses.

The method, which is correct in case of linear systems, however provides conservative results if non-linearities are present.

INFLUENCE OF CONNECTIONS BETWEEN EQUIPMENT ON THEIR BEHAVIOUR

The current seismic regulations disregard the effect, on dynamic behaviour, of cables or other connections between the different pieces of equipment installed in a substation. These connections, owing to their stiffness or to their mass, may modify the response of the equipment: although the amount of this modification is, at present, unknown, it could possibly make meaningless the results obtained by current qualification procedures. An approach to this problem based on the two methods described above is now under study at ISMES (within the framework of its co-operation with ENEL). The proposed testing procedure calls for the simultaneous excitation, by means of concentrated forces, of two or more interconnected equipment, in operating conditions in a substation. Moreover, the application of suitable load cells in the connecting points will allow the forces directly generated by the excitation to be separated by those induced by the connections. By means of this procedure, it is possible to compare the responses of the equipment with and without connections and to determine their influence with the aim of studying the possibility of simulating this influence during the qualification tests of a single equipment.

CONCLUSIONS

Current qualification procedures may be inapplicable when very large and heavy equipment or assembled systems have to be tested. The new testing methods illustrated tend to refine the usual qualification techniques, in order to avoid, on one hand, too conservative or expensive procedures and, on the other, some important aspects of the problem being disregarded, thus leading to improper interpretation of the tests results.

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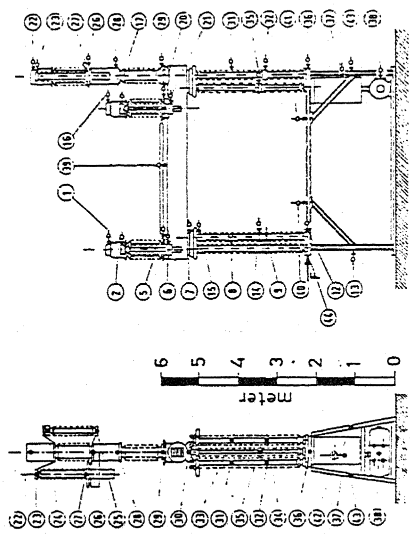

Fig.1 - Gas circuit breaker 362 MHM

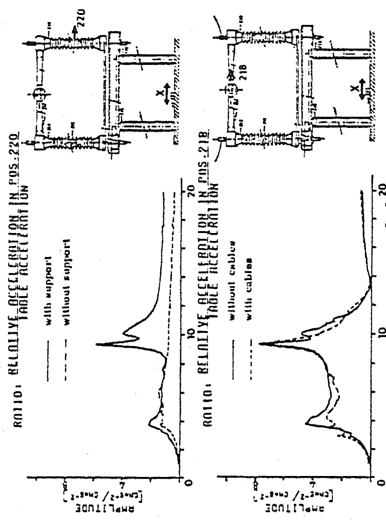

Fig.3 - Comparison of response curves

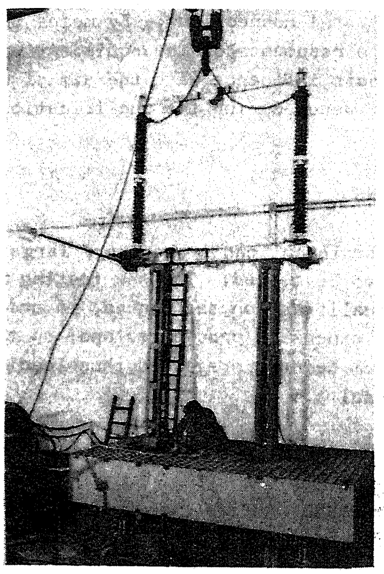

Fig.2 - Center break disconnector
245 KV

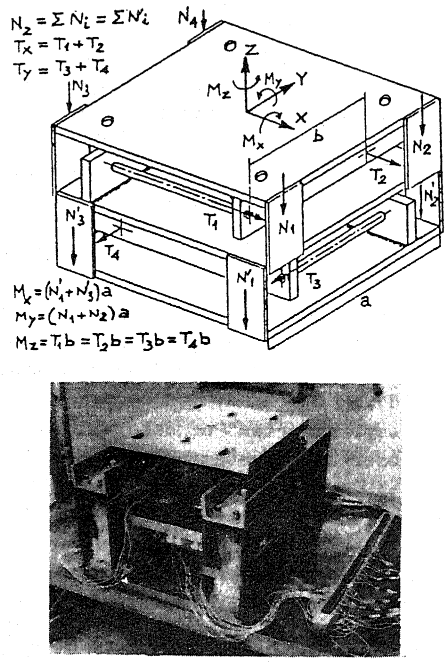

Fig.4 - Load cell