# ELECTRICITY METERS & INSTRUMENT TRANSFORMERS

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# PREFACE

THE advent in Great Britain of the electricity meter as a commercial article dates back to 1880 or thereabouts, and during the intervening years there has been constant improvement in design and manufacture to meet the growing needs of the electricity supply industry. From time to time a new book has appeared dealing with electricity meters, their construction, performance, and testing. Many of these books have been written by engineers connected with the electric supply industry, and few, if any, have been compiled in this country by an engineer closely associated with the manufacture of these instruments. Having spent the greater part of my working life in the designing, manufacturing and testing of electricity meters and accessory apparatus, I have ventured to trespass on this close preserve, in the hope that I may be able to present some of the facts relating to practical meter work as viewed by a manufacturing engineer, and to place on record something new or about which little has been written hitherto should this be possible.

Many of the matters dealt with in this volume have been considered in greater detail than is customary in books on meter practice, and it is hoped that this treatment of the subject will be of assistance to the student and the young engineer without being too wearisome to the meter engineer of more mature experience. Mathematical expression has been reduced to a minimum but it was felt that a clear understanding of the working of polyphase and reactive meters could better be achieved by some reference to elementary trigonometry and to vector representation. Two-phase metering is uncommon in Great Britain but reference to this subject has been included for the information of readers overseas, where extensive use is made of two-phase supplies.

Considerable practical importance attaches to prepayment meters, of which many are in use. The varieties and types are diverse—much too diverse in my opinion—and it remains to be seen whether simplification and unification of tariffs, which problem is now under consideration by the appropriate authorities, will result in the abandonment of some of the complex devices in use at the present time. The two chapters devoted to prepayment meters are barely sufficient to cover the fringe of a very large subject. The question of tariffs as applied to large power

consumers also has a bearing on the use of reactive meters, kVA meters, and maximum demand indicators, and increasing importance is likely to be attached to the association of these auxiliaries with the ordinary polyphase meter. A separate chapter is devoted to a consideration of each of these classes of instrument.

Very little has been written hitherto concerning summation metering, which was first adopted extensively in connection with the large-scale generation of power and its transmission by means of the Grid to distribution centres covering the whole country. Its purpose in the past has been to measure and record the maximum demand, with the object of determining the charges for power generated or delivered in bulk, and now another important function is to obtain statistical information. The operation and maintenance of the equipment has been largely in the hands of specialist engineers on the staff of the (former) Central Electricity Board. Increasing use is now being made of summation metering for the measurement of bulk supplies to large power consumers, and in this connection is coming more and more into the province of the meter engineer attached to supply undertakings, now the British Electricity Authority Area Boards. The chapter devoted to summation metering provides an elementary introduction to a method having possibilities for extensive use in the future.

Many current and voltage transformers are used in connection with the metering of large power consumers and bulk supplies; a knowledge of their characteristics is essential to the meter engineer and a chapter has been devoted to the consideration of each of these accessories. The comprehensive index provided will, it is hoped, assist materially in locating specific subjects.

References have been made in the following pages to British Standards, particularly *B.S. 37: 1937, *Electricity Meters*, and B.S. 81: 1936, *Instrument Transformers*. For many years it has been my privilege to be associated with some of the foremost meter and instrument transformer engineers engaged periodically in the task of drafting and revising these specifications. With a full knowledge of the forethought and care exercised in this work I regard the complete acceptance of their provisions as very desirable in the interests of the industry as a whole. Extracts from these Standards are given by permission of the British Standards Institution, 28 Victoria Street, London, S.W.1, from whom official copies may be obtained.

The field embraced to-day by meter engineering is very wide and I

* See Appendix.

am conscious that in this volume the whole ground has not been covered. It is usual in a handbook dealing with electricity meters to devote space to the testing of these instruments. I consider that this work cannot adequately be covered in these pages and a companion volume is in course of preparation which will be devoted entirely to the testing of electricity meters and instrument transformers.

I wish to express my appreciation of the assistance I have received from manufacturers in supplying information concerning their products, and for the loan of blocks for the purpose of illustration. My thanks are due to the British Standards Institution for permission to quote extracts from Standards. I also acknowledge my indebtedness to management and colleagues at Chamberlain and Hookham Ltd., where I have spent many happy years, and to my associates on numerous Technical Committees, from whom I have derived some inspiration in the preparation of this volume.

*Birmingham*,
*January* 1950.

S. JAMES.

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CHAPTER I

# SPECIFICATIONS AND LEGAL REQUIREMENTS RELATING TO ELECTRICITY METERS

**1.1. The Need for Electricity Meters.** An electricity meter is an instrument which measures the consumption of electrical energy in a circuit and registers the amount in appropriate units on a scale or dial which permits an evaluation of the consumption to be made from time to time. The legal unit of electrical energy in this country and in the majority of others is one kilowatt-hour (symbolized kWh) or 1000 watt-hours, although a few make use of a unit of one hectowatt-hour or 100 watt-hours.

When electrical energy was first distributed by supply authorities the provision of means for measuring the consumption became a necessity in order that an equitable charge for the energy could be made. The earlier supplies of electricity which were generated and distributed were direct current and thus direct current meters were the first to be developed. At a later date alternating current supplies became available and suitable means for measuring these had to be devised.

For a long period direct current distribution predominated, but more recently, owing to standardization, alternating current distribution has taken its place and to-day the greater part of this country is fed from alternating current distribution systems. Direct current is still used for traction systems and for many industrial purposes including electro-deposition, electrolytic refining of metals, electric welding and the like. It is also used extensively abroad and consequently there is still a demand for direct current meters. It is true, however, to say that in the case of domestic consumers of electricity in this country by far the greater number receive supplies of alternating current.

In common with all other measuring devices, electricity meters have inherent errors which cannot be entirely eliminated. To achieve absolute accuracy in measurement is impossible although one may approach closely to this ideal. The modern electricity meter is a very accurate instrument and in certain types the errors over a wide range of measurement and under a variety of disturbing conditions can be reduced to negligible proportions. This observation applies particularly with

regard to alternating current meters, which have reached a remarkable degree of perfection, leaving little to be desired.

**1.2. Meter Specifications.** The earliest regulations concerning the accuracy of electricity meters were contained in Sections 49 to 51 and Section 57 of the Schedule to the Electric Lighting (Clauses) Act, 1899. These regulations have been amended by subsequent legislation and, in addition, specifications relating to the construction and performance of electricity meters have been issued by various authorities. The most important of these specifications is issued by the British Standards Institution. The current issue is entitled **British Standard for Electricity Meters, No.* 37: 1937. Amongst apparatus working in conjunction with electricity meters and having an influence on the accuracy thereof may be mentioned instrument transformers; these also are covered by a specification, the current issue of which is entitled **British Standard for Instrument Transformers, No.* 81: 1936.

These specifications are revised from time to time in order to keep pace with modern requirements, and both are in process of revision at the time of writing this book. The revision is carried out by representatives of the manufacturers of electricity meters and instrument transformers respectively, the British Electricity Authority, the National Physical Laboratory, Government Departments and others who are concerned in the quality and performance of electricity meters. Meters and instrument transformers made to conform to the requirements of these specifications may be regarded as of first-class construction and the accuracy called for is, in general, of a higher order than in comparable specifications issued in other countries.

**1.3. Legislation Affecting Electricity Meters.** Amending legislation affecting electricity meters was enacted in 1936, which had a very important influence upon meter construction and usage. By Section 1 of the Electricity Supply (Meters) Act, 1936, Meter Examiners appointed by the Electricity Commissioners under the Act were charged with the examination and certification of meters used or intended to be used in connection with the supply of electricity by authorized undertakers.

Prior to this enactment, supply authorities as they were then, were at liberty to purchase and install any type of electricity meter which in their opinion was capable of functioning satisfactorily. After fixing on consumer's premises, the accuracy of the meter was the sole concern of the undertaker and provided that the consumer did not question

* See Appendix.

the accuracy and that the undertaker was satisfied, the meter might remain undisturbed for a very long period.

Following the placing of the Electricity Supply (Meters) Act, 1936, on the Statute Book, the Minister of Transport fixed the 1st July, 1938, as the Appointed Day on which the provisions of the Act became operative. On this date certain obligations were imposed on Supply Authorities amongst which were the following:

1. To provide Standard and Substandard instruments and accessories in accordance with the specifications for such, as laid down by the Electricity Commissioners.
2. To employ efficient and fully trained personnel for the periodical calibration and checking of this substandard apparatus.
3. To carry out tests on all meters to be installed on consumers' premises after this date, with the object of ensuring that they conform to the statutory limits of error.
4. To submit such meters to examination by a Meter Examiner appointed by the Electricity Commissioners, for verification, certification and sealing.
5. To install on consumers' premises, only such meters as have received the approval of the Electricity Commissioners as regards construction and type and as have been duly certified and sealed.

It follows from Para. 5 above that manufacturers of electricity meters may supply to authorized undertakers, only such meters as have been approved by the Electricity Commissioners, if the meters in question are to be used for measuring the value of the supply to ordinary consumers. In the case of consumers taking a supply of electricity under special agreements, the use of an approved type of meter may not be essential.

The Electricity Act, 1947, resulted in a new constitution of the electricity supply industry and on April 1st, 1948, all supply undertakings, both municipal and privately owned, became State-owned and were merged into the British Electricity Authority. This Authority with fourteen Area Boards and with the North of Scotland Hydro-Electric Board became responsible for the generation and distribution of electricity throughout Great Britain. The powers hitherto exercised by the Electricity Commissioners are now vested in the Minister of Fuel and Power. This Minister is now responsible for the certification of meters and for the approval of meter types.

Prior to nationalization of the electricity supply industry several hundred supply authorities purchased meters and although the meter specification B.S. 37: 1937 was acceptable in the main to the majority many issued their own specification supplementing or modifying the British Standard. The effect of these multitudinous and diverse specifications was to render standardization of manufacture very difficult. The purchase of meters is now undertaken on behalf of the British Electricity Authority by officers representing the fourteen Area Boards. It might have been assumed that in these circumstances one specification acceptable to all the Area Boards would have been agreed to. Such however is not the case and at the present time each Area Board is at liberty to vary its specification quite independently of the others. In this respect the benefits arising from uniformity have yet to be achieved.

**1.4. Statutory Limits of Error.** The limits of error applicable to electricity meters have been subject to various changes from time to time; in practice the limits of error as laid down in the current issue of the appropriate British Standard (B.S. No. 37: 1937) are accepted. These limits are, generally speaking, closer than the permissible limits implied by Statute, but the legal limits which are expressed in very simple terms cannot make allowance for all the possible disturbing influences which tend to modify the basic errors under standard conditions.

In an authorization by the Board of Trade dated 13th June, 1913, the statutory limits of error were fixed as follow:

For meters in which the maximum current at full load—

(i) does not exceed 3 amperes, the error at any point from one-tenth load to full load must not exceed $3\frac{1}{2}$ per cent., plus or minus.

(ii) exceeds 3 amperes, but does not exceed 50 amperes, the error at any point from one-tenth load to full load must not exceed $2\frac{1}{2}$ per cent., plus or minus.

(iii) exceeds 50 amperes, the error at any point from one-twentieth to one-tenth load must not exceed $2\frac{1}{2}$ per cent. plus, and at any point from one-tenth load to full load must not exceed $2\frac{1}{2}$ per cent., plus or minus.

These allowable limits of error were applicable to direct-current meters and single-phase alternating current meters.

In 1937, the Electricity Commissioners issued an instruction as follows:

*Electricity (Supply) Acts, 1882 to 1936.*
*Limits of Error for Meters.*

In virtue of the powers exercisable by them under the Electricity (Supply) Acts, 1882 to 1936, and Orders made thereunder and Local Acts relating to the supply of electricity, the Electricity Commissioners HEREBY ALLOW the following limits of error, namely an error not exceeding 2½ per cent. plus or 3½ per cent. minus at any load at which the meter may be operating, for meters, the construction and pattern of which have already been or may hereafter be approved under the Acts and Orders aforesaid as meters capable of ascertaining the value of the supply on direct-current or alternating-current circuits.

The limits of error hereby allowed shall supersede the limits of error allowed by the Board of Trade by an authorization dated 13th June, 1913, and the said authorization shall cease to have effect as from the date hereof without prejudice to anything done or suffered thereunder.

*Signed by order of the Electricity Commissioners this 14th day of September,* 1937.

A. E. MARSON,
*for Secretary to the Electricity Commissioners.*

In comparing the latest permissible limits of error with those previously in force, the following points may be noted. In the authorization of 1913, the Board of Trade evidently took cognizance of the facts that:

(i) direct current meters of the smallest current ratings could not be expected to register as accurately as the larger current ratings;

(ii) meters, both direct current and alternating current, could not be expected to register as accurately on low loads as on high loads;

(iii) meters, both direct current and alternating current, could not be expected to register within acceptable limits of error at any loads below a certain minimum.

It may be true that, theoretically, some types of electrolytic meter for use on direct current circuits were capable of conforming to the limits imposed, but such meters suffer, as a class, from certain disadvantages which render them unsuitable or unacceptable for many purposes.

The Electricity Commissioners in their instruction issued in 1937, stipulate that a meter shall register within the prescribed limits of error *at any load at which the meter may be operating*, and they make no

distinction between meters for small current ratings and meters for large current ratings. This stipulation implies that no matter how large or how small the load, or what disturbing influences are present such as abnormal temperature, voltage, frequency or the like, the meter must register within the prescribed limits of error under all conditions. In the present state of the metering art, and notwithstanding the high degree of perfection which has been reached in many types, there is probably no meter which can in all circumstances satisfy this requirement and at the same time conform to all the other necessary requirements as regards constructional features.

In the foregoing statement no suggestion is made that existing meters are unsuitable for performing their functions. Such an inference would be ridiculous in the extreme. On the other hand the Electricity Commissioners were fully informed as to the capabilities and limitations of modern meters. It may be presumed therefore, that the phrasing of the instruction relating to limits of error is intended to avoid legal difficulties which might conceivably arise in certain circumstances had the Board of Trade authorization of 1913 remained in force.

A meter may be expected to give its best performance and to function consistently at loads from ten per cent. upwards. Below this point the stability is not so good and disturbing influences which may develop in course of time are more likely to result in inaccurate registration at low loads. It follows therefore, that in selecting a meter for any given installation, some regard should be paid to the probable minimum load as well as the possible maximum. It is extremely unlikely that any consumer, other than the small lighting consumer, will switch on the whole of the connected load at the same time, and it is desirable in the interests of good metering to pay some regard to the maximum continuous rating of the meter as well as the maximum probable loading of the installation.

**1.5. Rating of Meters.** Arising out of the previous paragraph, it is appropriate here to refer to the current rating of meters and to the relationship existing between rating and overload capacity. In B.S. 37: 1937, a number of clauses refer in some manner to the rating of meters. Clause 10 defines Marked Current as " the current in amperes marked on the nameplate of the meter ". Clause 37 specifies the limits of error with different currents, expressed as a percentage of the marked current, and Clause 43 specifies the duration of permissible excess currents for various types of meter with reference to the marked current.

In the case of direct current meters, limits of error are specified for current loadings up to 125 per cent. of the marked current. Most meters will safely carry for a limited period currents in excess of this value, but the errors of the meter during this period may be outside the guaranteed limits. Whole-current meters up to a marked current of 50 amperes will carry without injury and without the accuracy being permanently impaired, an excess current of 100 per cent. for thirty minutes. Whole-current meters above 50 amperes, up to and including 1,000 amperes, and also all meters with shunts up to 1,000 amperes, will in similar circumstances carry an excess current of 50 per cent. for thirty minutes. Whole-current meters and meters with shunts above 1,000 amperes will carry an excess current of 25 per cent. for thirty minutes.

In the case of alternating current meters the same conditions apply as for direct current, but there is an additional class of single-phase meter referred to in B.S. 37: 1937, as " Long-Range ", for which limits of error are specified up to 200 per cent. of the marked current. In addition, it is specified that a long-range meter shall not be injured and its accuracy shall not be permanently impaired by an excess current of 100 per cent. above marked current, i.e. by 200 per cent. of the marked current carried continuously.

Prior to the introduction of the long-range meter, the working range of a single-phase meter was from 125 per cent. to 5 per cent. of the marked current. Expressed as the ratio of the maximum to the minimum load, this corresponds to a range of 25 to 1. This working range still applies to whole-current single-phase meters of 100 amperes rating and to all meters operated from current transformers.

The extension of the range of measurement during the last twenty years has been progressive and at the time of publication of B.S. 37: 1937, meters having a range of 40 to 1 were in common usage. At the present time the majority of meters have a range of at least 60 to 1 and in one country a range of 80 to 1 is recognized. It cannot be assumed that progress has ceased and that this represents the ultimate limit, and there is surely something illogical in a system of rating which implies that a piece of apparatus, whether it be a meter, a generator or a power transformer, can operate continuously at three or four times its marked current, where the marked current is supposed to represent the full load condition.

Because of this continued extension of the working range and the illogical system of rating with which it has been associated, the current markings of single-phase meters have become anomalous and give no

precise indication of the maximum continuous rating. For example, a meter used to be capable of carrying a continuous overload of 25 per cent. which later was increased to 100 per cent. and has now reached 200 per cent. or more. The fact is, of course, that the maximum continuous rating is no greater to-day that it has ever been but the range of accurate measurement has been extended in the downward direction.

By comparison with a meter having a range of 25 to 1, the modern meter having a nominal range of say 60 to 1 is accurate from 125 per cent. load down to 2 per cent. load. Expressed in this manner the achievement appears less spectacular than is suggested by stating that the range is from 300 per cent. load down to 5 per cent. It may be anticipated that when the next revision of BS. 37: 1937 is completed, a more logical system of rating will have been adopted, which will remove the anomaly to which reference has been made.

**1.6. Approved Types of Electricity Meters.** Except where an agreement between the supply authority and the consumer exists to the contrary, all meters to be installed on consumers' premises must be of construction and pattern approved by the Ministry of Fuel and Power (formerly Electricity Commissioners). Request for approval is made by the manufacturer or his agent, who submits a number of samples of the type in question, accompanied by drawings and specifications giving full details of the construction, to the Director of the National Physical Laboratory, Teddington. Here the meter is critically examined and tested, and is then kept under observation for a considerable period in order to make certain that it is capable of complying with all the conditions laid down in the appropriate specifications as regards suitability, accuracy, and permanence of calibration. At the end of this period a report on the meter is submitted to the Minister of Fuel and Power, who, provided that he is satisfied in all respects, may grant the desired approval.

Prior to the passage of the Act of 1936, many types of meter were in use which had not been submitted for approval. Others which had been at one time approved, had been modified in various ways, thus invalidating the original approval and had not been re-approved. In order that use of these types might be continued after the Appointed Day (1st July, 1938), approval or re-approval became necessary. The normal period required for the granting of approval is from one to two years, but owing to the unusually large number of meter types submitted in a limited period, the Electricity Commissioners were at that time unable to cope with the enormous amount of work involved.

Accordingly, Provisional Approval was granted in many cases after a comparatively short period, provided that the initial performance was satisfactory. This Provisional Approval was subject to confirmation or rejection at a later date when circumstances permitted a more thorough investigation to be made.

Certain types of meter were regarded by the Electricity Commissioners as unsuitable for approval. These included one particular type of direct-current ampere-hour meter, namely the commutator motor meter which had been used to a limited extent in this country, mainly if not wholly on account of its low price. It has been and still is used extensively on the Continent of Europe where the standards of accuracy demanded by the authorities are much inferior to those enforced in Britain. It is probable that approval would be granted for meters of this type if they could be made sufficiently accurate and reliable as to conform to the specifications laid down, but it is significant that, so far as the author is aware, no such meters have yet been produced.

**1.7. Periodical Re-testing of Meters.** The Electricity Supply (Meters) Act, 1936, provided for the periodical re-testing of electricity meters installed on consumers' premises, at intervals not exceeding ten years from the date when last certified. This provision minimizes the possibility of errors going undetected for a long period if such should develop after the meter has been installed.

A further provision of the Act required that meters which were installed on consumers' premises prior to the Appointed Day (1st July, 1938), shall be removed within ten years of that day if they are of a type which had not been approved. This period has now been extended to fifteen years. All meters installed prior to the Appointed Day were regarded as certified meters although many such were of types which would not in other circumstances be regarded as satisfactory. Thus, this provision imposes a time limit of fifteen years for the use of possibly inaccurate meters.

**1.8. Meter-Testing Stations.** By Section 2 of Electricity Supply (Meters) Act, 1936, it became the duty of Electricity Supply Authorities, referred to in the Act as Authorized Undertakers, to provide and maintain in proper condition, such suitable apparatus as prescribed or approved by the Electricity Commissioners, for the examination, testing and regulating of meters used or intended to be used in connection with the supply of electricity, and to afford to Meter Examiners all necessary facilities for the use of such apparatus.

Since the Electricity Supply (Meters) Act, 1936, became effective,