NATIONAL BUREAU OF STANDARDS REPORT

7336

SOME RECOMMENDATIONS FOR STATISTICAL QUALITY CONTROL OF ELECTRICITY METERS BASED ON SAMPLE TESTING

by

Anna M. Glinski

and

Mary G. Natrella

A Report
to
American Standards Association
Committee C12, on Revision of the Code for Electricity Meters

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U. S. DEPARTMENT OF COMMERCE
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NBS PROJECT
1103-40-11132

August 30, 1961

NBS REPORT
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FOREWORD

Watthour meters are used to measure the electrical energy consumed by customers of the various power companies operating under either private or public ownership. The continuing accuracy in service of all meters used for revenue purposes is of concern, not only to the utility and its customers, but also to the regulatory bodies that have cognizance of rate schedules and other matters that affect utility customer relationships.

The ASA Code for Electricity Meters is very generally used by State Utility Commissions and other regulatory bodies, and by Utilities as a guide to acceptable practices. The current edition of the Code (1941) suggests an interval of not more than 96 months between periodic tests of service meters rated at 12kva or less, and this practice is followed in many areas. Recently, a number of studies have been made of statistical quality control methods for maintaining watthour meters in service. There is reason to believe that accuracy tests of appropriate samples of meters in service, rather than periodic tests of all meters, might work to the advantage of both the utility and its customers if the sampling procedure were based on proper criteria. For instance, the company might more quickly eliminate from service meters of a type or age group that shows poor performance while actually making a smaller number of tests per year. Several proposals have been made, and a number of statistical quality control plans are now in operation either on a trial, or an accepted basis.

ASA Sectional Committee C12 is presently engaged in a revision of the Code, and it seems proper that the new (fifth) edition include a statement of guiding principles on which acceptable statistical quality control plans for meters could be based. Accordingly the committee requested that the Statistical Engineering Section of the National Bureau of Standards examine the documents describing various sample-testing proposals and plans in being, to recommend guide lines that could be considered in the design of effective procedures for the statistical quality control of watthour meters in lieu of total periodic tests.

This report presents the results of the examination made by the Statistical Engineering Section (NBS) of documents detailing various studies, and has been prepared for the use of ASA Sectional Committee C12 on the revision of the Code for Electricity Meters.

Forest K. Harris, Chairman
ASA Sectional Committee C12

Some Recommendations for Statistical Quality Control of Electricity Meters Based on Sample Testing

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1. THE PRESENT SITUATION

a. With regard to meter testing

The current recommendation of the American Standards Association [1] is that alternating-current electricity meters up to and including 12kva (which includes most domestic meters) be tested at least once every eight years. It has been proposed that this recommendation be revised to allow the application of statistical quality control methods to meter testing. A number of utilities have already instituted statistical quality control programs (some with the approval of regulatory bodies) and these programs differ widely both in individual features and in overall effectiveness. It is recognized that no unique procedure can be recommended that will be universally satisfactory, but guidance can be given with regard to the necessary elements of a satisfactory program. Any acceptable procedure must be based on sound statistical principles. Greater overall effectiveness can be achieved by preliminary study of meter histories and by proper design of the sampling schedule.

b. With regard to meter performance

Meters manufactured after about 1940 (when surge resistant stable magnets were introduced) are believed to maintain calibration over much longer periods of time than do the earlier types. Test results in various areas indicate that some meter types are showing no deterioration with time. Other types show a small tendency toward decreased accuracy indicating, perhaps, that they should be adjusted more frequently or gradually replaced with other types. The behavior of some older types of meters is such that many of the newly approved testing programs have earmarked these meters for replacement as quickly as possible.

Performance statistics show that about 96 percent of all meters in use are within the prescribed tolerance range which is ordinarily 98-102 percent of correct registration at conventional test currents. Quality control methods will permit available funds and personnel, which are now expended in testing all meters on the present length-of-service basis (regardless of information about the relative accuracy of various types), to be used more effectively. The objection to the conventional testing scheme is that it treats all types alike regardless of their performance histories.

2. FACTORS AFFECTING METER PERFORMANCE

A study of quality control programs submitted by various utilities indicates that the main factors affecting meter performance are:

(1) Type of meter (identifying the manufacturer and the age of the meter).

(2) Location of meter.

Age of the meter is a very significant factor in meter performance, because a meter's age is an indicator of its design. Newer meters are inherently better able to maintain their accuracy because of significant design changes.

The individual manufacturer may not always be important because changes in design and material have been made at approximately the same time by all manufacturers in the past.

Location of the meter may affect its accuracy because of local environmental factors such as frequency of power surges, preponderance of lightning, or corrosive atmosphere.

3. AIMS OF A QUALITY CONTROL PROGRAM FOR METERS

Under the conventional system, the condition of only those meters just tested is known. The present condition of meters tested 7, 6, 5 ... etc. years previously is unknown. It would be desirable to have current information on the condition of all meters in the system. It is economically feasible to obtain such information only by the use of sample testing.

If all meters in the system were substantially alike, a sample properly drawn from all meters in the system (without any further breakdown) would provide such information. It is widely recognized, however, that all meters in service are not substantially alike (see 2 above). From studies of meter histories, it is possible to make logical groupings of those types of meters that have shown similar behavior in the past, and may be expected to behave alike in the future. These logical groupings will be called "groups" here. Each utility must precisely define "groups" for its system. Ordinarily a "group" will consist of meters of the same age class. Contemporary types of meters have shown essentially the same characteristics, and the dates at which major design changes have been made are well known. Ordinarily a "group" will include meters made by different manufacturers, but of the same vintage. Where location or environment are considered to be significant factors, the group will consist of similar types that are all located in the pertinent area(s).

A quality control program would require sampling enough meters of each "group" to determine (with some prescribed precision) the probable number or percentage of meters in the group that are within acceptable limits. A review of performance records for the defined "group" will indicate how a system can make the most of its expenditures on meter maintenance--which group needs to be sampled heavily, which more lightly. An estimate of performance for each group would be available each year, and possible undesirable trends appearing in types now considered satisfactory could be detected more quickly. At the same time, the quality control program should have suitable consumer-protection features to compensate for the fact that an individual meter may not be tested for a period longer than the present eight-year schedule.

4. RECOMMENDED GENERAL CHARACTERISTICS OF A QUALITY CONTROL PROGRAM*

a. Present requirements concerning the testing of a customer's meter on request should not be altered in any way by a sampling proposal. Nor should the proposal affect the practice of companies to check individual accounts for which billing seems to be out of line.

b. Any quality control plan should be based on accepted principles of statistics and must be mathematically sound. Accordingly, it is recommended that the plan be evaluated by impartial qualified mathematical statisticians.

c. Meters should be divided into separate groups as previously explained, to recognize differences in operational characteristics due to differences in design that affect the ability of meters to maintain sustained accuracy. Furthermore, meters so located that their ability to maintain sustained accuracy may be affected by unusual

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*Cf [2]. (Figures in brackets indicate the literature references in the Bibliography.)

location characteristics such as corrosion problems, abnormal lightning conditions or other unusual conditions should be segregated by area in a special group or groups in recognition of such special location characteristics.

d. The sampling procedure should be applied to each such individual group, except for those groups, if any, which have been designated for complete replacement.

e. For a meter group whose average accuracy is close to 100 percent with a spread that insures that only a negligible fraction are outside the acceptable limits of accuracy, a proposed plan should provide an adequate check that a satisfactory over-all level is being maintained rather than be designed to find the few unsatisfactory meters. These meters should be uncovered by company or customer request tests and other investigations.

f. In the event that the performance of a particular group of meters deteriorates and for any group whose performance is unsatisfactory, the plan should accomplish two things. First, it should warn that the condition exists and supply diagnostic information concerning its nature. Second, it should automatically require enough additional testing and adjusting to bring the over-all performance of the group back to an acceptable level. Furthermore, the information gained from the sampling results should provide a basis for a decision as to whether it would be more economical to embark on a systematic upgrading or replacement program for all meters in the group.

5. DETAILED FEATURES OF A QUALITY CONTROL PROGRAM

Any quality control program should contain the following features:

a. definition of one or more meter "groups" for sampling purposes.

b. specification of an acceptable level of performance for each meter group.

c. the "sampling plan" itself.

d. the method of drawing the sample.

e. rectifying features of the program.

f. necessary records.

Further explanation of these features, and aids in evaluating specific provisions, are given below.

a. Definition of One or More Meter "Groups" for Sampling Purposes

A sample, properly drawn, reflects the characteristics of the population sampled. The population from which the sample is to be drawn should therefore be carefully defined. The conclusions based on the sample will be more meaningful if the sampled population is as homogeneous as possible. The sampled population, in this study, is the meter "group", as defined in Section 3, in which age and location are the significant factors considered. (What we call here the "sampled population" is what is called an "inspection lot" in the applications of sampling to the acceptance of manufactured product.)

b. Specification of an Acceptable Level of Performance for a Meter Group

An acceptable level of performance for individual meters has been established in many states. Customarily, a meter's performance is considered to be within the acceptable limits of accuracy if it registers between 98 and 102 percent of correct registration at conventional test currents. In order to institute a sampling program, a further decision must be made--namely, what is an acceptable level of performance for the group? Obviously we cannot be sure that each meter in a group is within acceptable limits unless we test each meter. (Even if this were economically possible, the history of inspection and testing in many fields gives clear evidence that 100 percent testing does not insure 100 percent perfection because heavy demands on testing personnel result in less careful work.)

The decision then to be made is-- what percentage of defective meters may be permitted to be present in the group without taking further action? For example, if we knew that exactly X percent of the group was outside the tolerance limits, would that be an acceptable state of affairs? If it were not, "further action" would probably consist of testing more samples this year or increasing the amount of testing next year, or subjecting that group of meters to an accelerated replacement program.

If a meter group with no more than X percent of the meters outside of tolerance constitutes an acceptable state of affairs then this maximum acceptable fraction defective, expressed as X percent, once specified, is called the Acceptable Quality Level (AQL).* Study of a number of proposals from

*See [3] and [4]

power companies in different states indicates that a satisfactory AQL for some groups of meters is approximately 2 percent.

c. <u>The "sampling plan" itself</u>

The program should contain a table of mathematically calculated sample sizes and related constants for determining acceptability. Such a table should be accompanied by the appropriate Operating Characteristic Curves, (OC Curves),** for the sampling plans given. One of the advantages of sampling is the opportunity to predetermine risks of incorrect decisions using the laws of mathematical probability. From the OC Curves, one can determine the protection afforded to the utility company (from the risk of an incorrect decision, i.e., taking "further action" when the group of meters actually does meet the level of performance specified as in 5b) and the protection afforded to the consumer (from the risk of an incorrect decision, i.e., not taking "further action" when the group of meters is actually worse than the specified AQL). The plan may be so designed that the risk to the consumer is controlled so that it never exceeds a certain small value.

The sampling plan may come from a standard collection of sampling plans (e.g., [3] and [4]) or may be tailor-made. The statistician who designs the plan will consider such alternatives as attributes vs. variables sampling, and single vs. double sampling plans, etc., but such features are less important to those evaluating the program than those features described herein.

The sample sizes given will usually vary with the size of the group, but the rate of sampling is not the important thing in determining the protection afforded. It should be strongly emphasized that, except in the case of very small groups, the protection obtained from a sampling plan depends on the absolute size of the sample rather than the relative size. A proposed plan with a constant sampling rate (say 1 percent) should not be considered as a good proposal.

The sampling plan should also provide specific instructions on what to do if the sampling results indicate unsatisfactory performance for the group. A number of corrective action features are possible--a more stringent sampling plan to be used in the future, or a rectification procedure to be instituted immediately and completed within a specified

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**See [3], [4] and [5]

period of time, (see 5e). For a group of meters which is performing better than expected, it is possible to include a reduced testing schedule for the future. The specific corrective action features may be different from place to place and should be established in light of previous performance records.

In order to make valid non-trivial generalizations from samples about characteristics of the populations from which they came, the samples must have been obtained by a sampling scheme which insures (1) that the relevant characteristics of the populations sampled bear a known relationship to the corresponding characteristics of the population of all possible samples associated with the sampling scheme, and (2) that generalizations may be drawn from such samples in accordance with a given "book of rules" whose validity rests on the mathematical theory of probability.

"That which can be and should be representative is the sampling plan, which includes the manner in which the sample was drawn (essentially a specification of what other samples might have been drawn and what the relative chances of selection were for any two possible samples) and how it is to be analyzed."*

d. The Method of Drawing the Sample

It cannot be overemphasized that the randomness of a sample is inherent in the sampling scheme employed to obtain the sample and not an intrinsic property of the sample itself. Experience teaches that it is not safe to assume that a sample selected haphazardly, without any conscious plan, can be regarded as if it had been obtained by simple random sampling. Nor does it seem possible to consciously draw a sample at random. As stated in [6] page 13, "We insist on some semblance of mechanical (dice, coins, random number tables, etc.) randomization before we treat a sample from an existent population as if it were random. We realize that if someone just 'grabs a handful', the individuals in the handful almost always resemble one another (on the average) more than do the members of a simple random sample. Even if the 'grabs' are randomly spread around so that every individual has an equal chance of entering the sample, there are difficulties. Since the individuals of grab samples resemble one another more than do individuals of random samples, it follows (by a simple mathematical argument) that the means of grab samples resemble one

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*See [6] p. 18

another less than the means of random samples of the same size. From a grab sample, therefore, we tend to underestimate the variability in the population, although we should have to overestimate it in order to obtain valid estimates of variability of grab sample means by substituting such an estimate into the formula for the variability of means of simple random samples. Thus using simple random sample formulas for grab sample means introduces a double bias, both parts of which lead to an unwarranted appearance of higher stability."

As has been brought out above, the method of choosing a sample is an all-important factor in determining what use can be made of it. In order that most of the standard techniques of statistical analysis be valid as bases for making statements from samples about populations, we must have unrestricted random samples from these populations. In practice it is not always easy to obtain a random sample from a given population. Unconscious selections and biases tend to enter. For this reason, it is advisable to use a table of random numbers as an aid in selecting the sample. Two recommended tables of random numbers are [7] and [8]. These tables contain instructions for their use.

e. Rectifying Features of the Program

It is expected that meter groups with sufficiently poor performance histories will be designated for complete replacement and when so designated should be removed from the sampling schedule.

The quality control plan itself should provide for a corrective action program to be applied when the results of sampling indicate unsatisfactory performance. One possible action that could be taken is the following. For each sampled group found to be unsatisfactory, test all the remaining meters in the group within some specified period less than eight years and adjust or replace all meters found to be unsatisfactory. Another possible procedure is the one proposed by F. J. Anscombe in "Tables of Sequential Schemes to Control Fraction Defective."[9]

f. Necessary Records

Finally, it is imperative, for quality history purposes, to compile and maintain a certain amount of data regarding the sampling procedure used and the inspection results. In addition to complete identification of the type of meter inspected and the date of inspection, the record should include information as to the AQL, the group size, length of time since a sample from that group was last inspected, the sample size, a distribution (tabulation) of the sampling results indicating the number of meters found outside the accuracy limits, whether or not the group was found to be acceptable, and, if not, what corrective action was or is to be taken. This information should be summarized in periodic reports for reference.

6. CONCLUDING REMARKS AND EXAMPLES OF GOOD PRACTICES

In the development of a long-range quality control plan for meters, the logical steps should be:*

(1) To conduct a preliminary analysis of available data for the purpose of developing estimates of parameters needed in the design of the sampling program.

(2) To design a sampling plan to estimate with prescribed precision the proportion of inaccurate meters for different groups of meter types.

(3) To determine the change in meter performance with regard to time.

(4) To devise a feasible sampling procedure for subsequent years.

The proposed plan should be flexible enough so that as additional data on test results is accumulated, the information given can be readily used in making adjustments to the initial proposals regarding a time schedule for carrying out the program, classification of meters into groups, severity of inspection, acceptable quality level and other factors based on past history, as may seem efficient and economical for future practice.

Comparisons between alternative methods of testing, such as shop-testing vs. field-testing, and rated-load registration vs. light-load registration should be investigated for possible significance in estimating over-all meter population accuracy.

In the light of these objectives, the sampling plans currently in use by the Baltimore Gas and Electric Company [11], the Duke Power Company [10], and the recommended plan developed by the Michigan Electric Association [2], are three examples (of many in existence) which illustrate effective applications of statistical sampling techniques to the problem of electric meter testing.

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*Cf [10]

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