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POWER TRANSFORMER NOISE--PREDICTION AND CONTROL

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Power transformers located in outdoor substations can be a significant source of environmental noise disturbance, especially during nighttime hours. The dominant characteristic of transformer noise is the low frequency "hum" generated within the magnetic core as a result of the magnetostrictive properties of the core steel. The core-generated noise consists of the harmonics of the fundamental frequency, 120 Hz (twice line frequency). The noise of a transformer is virtually independent of the load carried.

Recently, Bolt Beranek and Newman Inc. (BBN) undertook a noise survey [1] of thirty-four of the three hundred substations owned and operated by the Bonneville Power Administration (BPA) in the Pacific Northwest. This paper describes some of the observations and findings which have derived from studies [2] of the survey data, and of other data [3] made available to us by the Empire State Electric Energy Research Corporation (ESEERCO).

PREDICTION OF TRANSFORMER CORE NOISE

Maximum recommended levels (in dBA) for transformer noise are laid down by NEMA [4]. These levels increase in value in accordance with a 10 log (MVA) relationship. The levels also take account of the design voltage and the type of cooling utilized.

Unfortunately, the NEMA Standard levels were derived rather arbitrarily. They do not necessarily represent the current state-of-the-art as regards transformer design, especially where large power transformers are concerned. Furthermore, the Standard provides no direct information on the levels at the tonal components which, almost always, determine the environmental acceptability of a transformer installation.

Statistical studies of data obtained on the sixty transformers included in the BPA substations survey, and of data collected in connection with the ESEERCO study have shown that the A-weighted, core-generated noise of a transformer is well correlated with its maximum (fully-cooled) rating (R) in MVA. The least squares regression line and the 95% confidence intervals (on the average levels) are shown in Fig. (1), together with the data points that were used in the study. For the purposes of the study, all data were normalized to represent average levels at a distance of 500 ft from each transformer.

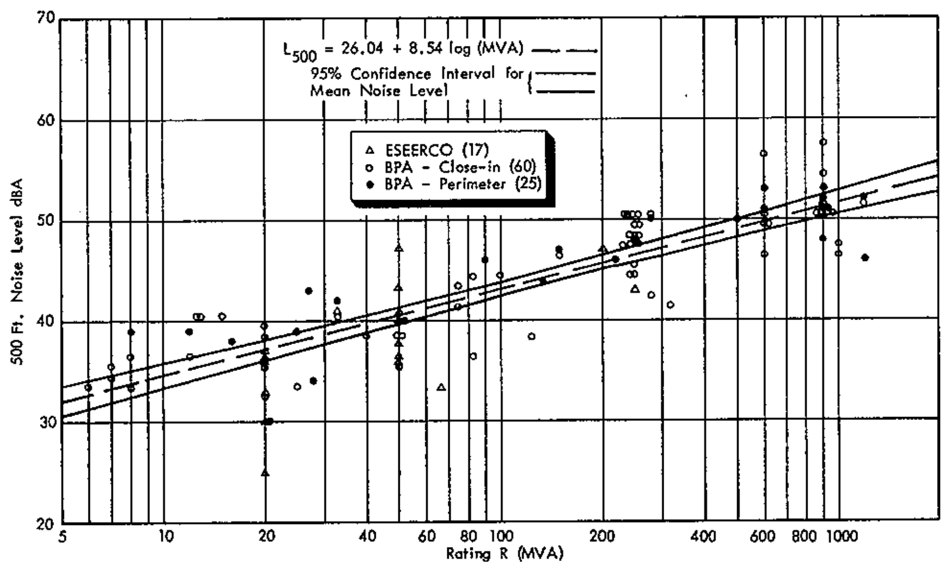

FIGURE 1. RESULTS OF REGRESSION ANALYSIS ON BPA [REF. 1] AND ESEERCO [REF. 2] DATA

The study showed that the noise level (in dBA) represented by the combined transformer tones can be predicted by the relation:

$$L = 26 + 8.5 \log (R) \quad , \qquad (1)$$

where L is the 500 ft average level and R is the maximum transformer rating in MVA.

The data population used in the analyses covered a rating range of 7.5 MVA to 1200 MVA. Design voltages ranged from 115 kV to 500 kV. Both three-phase (single-tank) and single-phase (three-tank) units were involved. At least 17 different manufacturers were represented.

A homogeneity analysis of the data population showed little dependence of noise level upon design voltage and no significant dependence of noise level upon the type of construction (single- versus three-phase) or manufacturer.

An analysis of the first four tonal components showed that the dependence of each of these upon rating differed insignificantly from the dependence shown in Eq. (1). The sound pressure levels of the tonal components can be predicted by *adding* the following values to the predicted dBA level.

Tonal Frequency (Hz)	120	240	360	480
Add the Value (dB)	+15	+3	-6	-10

A comparison between Eq. (1) and the 500 ft levels that would be deduced from the NEMA Standard levels indicated that the NEMA Standard overestimates core-noise levels very substantially (by up to 10 dBA) at the higher MVA ratings.

ENVIRONMENTAL REGULATIONS

BPA's high voltage transmission system encompasses all of the Columbia River Basin in the States of Oregon, Washington, Idaho, and Montana. Initially most of the 300 substations included in this system were located on sites well removed from residential properties. However, over the years, at many of these sites, communities have grown and encroached upon the land adjoining the substation. In such situations, there can be severe difficulty in complying with noise regulations.

The problem is further complicated by the wide variety of levels which are encountered in these regulations. For instance the States of Oregon and Washington would impose limits upon substation noise *at night* of between 35 and 50 dBA, and between 57 and 60 dBA, respectively. In the case of Oregon, the range arises because of a complicated secondary limit set upon pure tones. In Washington, the range depends upon whether a substation should be classified as a commercial or an industrial source.

The City of Seattle and King County (in Washington State) have both recently enacted their own separate regulations. These differ from each other (although they were developed jointly) and from the regulations in the States of Oregon and Washington.

Clearly it would be in BPA's interest to be able to adopt a uniform noise level policy for the total transmission system. Such a policy, so long as it were not too restrictive, would allow BPA to handle present noise problems in a reasonable manner and undertake future substation developments logically and economically.

In the present regulatory climate however the different requirements can have a severe effect upon the costs of noise control.

NOISE CONTROL METHODS AND COSTS

The problems and costs encountered in correcting substation noise problems can best be illustrated using two examples.

The BBN survey indicated that several substations in the State of Oregon were in default of the State Regulations. In particular, one substation located close to Portland was indicated as being in excess to the extent of 20 dB at the 120 Hz frequency. A view of the transformer bank at this substation is shown in Fig. 2.

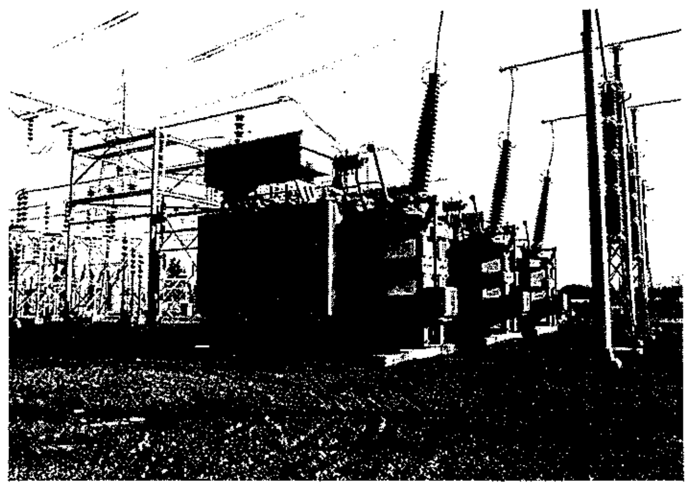

FIGURE 2. VIEW OF TRANSFORMER BANK

Each of the transformer tanks is 24 ft long, 12 ft wide, and 17 ft high. The weight of each unit is 570,000 lbs. The transformer is rated at 3 x 300 MVA, 500 kV.

Total enclosure of this transformer bank could not be contemplated for safety and operational reasons. It was judged that an attenuation close to that required would be achieved using a "wall enclosure" type of treatment. However, since it was likely that this transformer would have to be replaced in ten years because of load growth, it was important to consider the investment required in quieting the existing bank in this context. Several alternatives, giving different levels of solution, were developed and costed as follows:

	Alternative		1978 Cost (k$)
1)	Wall Enclosures (total solution)		600
	Transformer Replacement in 1988		2,922
		Total	3,522
2)	Relocate Transformer (total solution)		310
	Transformer Replacement in 1988		2,922
	Additional (3 MW) line losses (1977 to 1988)		2,110
		Total	5,342
3)	Three-Sided Barrier (partial solution)		150
	Transformer Replacement in 1988		2,922
		Total	3,072
4)	Three-Sided Barrier (partial solution)		150
	Transformer Replacement in 1982		3,478
		Total	3,628
5)	Transformer Replacement in 1982	Total	3,478

The above transformer replacement costs represent costs of future construction using 5% escalation and 8-1/4% interest rates. Alternative (3) or (4) is being pursued subject to evaluation of the effectiveness of the noise barrier, since both provide some relief without the large initial cost of alternative (1). A temporary three-sided barrier will provide an attenuation of about 10 dBA which, incidentally, will allow the substation to comply with the 50 dBA base requirement of the Oregon Regulations. The barrier that is contemplated will be 22 ft high with a total length (including the two short sides) of 165 ft.

The replacement transformer bank which is implicit to each of these alternative approaches will (if required) be rated at 3 x 533 MVA. The noise level requirements will be met by a combination of special low sound level construction and sound reduction methods to be applied after installation. Costs for these are included in the cost estimate.

A good example of the latter, forward-planned, approach to substation planning is to be found at a substation near Seattle, Washington. Just prior to the adoption of the Washington environmental regulations, a 3 x 533 MVA transformer bank was designed for this substation. The close proximity of residences to the site suggested a potentially serious problem. It was decided to limit sound levels from the new installation to 50 dBA at the residential property line. This implied that the surface noise level measured in accordance with the NEMA Standard would have to be 78 dBA, 14 dBA below the NEMA Standard level.

Various methods to achieve an attenuation of 10 dBA, or more, were considered. These included tank enclosures, barrier walls, berms, and, just prior to commencing final installation design, a below-grade installation. These design studies were all based on receiving units 4 dBA below NEMA.

The manufacturer then offered to guarantee (at no additional cost) a NEMA level of 84 dBA (8 dBA below standard), so only 6 dBA additional noise reduction was required. It was estimated that the below-grade installation would provide about 7 dBA attenuation. At a cost of $80,000, this solution was most attractive.

The below-grade design places the transformers on pads 17 ft below the level of the surrounding ground. Only the tank tops and bushings of the transformers are visible from the closest communities. In addition to providing a satisfactory noise solution, the below-grade installation improves the visual appearance, security, and oil-spill containment of the site.

CONCLUSIONS

The results of the data studies have indicated that the core-generated noise levels (both overall and tonal) of a transformer can be predicted purely on the basis of its MVA rating. The procedure should be useful in "screening" existing substations for compliance with noise regulations and in making layout and design judgments for future substation installations. The study has shown also that current NEMA standard levels for transformers can severely overestimate the actual situation, especially at the higher MVA ratings.

Notwithstanding the usefulness of a noise prediction technique, the noise problems associated with power transformer installations are severely complicated by the lack of uniformity and stability that exists in the area of environmental regulations. The costs of "retrofitting" transformer installations to meet a recently enacted environmental regulation can be prohibitive. Similarly high costs can be encountered for new installations when the regulations are unreasonably stringent.

REFERENCES

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[3] "Characterization of Transformer Noise Emissions," BBN Report 3305, July 1977.
[4] "Transformers, Regulators and Reactors," NEMA Standard Publication, TRI- 1974.