SOLID STATE TARIFF METERS-ANALYSIS AND DEVELOPMENT

A DISSERTATION

submitted in partial fulfilment of
the requirements for the award of the Degree
of

MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(Measurement and Instrumentation)

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By

SHAKTIDEV MUKHERJEE

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DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE (INDIA)

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CERTIFICATE

Certified that the dissertation entitled, 'SOLID STATE TARIFF METERS- ANALYSIS AND DEVELOPMENT', which is being submitted by Shakti dev Mukherjee in partial fulfilment for the award of the degree of Master of Engineering in Electrical Engineering(Measurement and Instrumentation) ofthe University of Roorkee, Roorkee, is a record of bonafide work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further certified that he has worked for seven months from Feb., 1977 to Aug., 1977 for preparing this dissertation at this university.

(H.K. VERMA)

Reader in Electrical Engineering
Department of Electrical Engineering
University of Roorkee, Roorkee.

Dated August 25, 1977.

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S. MUKHERJEE

ABSTRACT

This Dissertation aims at studying the developments in the field of solid state tariff meters as well as analysing the performance of the same. The review work on the topic gives sufficient background to understand the trend of development in the field.

Successful attempts were made to develope energy meters and two types of demand meters i.e., Integrating and Lag type. Sufficient details have been worked out to make prototypes of these meters.

Studies of the present methods of remote sensing and monitoring of tariff data helps in exploring the possibilities of evolving a widely acceptable method in future.

As a result of these studies the salient features and future prospect of solid state tariff meters could be brought into light. Development work undertaken by the author leads to interesting conclusions, regarding the feasibility of the scheme. At the end suggestions have been made for further work in the field which can lead the solid state tariff meters towards a better alternative to the conventional type.

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CHAPTER 1

INTRODUCTION

As electricity cannot be stored in quantity like many other items, it has to be generated according to the requirements of consumers, who are charged for their share of consumption. System of evaluation of this share is as old as the supply industry. Understanding of the methods for determining the consumers' share of consumption is required to develope suitable means of doing it.

1.1 Tariff and Tariff Meters

The list of various charges paid by a consumer for consuming electricity is known as electricity tariff. Total cost of an electricity supply does not depend only on the total output of the source in units of energy or kilowatt-hours, but also upon the capacity of the plant required to meet the combined maximum demand of all the consumers. These total costs are of two types viz. the running costs proportional to the kWh output and including part of the costs of fuel, oil, water, wages etc. and standing costs proportional to the plant capacity and including all but running cost. If the total costs of supply, including profit are shared equitably by all consumers, then the cost of supply to any consumer depends upon his consumption in kWh, and upon his contribution to the combined maximum demand which fixes the plant capacity. This contribution to the combined maximum demand depends upon the actual maximum demand of the consumers, and upon the diversity of the group of which he is a member, the higher the diversity the less will each kW of his maximum demand increase the combined maximum demand. As the maximum demand per kWh of consumption depends on load factor, it follows that as either or both the load factor and the diversity of a consumer's supply increase, the cost of supply per kWh falls.

Instruments used for recording consumption of electricity are known as tariff meters. These are used for metering the followings:

(a) kWh and kVAh

(b) kW and kVA Maximum Demand(for a fixed integration period like 15 mts, 30 mts etc.)

(c) Reactive kVAh.

These meters should faithfully measure the consumption of electricity with minimum error such that neither the consumer is penalised nor the supplier is at a loss. Design, fabrication and calibration of tariff meters are done according to electricity tariff rules prevailing in a particular country and also these are checked and certified by competent authorities to ensure that the error is within the limits allowed by the tariff law.

Besides being used for charging the consumers, the metered informations are used for operational, planning and statistical purposes too. These can be enumerated as:

(a) Preparation of daily, weekly, monthly and annual load curves for analysing consumptions by various classes of consumers during given periods.

(b) Examining demand pattern load curves for various periods e.g. night time, weekdays and seasons of the year.

(c) Obtaining power factor of the system from kW and kVA demands.

(d) Calculating load factors for periods under review i.e., daily, monthly or annually, from kW and kWh readings.

(e) Calculating diversity factors from the relationship of suppliers' simultaneous demand and aggregate of demands on individual points of supply.

(f) Estimating the difference between units generated and units sold to consumers, which provides a measure of the units lost in transmission and distribution.

(g) Deciding the demand and units taken at individual points of supply, and those passed through the suppliers' primary system, which provide essential data for the future planning and development of the suppliers' primary system.

1.2 Types of Tariff

There are various methods of charging electricity tariff in different countries. Basic principle of formulating tariff systems lies around the fact that each consumer should pay correct charges for consumption of electricity and at the same time should feel encouraged in using more electricity. Based on this principle and evolved as a result of long experience of supply industries and an understanding between supplier and consumers, the following types of tariffs are well known:

1.2.1 Tariffs for domestic and shop consumers

(a) Flat rate tariff

After estimating the load and diversity factors of a group of consumers for various uses of electricity, the equitable contribution to the standing costs of supply for each kWh consumed can be calculated and two charge components can be merged to form a flat rate per kWh of consumption. Flat rate generally varies with the method of using the supply. There are different rates for heating, lighting, power etc. and consequently different meters are required for each type of load. This type of tariff depends only on the kWh consumption and is easily understood by the consumers.

(b) Two-part tariff

Under this type, charges for electricity supply are divided into two components as one proportional to the kWh consumption and the other on a quantity supposed to depend upon the maximum demand. The first component being the unit charge and the second a fixed charge independent of consumption. The fixed charge may be assessed on either size of premises or so called connected demand or the combined kW capacity of all the consuming devices.

(c) Block-rate tariff

The consumer has to pay a fixed charge irrespective of consumption in case of the above mentioned two part tariff, which seems to be a drawback on part of the consumer. Hence, under the block-rate tariff, the fixed charge is merged into the unit charge for one or two blocks of consumption, all in excess of these blocks being charged for at the low unit rate. The number of kWh applicable to each block is fixed by the size of house or the rateable value; the kWh rate for the first block being highest, that for the second block is intermediate between the highest and the lowest rates.

1.2.2 Tariffs for industrial consumers

(a) Maximum demand power tariff

Under this system of tariff, the total charge consists of two components, one proportional to the kWh consumption and the other to the maximum demand. This maximum demand can be either kW or kVA. Main object of MD tariff is to encourage the consumer in avoiding sustained high peaks, and maintain so far is possible a steady load for long periods. There are different types of MD tariff systems. One is general type and the other is restricted-hour type. In both types, there is an instrument for recording demands over every fixed interval of time varying from 15 to 60 minutes. In our country work interval is under use. In general type there is only one instrument for recording demand and its readings are taken every month or every quarter as the case may be.

In restricted hour type there are two instruments one for peak load hours and other for off peak hours, charges are lower for off peak hours.

(b) Power factor tariffs

In case of A.C. supply, the total capacity of the electrical plant in kVA depends not only on the MD in kW but also upon the power factors of this demand, so that the equitable contribution of a power consumer tothe total standing costs depends upon the power factor of his supply. Power factor tariffs are methods of charging for A.C. power supplied under which the overall rate per kWh depends upon the power factor. These are of three types.

(i) KVA MD tariff

Under these tariffs the two components of the charge are proportional respectively to the kWh consumption and to the MD measured in KVA.

(ii) Sliding scale power factor tariff

Under these tariffs the rates of charging vary according to the measured average power factor of the supply, usually rising by a fixed percentage for each 0.01 by which the power factor falls below 0.8, and falling by a smaller percentage for each 0.01 rise of power factor above 0.8.

(iii) kWh and kVArh tariff

Under these tariffs the charge for the supply is made up of two components, the one proportional to the kWh consumption and the other to the measured consumption of reactive kVAh.

Besides the above tariff methods for domestic and industrial consumers, there is one more method called prepayment system, which can be applied with any of these. Under this system, all supplies have to be prepaid into a special meter which cuts off the supply when the amount prepaid is exhausted.

1.3 Conventional Tariff Meters

Before discussing the solid state tariff meters it will be useful to have an idea about the existing conventional tariff meters of which equivalents are to be developed with solid state devices.

1.3.1 Classification

Conventional tariff meters can be classified as follows:

(I) D.C. meters

- (A) Ampere hour meter
- (B) Watt hour meter

(II) A.C. meters

- (A) Single phase kWh meter
- (B) Polyphase meters
  - (a) Energy meters(kWh, kVAh and kVArh)
  - (b) Demand meters(kW and kVA)
    - (i) Lag type
    - (ii) Integrating type

Besides above, there are prepayment and summation meters which essentially performs any of the above functions but in a different manner. Well known principles of conventional meters are not included here. Certain desirable features and shortcomings of most popularly used meters are discussed in brief for justifying the necessity of switching over to solid state tariff meter.

1.3.2 Salient features and sources of error

(I) Energy Meters

Induction type energy meters are being most widely used, of which, several built in features are as follows:

(a) Visual indication of operation
(b) Visual display of cumulative readings
(c) Virtual freedom from zero drift
(d) Good overload range
(e) Robustness
(f) Comparitive freedom from interference both physical and electrical
(g) Reversible operation

Along with these, they have following sources of errors too:

(a) Permeability of iron in current electromagnet varies with main current
(b) Eddy current brake acting on rotor varies with main current.
(c) Friction in rotor bearings and in register
(d) Possible lack of symmetry in electromagnet system.

(e) Error due to change of frequency are because of:

(i) Permeability of the voltage electromagnet cone will be changed and different parts of the magnetic circuit may be changed by different amounts.

(ii) Cu-loss and Fe-loss in voltage electromagnet vary with frequency.

(iii) Voltage flux varies inversely with frequency but current flux is not affected.

(iv) Phase displacement between applied voltage and leakage flux vary.

(v) Impedance of the paths traversed by the eddy currents in the rotor disc changes.

(f) Temperature error is present due to

(i) Voltage coil resistance will increase. It will have little effect on non-inductive loads but the phase angle of the voltage flux will be reduced and this will cause the meter to register slower on inductive loads. The effect increases as the p.f of the load becomes lower.

(ii) The flux in the gap of the brake magnet or magnets will decrease with the result that the braking torque will be reduced and the meter will register faster under all load conditions. Chrome and tungstun steel material will register more than Cobalt-Nickel alloy.

Besides the above sources of error, there can be trouble in operation due to following reasons:

(a) Foreign matter in the permanent magnet gap or between the disc and one of the electromagnet limbs
(b) Iron in disc.
(c) Faultstop bearing or top pin
(d) Rough or worn bottom pivot
(e) Cracked or rough bottom jewel
(f) Friction in counting mechanism due to bent tooth, faulty, spindle or bearing, dirt in one or more teeth, sticky bearings or a rough worm.
(g) Incorrect adjustment of the top bearing, or bottom jewel.
(h) Buckled disc or bent spindle
(i) Incorrect adjustment of friction compensating loop.
(j) Discontinuity in pressure or series coil.

Most of the above sources of trouble are due to moving mechanism which will be eliminated in solid state meters.

(II) Demand Meters :

(i) Integrating type

It consist of the energy meter with arrangements for recording the energy consumed in every 30 mts or as the case may be. A pointer moves along with a dummy one on a dial calibrated in kW or KVA, which is periodically disengaged by a mechanical device actuated with synchronous motor. This is known as Merz type and is being most popularly used.

Though integration type records correctly the MD as per definition, its reading is considerably affected by the clocktime, at the occurance of peak load. Due to peak-splitting between two integrating periods this MDI has a tendancy to underread. The other disadvantages are its high initial cost, higher maintenance, dependance of accuracy on the driving kWh or kVAh meter.

(ii) Lag type

In lag type demand indicator, a signal proportional to I^2 is generated with thermal effect in a manner that 90 per cent of the maximum value to which the meter is subjected to at a time is reached in 30 mts of time interval. It has various drawbacks as

(a) It records current demand only assuming a constant voltage, thereby leaving scope for over or under recording with voltage fluctuation.

(b) Non linearity of scale

(c) Short life

(d) Poor stability of calibration

(e) Inconsistency of performance

(f) Sluggish response to sharp peak loads

1.3.3 Necessity for a change

Conventional tariff meters have passed through long years of development. So far, there has not been any change in the basic principles involved except for some improvements in the accuracy by refining the design. So it can be safely concluded that, instead of making attempts for further improvements in them. Change over to schemes with solid state devices will be more wise. Error limits of tariff meters lie within ±2 % which can be brought down to ± 0.5 % or even lower range by solid state meters.

1.4 Solid State Tariff Meters

Basic functions of solid state meters remains same as that of conventional meters but the transducer for converting the tariff quantity to a proportional measurable quantity is made out of solid state devices. Once the transducer is developed the metering schemes can be worked out in detail.

Basically the design of solid state tariff meters can be summed up as:

(a) Signal conditioning
(b) Transducing the tariff quantity to a measurable form.
(c) Measuring/Integrating the transducer output.
(d) Displaying the output and provide facilities for testing
(e) Providing power supplies and suitable enclosure.
(f) Matching with the cost and quanity of conventional type.

Each of the above points can be elaborated as follows.

1.4.1 Signal conditioning

Standard ouputs of (110V, 5A/10A)P.T and C.T used in metering cannot be directly put to sold state devices. Signal conditioning is done by error compensated P.T and C.T. A suitably designed current shunt can also be used for lowering the current limit.

1.4.2 Transducers

Tariff quantity to be measured may be either VIcos ϕ, VIsin ϕ or VI. Suitable multipliers are used as transducer for performing these functions. Among various multiplication techniques available, followings can be used in making Wattmetric transducers for tariff meters:

(a) Using Hall Effect

(b) Using Quarter square circuits

(ii) Using Pulse width/height modulations technique.

So far (b) and (c) have been more extensively tried.

Quater square circuits are based on the equation

$$4\,ab = (a+b)^2 - (a-b)^2 \qquad (1.1)$$

This function can be realised by devices relying on square law characteristics such as thermal devices, semiconductor devices like F.E.T or by devices which synthesize a square law by a series of straight line approximations using biased diodes or Zener diodes.

Pulse width/height modulation technique includes generation of a train of rectangular pulses , the width of which is modulated by one input where as other input modulates the height of it. The area of the pulses obtained becomes proportional to the vector product of the two inputs.

1.4.3 Integrators

Output of the multiplier is to be integrated for energy measurment as well as demand recording by integration over a fixed time interval. Otherwise it can be directly fed to a circuit for lag type demand indicators as discribed in chapter IV. There are two common methods of integration such as (i) charge compensation method (ii) dual slope integration method. In charge compensation method the multiplier output is allowed to charge the capacitor of an integrator until a threshold voltage is reached, when a predetermined charge is extracted from the capacitor, which then resumes charging. The charging rate is proportional to the power and a pulse is produced each time the trigger operates.

The dual slope integrator employs a capacitor that is charged by the multiplier output to a threshold voltage, whereupon the input to the capacitor is reversed until a reverse limit is reached, when the input is again reversed. A pulse is produced at each alternate reversal.

Both system have merit in certain circumstances. In the first method, the frequency of impulsing is limited by the time taken to extract the predetermined charge and the load range covered tends to be less than for the second method, although accuracy is less dependent on capacitor stability.

1.4.4 Display and testing

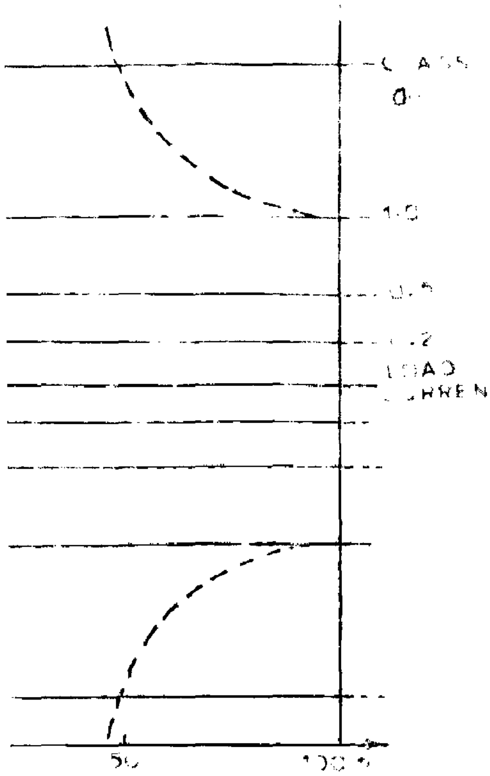
The obvious display for solid state meter is digital readout. At present however no economical displays are available that can retain its readings and memorise them when the supply is disconnected. It is clearly necessary for a meter to be able to be read at any time. Presently the integrator outputs are counted in a conventional mechanical counter. For testing purpose the integrator output can be measured either independently by a precision method or can be compared with a set of standard pulses.

1.4.5 Power supply and enclosure

Tappings from the voltage signal conditioning transformer can be taken at required points which has to be rectified, filtered and stabilised for obtaining ripple free con constant d.c voltage to bias the solid state devices. Solid state meters have to be provided with suitable enclosures for protection against dust and moisture.

1.4.6 Matching with conventional meters

Since still the solid state tariff meters are under development stage, actual cost with large scale production can not be definitely worked out at this stage. However a comparison between cost/precision characteristics of electronic and conventional meters in Fig.   reveals that cost is similar at higher precision limits where as it is higher at lower precision limits.



RANGES OF ERROR FOR VARIOUS METER PRECISION CLASSES AT COS φ

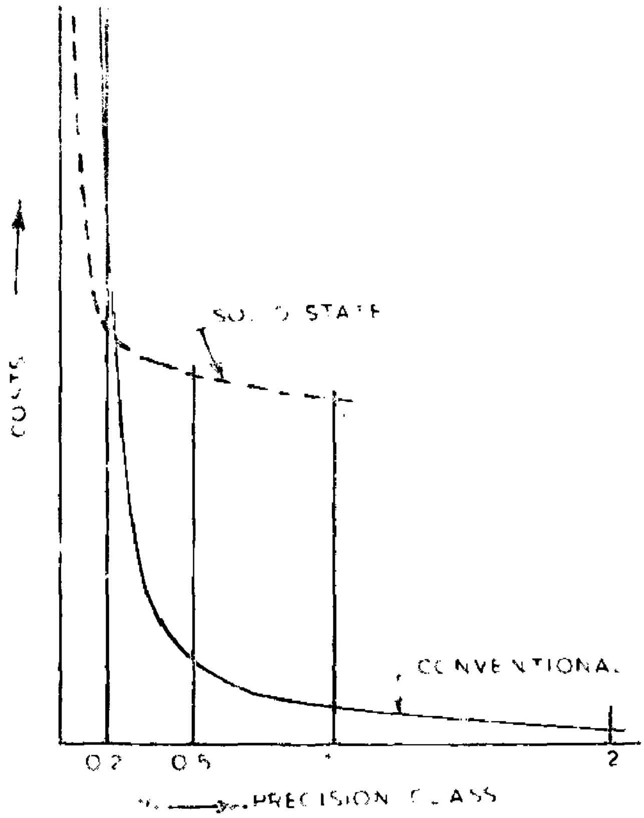
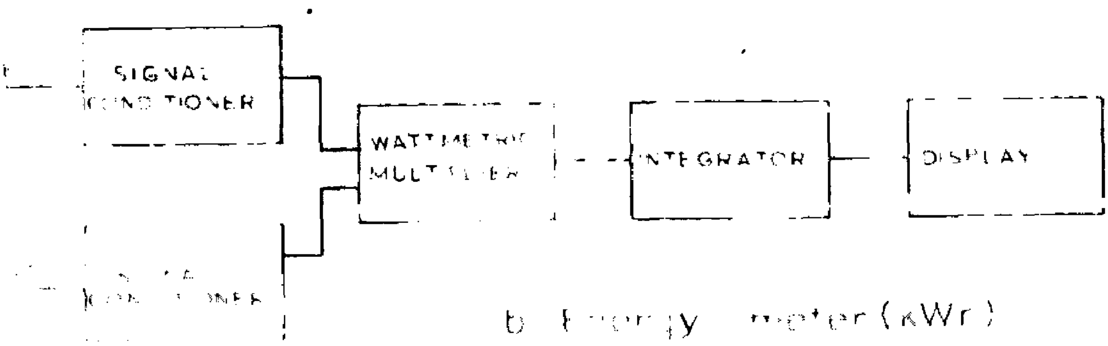
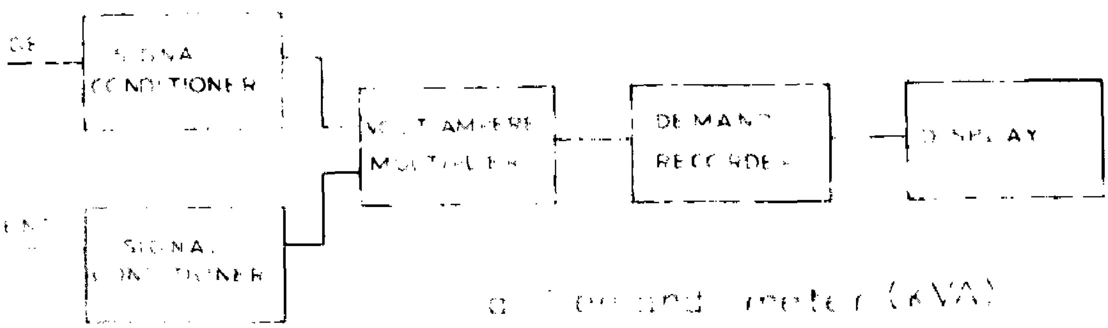


FIG 1.3 COST/PRECISION COMPARSION BETWEEN SOLID STATE AND CONVENTIONAL METERS



b) Energy meter (kWh)



a) Demand meter (kVA)

1.4 BLOCK SCHEMATIC OF SOLID STATE TARIFF METERS (Typical cases)

1.5 Overview of the Dissertation

Chapter 1 on introduction has threefold purpose of reviving the concept of tariff and tariff meters, justifying switching over to solid state type and introducing the solid state tariff meters.

Chapter 2 deals with a review of various phases of development in use of solid state devices in tariff meters. It starts with a description of conventional meter testing with electronic computer. This is followed by an illustration of working principles of four meters with partial use of solid state devices. These are namely, a summation meter, two kVA meters and a standard Whr meter. Next comes the details about various solid state wattmetric transducers developed for tariff meters. After this, operating principles and error analysis of complete solid state tariff meters have been described. It is divided into two sections of precision and general purpose type. Precision type is further subdivided into two sections as portable one for testing meters while on situ and another for using as a bulk supply meter.

Chapter 3 is devoted to the development and testing of Energy meters undertaken by the author. These are kWh and kVAh meters. Testing has been conducted under various conditions of voltage, current and power factors. Test results plotted indicate errors within allowable limits. Apart from this a detail proposal for developing a suitable prototypes have also been included. A feasible scheme of kVArh meter has been presented at the end.

Chapter 4 describe the development and testing of two types of demand meters viz. integrating and lag type undertaken by the author. Principle of the proposed integrating type meter has been succesfully tested based on which a prototype can be developed. The lag type meter has been successfully tested under various conditions of load as steady, stepped, peak, stepped rise and stepped fall etc. Errors calculated from plotted results are within reasonable limits.

Chapter 5 covers basic requirements and principles involved in remote sensing and monitoring of tariff data. Three schemes using different methods have been reported.

Chapter 6 is the conclusion of the dissertation. This illustrates various desirable features of solid state tariff meters which make it a superior alternative to the conventional type. Then, various factors involved in the replacement of conventional tariff meters with solid state equivalents have been examined. At the end, scopes for further work in the field have been elaborated.

CHAPTER 2

DEVELOPMENT OF SOLID STATE TARIF METER-A REVIEW

First phase of the application of solid state devices in tariff metering started with its use in testing of conventional electromechanical type meters. Then came the meters with partial use of solid state devices in conventional types, for better performance. After passing over all these preliminary stages of development in sixties, complete solid state tariff meters came into being with the starting of the present decade. Before discussing the complete solid state tariff meters, a very brief review of the initial phases of development seems relevant.

2.1 Use of Solid State Devices in Conventional Meter Testing:

With the increase in number of consumers and improvements in the accuracy standards of tariff meters, there arose a necessity for testing facility of large number of meters in short period. The obvious solution was use of solid state devices in forming a testing circuit with an electronic computer. Though, there are various schemes available for this purpose, the one having large capacity with more accuracy is described here.

(i) Principle of Operation: This test equipment was developed by Japan Electric Meters Inspection Corporation(8). It can test 60 meters per hour with an accuracy within ±0.2 %. The equipment consists of meter desks, electronic computer, a controller, power supplies and a control panel. The errors of the meters are measured by comparing the speed of their discs with that of a precision rotating standard, and then calculated and printed automatically according to the computer program. The comparison of the speed is carried out by counting the standard pulses from the precision rotating standard by means of a counting system. The percentage error of the meter is given as

$$\epsilon = (N-n)/n \times 100 + \epsilon_s \qquad (2.1)$$

where, n = Actual count of the standard pulses of a given number of revolutions of the meter.

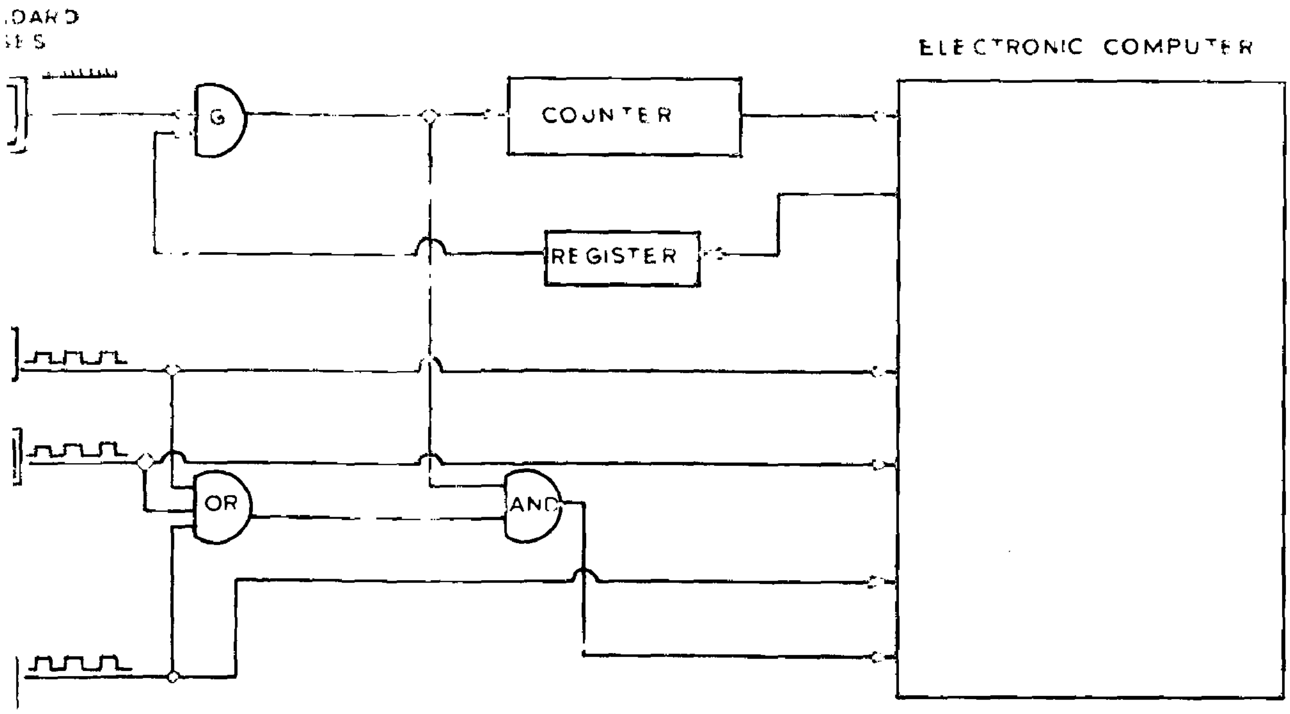
N = The count of the standard pulses which a correct meter would require from correct standards for a corresponding number of revolutions.

ϵ_s = Inherent error of the standards (precision rotating standard and current transformer).

The counting system is shown in Fig 2.2, starts with the 'start' signal which opens the gate G and the counter starts. Whenever one or more signals of the meter come to the 'OR' circuit, its output signal is synchronised with the front edge of the standard pulse through the 'AND' circuit and sent to the computer as the 'Interruption' signal. The computer calculates error and registers it. At a time one meter is tested and the next is taken up after the error registration of the first.

(ii) Comments: The measuring accuracy of the system is determined by the followings -

(a) Counting accuracy



2 2 _ CONVENTIONAL METER TESTING WITH ELECTRONIC COMPUTER

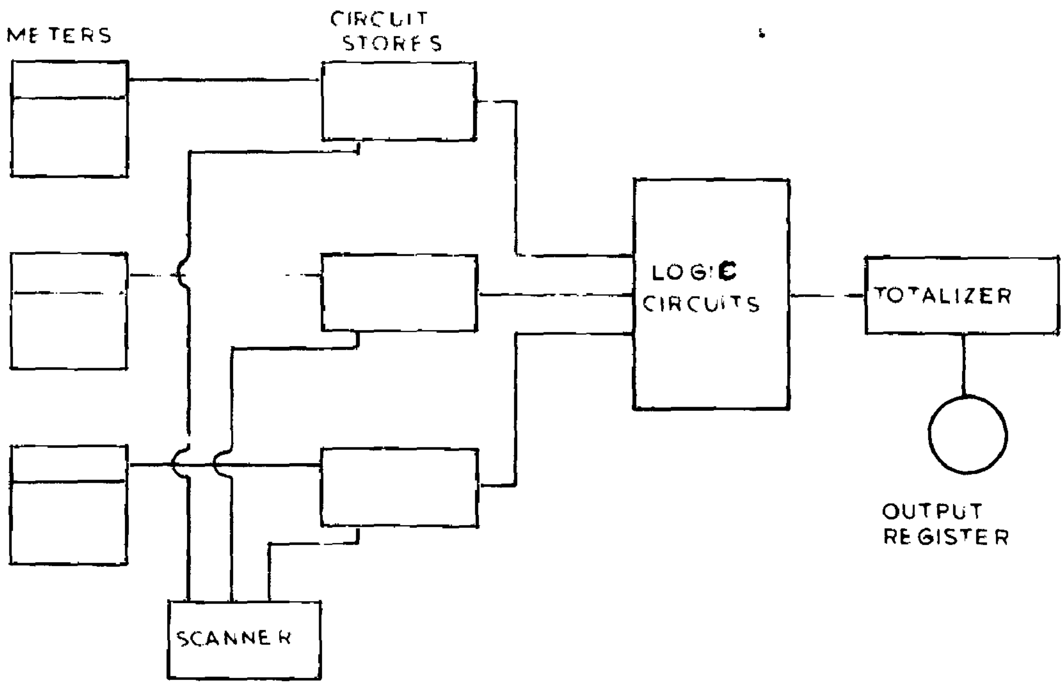


FIG 2 1 _ BLOCK SCHEMATIC OF SUMMATOR METER

(b) Fluctuation in one revolution of the standard meter

(c) Variation in the power supplies and ambient conditions

Efficiency is determined by the time and for self heating which is more than 30 mts and it enables 60 meters to be tested an hour.

The electronic testing system of conventional meters refered above was successfully implemented in Japan during late sixties. With the arrival of complete solid state meters, this method can be suitably modified for testing them.

2.2 Tarrif meters with Partial use of Solid State devices.

2.2.1 Summation meter

(i) Principle of operation: One of the earliest attempt on electronic summator meter is described here(19). This was developed in late sixties as a result of experience with the limitations of conventional type summation meters.

Schematic diagram shown in Fig.2.7 ,consists of

(a) Meter transmetter
(b) Circuit store
(c) Scanner
(d) Logic circuits
(e) Totaliser
(f) Output register

Summing is done of informations collected at various energy meters of conventional type. There is temporary store for each channel and a scanner empties these stores in sequence, thus separating into orderly sequence impulses which may arrive simul-taneously on several input channels. These spaced impulses can than be divided, subtracted from one another and finally totalised. Having obtained a pulse rate equivalent to the desired quantity this must be displayed on a register. A binary circuit with the windings of the register stepping motor forming its collector load does this duty. A power output to drive a printometer or other form of external equipment may be obtained by using a transistor switching circuit.

(ii) Comments: This was an initial attempt towards electronic summation metering using signals from conventional meters. With the coming up of all electronic meters, summation can be done in simpler and more accurate manner. Though yet to be commercialised, complete electronic summation meters will supersede the type described above.

2.2.2 KVAh Meter and KVA Maximum Demand Indicator

(a) Zero phase angle type(4)

(i) Principle of Operation: In order that an induction disc kWh meter registers kVAh at any phase angle, it is necessary either to maintain the current in phase with the voltage or maintain the voltage applied to the meter voltage coil constantly in phase with the current. The current may vary between zero and a maximum value whereas the voltage is a relatively constant feature. Hence, it is simpler to operate on the voltage component using the current as a reference from which control signals may be formed to lock the voltage in frequency and phase with the current. The block schematic of the meter is shown in Fig.2·1. The first stage of the conversion of the supply voltage into a current phase related quantity is to rectify the a.c to produce a d.c voltage of equivalent magnitude. This d.c is then supplied to the second stage which is a frequency and phase locked a.c. generator. Phase locking is achieved by means of pulses which are formed by the passage of the load current through a pulse generator. The generator frequency is therefore identical with the frequency of the load current.

Block schematic shows a single phase system but it can be used in a polyphase system also. On a system unbalanced in voltage and current magnitude and phase angle it would be necessary to generate each phase voltage by a separate invertor system triggered by its appropriate current. The voltages and currents would be connected to a 3-element Var meter for integration and registration.

(ii) Comments: The performance of the meter has been reported to be quite satisfactory with variation of magnitude and waveform of load current, phase angle, voltage and ambient temperature. Slight inaccuracy can creep in with change of voltage waveform because d.c voltage derived from supply is a function of peak value rather than r.m.s value. It is doubtful whether this method can prove itself superior to complete solid state type kVAh meters yet to be developed.

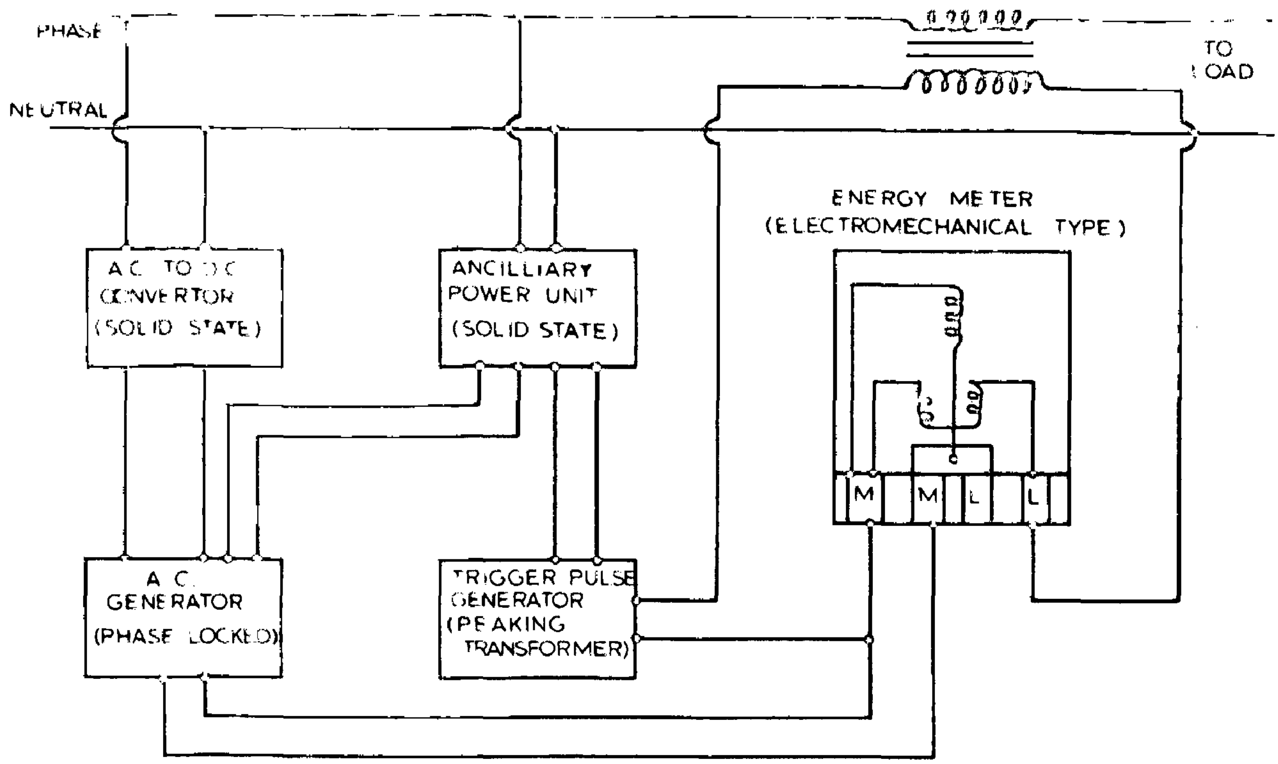


FIG 2.4 BLOCK SCHEMATIC OF kvAh METER WITH PARTIAL USE OF SOLID STATE DEVICES

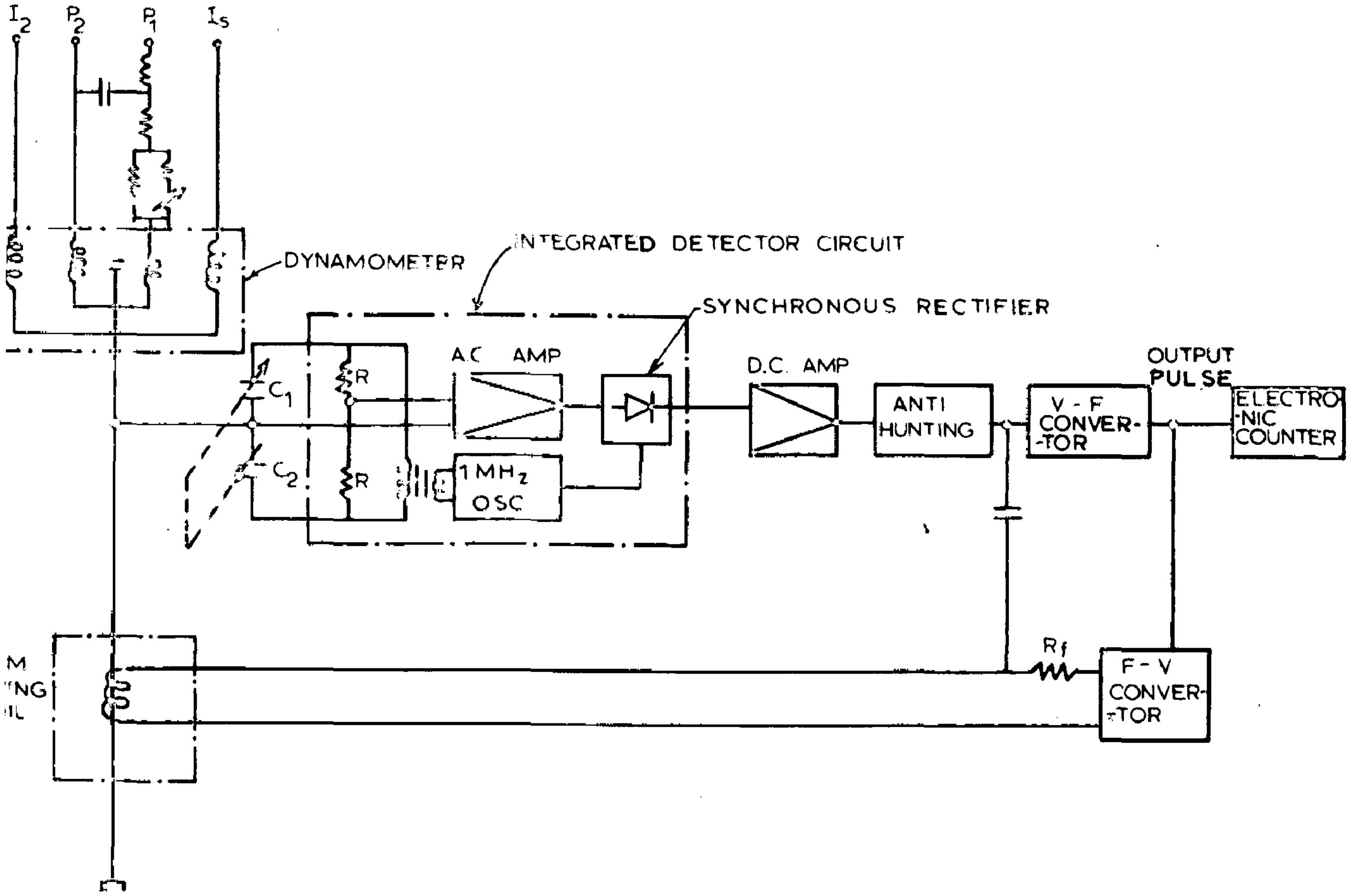


FIG 2.3 BLOCK SCHEMATIC OF STANDARD Whr METER USING ELECTRODYNAMOMETER

(b) Square root type(6)

(i) Principle of operation: Principle of this meter uses the method of computing kVA from kWh and kVAr. Impuses from conventional kWh and kVArh meters are received by the system which electronically calculates kVAh over a sampling period and the output is fed to drive a Merz type MD indicator.

Under normal conditions of fluctuating power factor kVA demand over a sampling period of 't' can be put as $Q/t = (Q_1 + Q_2 + \ldots + Q_n)/t$, Q_n = kVAh during a given sample $= \sqrt{P_n^2 + R_n^2}$ (2.1a), where R_n and P_n are respectively kVArh and kWh during the same interval. Here power factor has been assumed constant over the sampling period. Assuming $P_n + R_n$ = constant = C. Equation 2.1a can be modified to

$$Q_n = C - C\left(1 - \sqrt{\frac{1}{2}\left[\left(\frac{2R_n}{C} - 1\right)^2 + 1\right]}\right) \qquad (2.2)$$

$$\text{or,} \quad Q_n = C - f(R_n) \qquad (2.3)$$

$$\text{or,} \quad Q_n = P_n + (R_n - f(n)) \qquad (2.4)$$

Equation 2.4 is realised through a digital system where f(n) is digitally synthesised. To the kWh pulses are added a number of pulses determined by the kVArh pulses received during each sampling period.

(ii) Comments: On testing the prototype, error of very random nature without any set pattern has been reported under varying condition of power factor. A better performance is expected with slightly varying power factor load. The scope of its commercial exploitation in future seems not to be very bright.

2.2.3 Static Standard Watthour meter(17)

(i) Principle of operation: The meter under discussion has an electrodynamometer which is automatically torque balanced and does not rotate and hence is more accurate than rotating induction type meters. Block diagram of this meter is shown in Fig2.3 . The principle is based on self-balancing system,i.e., the dynamometer torque caused by the power under test is counter-balanced by the torque of the permanent magnet moving coil element by feedback current. The deflection of the moving shaft is detected by a detector of capacitance transducer type, and converted to a d.c voltage signal which drives the pulse oscillator through the anti-hunting circuit. This pulse oscillator is V-F converter. The output pulse of this oscillator is changed to a constant voltage-to-time area rectangular pulse, by the F-V converter.

(ii) Comments: The meter has undergone trials for 3 years at the time of reporting. It has high accuracy and stability to become a standard meter. No effect of change in waveform is observed. Effects of change in voltage, current and frequency are also very small. Although consisting of an electrodynamometer, it is being claimed to be very compact and light. Whether its cost/accuracy characteristics can be comparable with that of high precision all electronic type standard meter or not is yet to be decided.

2.3 Solid State Transducers

As mentioned in section (1.4) multipliers are used as transducers in solid state tariff meters. So far, multipliers of (a) Mark/Space amplitude modulating type and (b) Quarter square type have been tried extensively. In the begining of development stage output of multiplier was integrated to obtain train of pulses with frequency proportional to the measurand i.e. power. Later on, a direct power to frequency converter has comeup. A brief review of principles involved in various transducers is of interest here.

2.3.1 Mark/Space amplitude modulating type(16)

(i) Principle: One of the input quantities, say current(Figure 2.6a) is used to modulate the mark/splace ratio of a multivibrator, oscillating at a relatively high frequency (10-20 kHz). This produces a signal as shown in Fig 2.6b which is used to switch the instantaneous voltage signal 'on' and 'off'. By using a bidirectional electronic switch operated in anti-phase, full wave switching is obtained, resulting in a net output as shown in Fig 2.6b. This has a d.c component proportional to the power being measured (VI cos ϕ) together with double frequency and high (switching) frequency components which can be readily smoothed out before further amplification. It is designed for multiplying at all power factors from 0-360° and can be used for import/export applications. Its accuracy is independent of switching frequency and waveform.

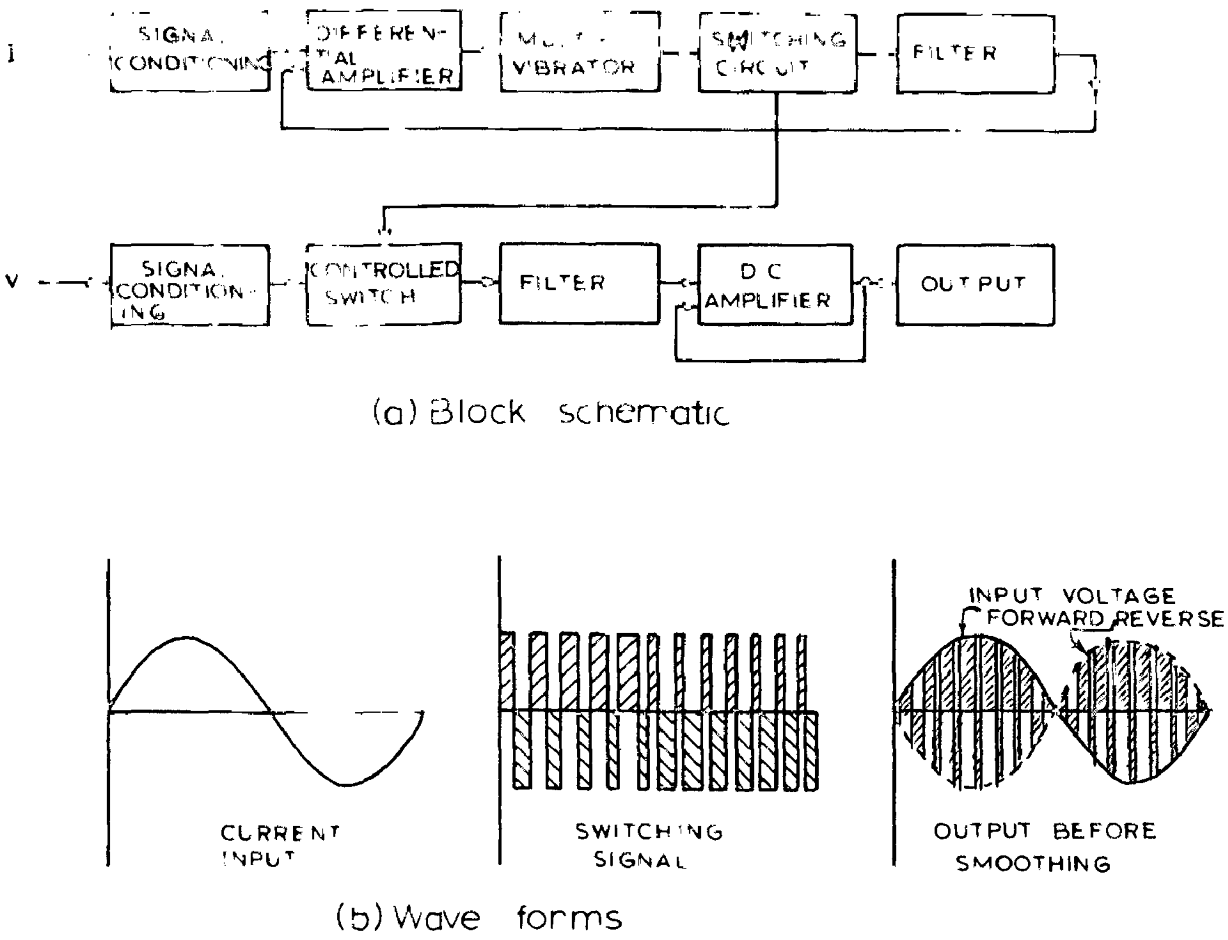


FIG 2 6_MARK/SPACE AMPLITUDE MODULATING MULTIPLIER.

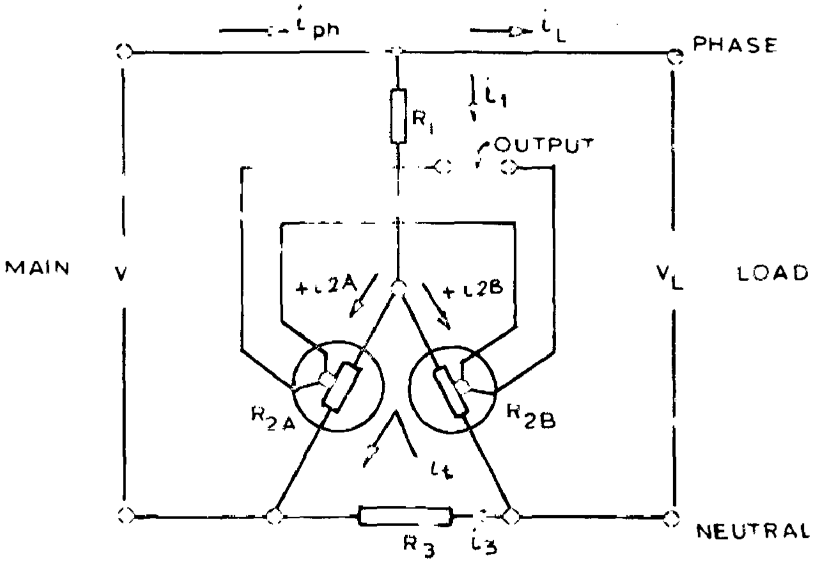


FIG 2 5_THERMOCOUPLE MULTIPLIER.

(ii) Comments: The above transducer had undergone trial for 5 year at the time of its reporting. Its long term stability is yet to be established. An error of 0.1 % in calibration during a year has been reported. Its accuracy limits suggests it to be suitable for meters of general purpose type. Till it goes to mass production, its cost/performance characteristic cannot be compared with conventional meters.

2.3.2 Quarter Square Type

(a) Using Thermo-couple(7)

(i) Principle: It is based on the principle that the output from a thermojunction is approximately proportional to its temperature, which, in turn, is approximately proportional to the square of the current flowing through the heating wire. The current through thermocouples is limited by R_1(Fig 2.5) and is proportional to the main voltage Vph. When a load is connected across the output terminals(Ph and N) most of the load currents flow through R_3 developing a voltage across it. A fraction of the load currents i2A and i2B passed through the thermocouples, whose heater resistances are denoted R_{2A} and R_{2B}. A part of the load current that does not flow through R_3 but through thermocouples only is denoted by i_t. Now if $i_{2A} = +y$, $i_{2B} = -y$ and $i_t = x$ then the function $1/4\left[(x+y)^2-(x-y)^2\right] = xy$ can be realised through the circuit shown in Fig 2.5. A voltage proportional to the product VI cos ϕ can be obtained at the output of the multiplier.

(ii) Comments: Mismatch between thermocouples can introduce error. Upper limit of load current depends on the power dissipation in R_3. It should take care of varying voltages and power factor within working limits. comments on its performance could not be made in the absence of requisite data.

(b) Using diode array

(i) Principle: The principle of quarter square multiplier using diode resistor network is explained as follows (Fig 2.7):

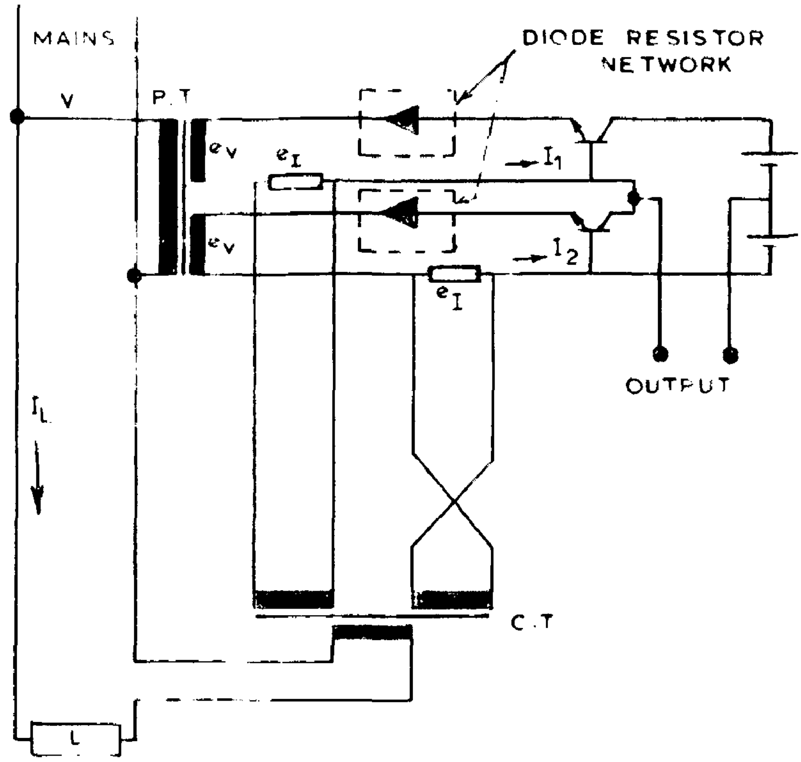
Let 'd' be the voltage drop across each diode at the base emitter junction. R_k is the last resistor in the chain to conduct when voltage is V. All resistors have the same value 'R'.

Then $i_1 = \frac{V-d}{R}$, $\quad i_2 = \frac{V-3d}{R}$, $\quad i_k = \frac{V-(2k-1)d}{R}$

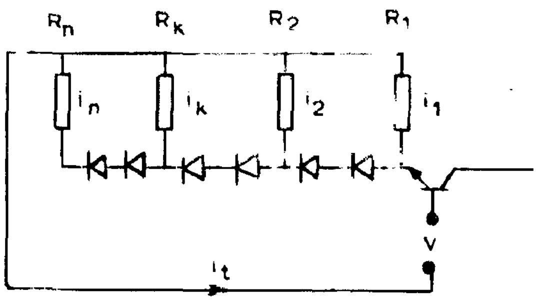
since, $2kd \geq V > 2(k-1)d$

If $V = 2kd$, $\quad i_t = \frac{d.k^2}{R} = \frac{V^2}{4Rd}$ (2.5)

Voltages proportional to (v+i) and (v-i) and applied across two identical diode resistor networks. As the voltage rises, successive branches pass current and it can be shown that the resulting current approximate to a function of the square of the voltage. Clearly the resulting current curve will advance in steps, and the approximation to a square law will be closer with increasing number of branches.



a _ Schematic circuit diagram



b _ Diode resistor network

FIG. 2.7 _ MULTIPLIER WITH DIODE ARRAY

(ii) Comments: The fact that diode breakdown does not occur instanteneously, however, but in a progressive transition, smooths the steps and produces an error within limits of a general purpose meter. The method is simple using passive elements(diodes), which do not require careful matching. Mass production is possible with thin film technique.

2.4 Complete Solid State Energy Meters

2.4.1 Precision Meters

(a) Portable type(10)

(i) Principle: This is a portable precision meter for testing conventional meters while on situ. Block diagram of the meter is shown in Fig 2.9. Input current to the multiplier is made to vary within a small range with variation of load current over a wide range, through a set of burden resistances R, 4R, ... 256R. Each of them is associated with a certain range of the input current I, according to the table below

I(A)	>24	24...6	6...1.5	1.5...0.375	0.375... 0.
$B = \alpha R$	R	4R	16R	64R	256R

The range detector monitors the current value transformed by T_2 and selects the proper resistance. Multiplier output current i_m goes to an analog-frequency converter with an output frequency 'f' proportional to the average $\bar{i}_m$. Since, with decreasing I, B increases by a factor α, the output of analog frequency

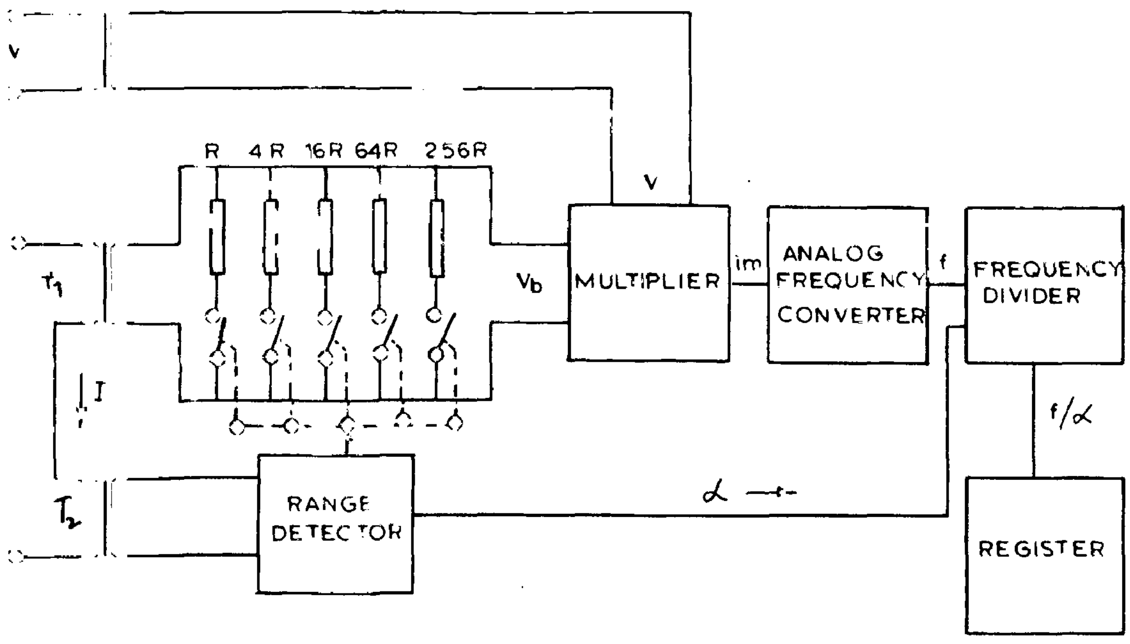


FIG. 2.9 _ BLOCK SCHEMATIC OF PORTABLE STANDARD METER

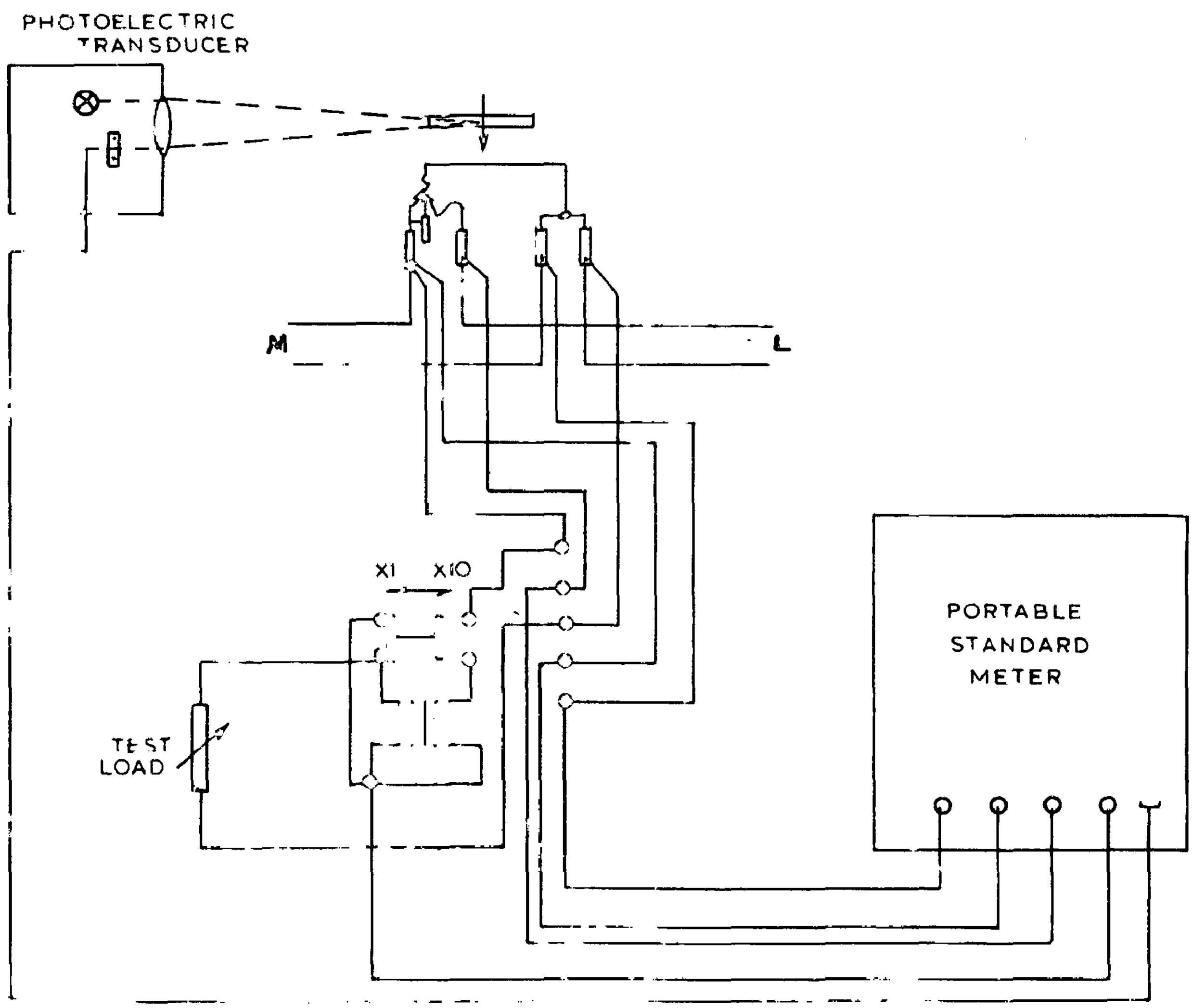


FIG. 2.8 . ARRANGEMENT TO TEST A METER WHILE IN SITU

coverter 'f' has to be divided by α to maintain a constant ratio between the frequency input to the pulse counting register and input power. This is done by a frequency divider controlled by the range detector. ~~V_p, f and f/α as function of I is shown in Fig~~ .

(ii) Method of use: An arrangement showing the application of the meter for testing conventional meters while on situ, is shown in Fig 2.9 . The test loads desired at unity p.f are set with an additional portable device. Output signal for each revolution of meter is picked up with a photo-electric transducer used either for starting or stopping the registering counters as well as for counting the pre set number of disc-revolutions. The standard meter provides a count of 1000 pulses during the test periods if the meter under test is error free. Deviations are indicated in units of 0.1% within the range of ± 9.9%. If error is beyond this limit than the display flickers.

(iii) Error analysis and comments: Quantitative errors reported are as,

For a current varying between 0.025A and 100A at a constant 220V, the instrument inaccuracy lies within ± 0.05%.

A change of voltage from 100 to 250V causes less than 0.05% variation in error.

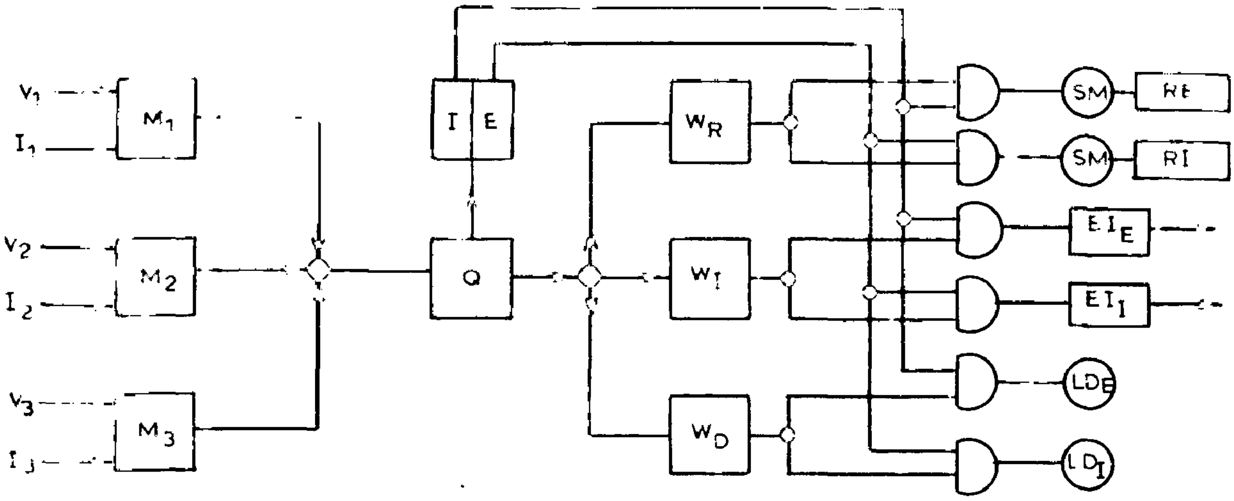
There is no effect of frequency variation between 40 to 65 Hz

Temperature coefficient (0-50°C) is 0.03% per °C.

Qualitatively, above shows that the instrument is more accurate with variation of current than voltage, which is the requirement of a standard meter for testing. There is no indication of the effect of power factor variation on the meter performance. Although, it can test meters for varying power factors by giving suitable test load or by providing a phase shifter, but its performance accuracy under that condition is unknown. Temperature coefficient reported is rather high i.e. 300ppm per ^{o}C.

(b) Bulk supply type

(i) Principle: Very high accuracy is required for metering bulk supplies. For instance if the average power to be metered is 100MW, a reduction of meter error by only 1% means an improvement of the billing accuracy by approximately 880 MWh per year. Block schematic of a meter developed by M/s Siemens, Germany, for bulk supply metering is given in Fig.2.10a. A multiplier is provided for each phase which forms a signal proportional to the power to be metered. Sum of the three values measured is fed on to a quantiser Q which emits a pulse every time when the time integral over the totalised power reaches a definite value. The signal representing the electrical work is matched to the particular output element and then passed on to the output elements which comprise a register R, electronic impulsing device EI and a Light emitting diode LD. Frequency division is carried out by electronic frequency divider. It is possible to measure the energy flow (imported and exported energy) with one set



M : MULTIPLIER

Q : QUANTIZER

I/E : IMPORT - EXPORT DETECTOR

W : FREQUENCY DIVIDER

SM : STEPPER MOTOR

OUTPUT ELEMENTS

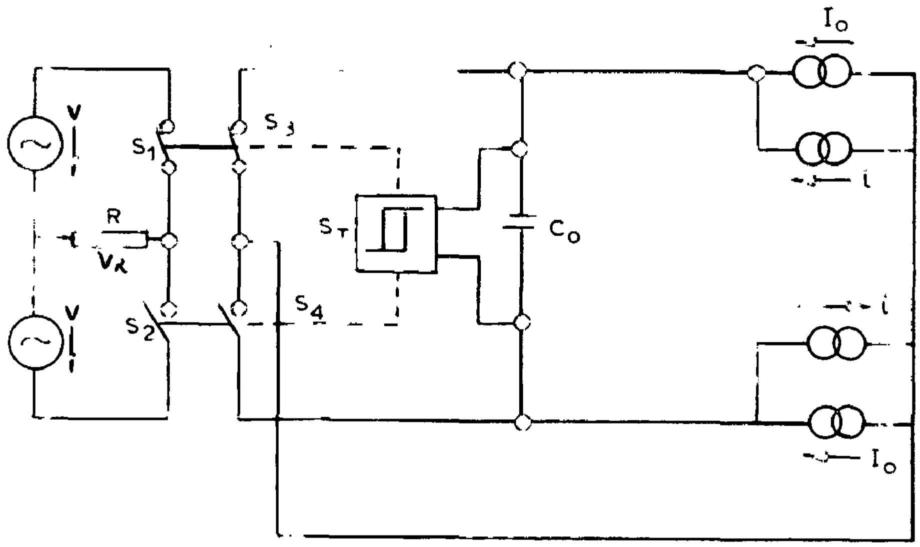
R_E : REGISTER FOR EXPORT

R_I : REGISTER FOR IMPORT

EI : IMPULSING DEVICE

LD : LIGHT EMITTING DIODE

a _ BLOCK SCHEMATIC



b _ MULTIPLIER

FIG 2.10. PRECISION TYPE BULK SUPPLY ENERGYMETER of multipliers and one quantiser. Multiplier is shown in Fig 2.10 . in which, R is a load resistance across which the signal v.i representing the power is formed. The voltages +v and −v are alternately applied to load resister R through switches S_1 and S_2. If T_1 and T_2 are closing time of S_1 and S_2, voltage v_R averaged over T_1+T_2 is given as:

$$v_R = \frac{T_1}{T_1+T_2} .(v) + \frac{T_2}{T_1+T_2} (-v) = \frac{T_1-T_2}{T_1+T_2} .v \qquad (2.6)$$

T_1+T_2 should be small in comparison with the period of v i.e., 20ms, it is taken as $T_1+T_2 = 100\mu s$.

Switches S_1 and S_2 are actuated synchronously with S_3 and S_4. States of S_3 and S_4 is, in turn, changed by Schmitt trigger ST when the voltage of the capacitor C_o - connected to the input of the trigger reaches the upper limit value $+v_o$ or the lower limit value $-v_o$. When S_2 is closed, the capacitor is charged with a current I_o-i, I_o being a constant direct current. The capacitor is discharged with a current I_o+i when S_4 is closed and S_3 is open. Since the capacitor voltage always varies between the values of $+v_o$ and $-v_o$, the charge applied to the capacitor during T_1 is always equal to the charge taken off during time T_2.

$$\therefore \quad T_1(I_o-i) = T_2(I_o+i)$$

$$\text{or,} \quad \frac{T_1-T_2}{T_1+T_2} = \frac{1-\dfrac{I_o-i}{I_o+i}}{1+\dfrac{I_o-i}{I_o+i}} = \frac{i}{I_o} \qquad (2.7)$$

from (2.6) and (2.7) $v_R = v.i/I_o$

Hence voltage across load resistor R is proportional to the instantaneous value of power v.i. I_o has to be maintained at a constant level for good linearity. The quantiser works on charge compensation method.

(ii) Error analysis and comments: Quantitative errors reported by the manufacturer are as:

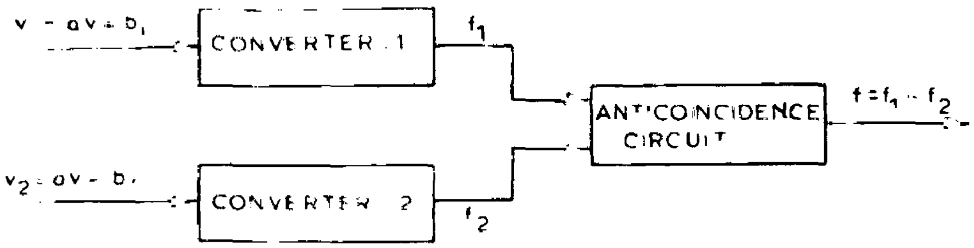
Linearity error within a load range of of 1:120 —— ——	± 0.2%
Maximum deviations of metered value	<0.1% per 10% voltage variation
	≤0.1% per 10°K change of temp.
	<0.05% per 10% frequency variation.

Qualitatively, above shows that the inherent instrument non linearity is more prominent than effects of voltage, frequency and temperature variation on instrument reading. It is to be examined whether a compromise between the two can be reached for doing justice to the bulk supply metering.

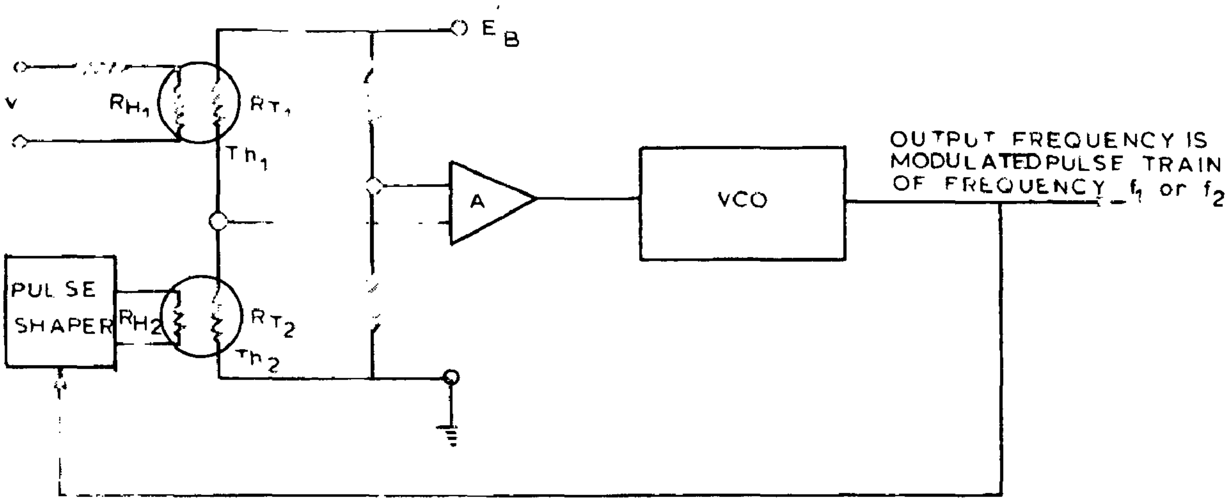
2.4.2 General Purpose Meters

(a) Using Thermistors(20)

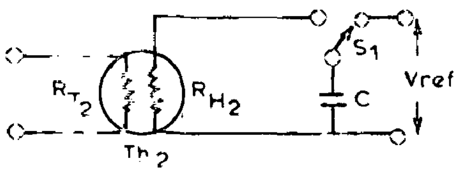
(i) Principle: It consists of two mean square value to frequency converters followed by an anticoincidence circuit that digitally perform the difference between the coverter output frequencies f_1 and f_2. The converter 1(Fig2.11) input voltage is the sum of a signal proportion to the voltage v and a signal proportional to the current i, while the converter 2 input voltage is the difference between these signals.



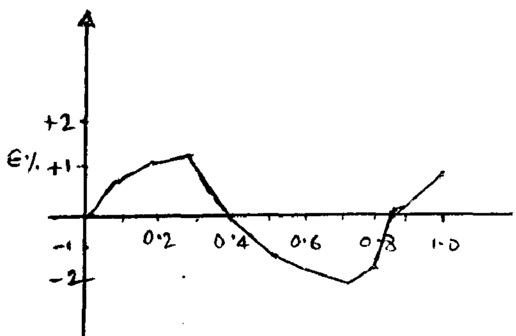
a. Block schematic of P-F CONVERTER



b_Circuit of converter 1 or 2 (schematic)



c_ Pulse shaper (schematic)



d- CONVERSION ERROR VS INPUT SIGNAL.

FIG. 2.11 _ ENERGY METER USING THERMISTORS

Output frequencies of converters are related to the inputs by

$$f_1 = k.\frac{1}{T}\int_0^T v_1^2 dt = k.\frac{1}{T}\int_0^T (av+bi)^2 dt \qquad (2.8)$$

$$f_2 = k.\frac{1}{T}\int_0^T v_2^2\, dt = k.\frac{1}{T}\int_0^T (av-bi)^2 dt \qquad (2.9)$$

$$f = f_1 - f_2 = k.4ab.\frac{1}{T}\int_0^T vi\ dt = 4abkP \qquad (2.10)$$

A digital measurment of the frequency f results in a digital measure of the power P. If the two frequencies f_1 and f_2 are applied to the input of a reversible counter, a digital measure of the energy is stored in it. Functions (2.8) and (2.9) can be realised by means of circuit given in Fig 2.11b. A square law relationship between input voltage and output frequency was obtained under the assumptions.

Negligible bridge unbalance
Constant conversion factor k
Close matching of the thermistors

If P_1 and P_2 are power dissipated in the heaters of Th_1 and Th_2 then,

$$P_2 = f_1 W \qquad (2.11)$$

where, f_1 is the output frequency

W = A fixed amount of energy delivered for complete discharge of C(Fig 2.11c)

$$= \frac{1}{2}CV_{ref}^2 \qquad (2.12)$$

Due to assumption of close matching

$$P_2 = P_1 = \frac{R_{H_1}}{(R_{H_1} + R_{in})^2} \cdot \frac{1}{T} \int_0^T v_1^2 \, dt \tag{2.13}$$

$$\text{or,} \quad f_1 = k.\frac{1}{T} \int_0^T v_1^2 \, dt \tag{2.14}$$

$$\text{where} \quad k = \frac{R_{H_1}}{W(R_{H_1} + R_{in})^2} = \text{A constant} \tag{2.15}$$

From (2.15) we find that constancy of k depends on R_{H_1}, R_{in} and W. W can be made constant by the pulse shaper shown in Fig. 2.11c. Each output pulse actuates the switch S, which discharges the capacitor C on the heater R_{H_2}. Provided that the pulse width is sufficient to assure the complete discharge of C a fixed amount of energy is delivered. Change in R_{H_1}, due to heating is reduced by making $R_{in} = R_{H_1}$.

(ii) Error analysis and comments: If converter non-linearity error is taken into account then,

$$f_1 = \frac{k}{T} \int_0^T v_1^2 \, dt \pm \Delta f_1 \tag{2.16}$$

$$f_2 = \frac{k}{T} \int_0^T v_2^2 dt \pm \Delta f_2 \tag{2.17}$$

$$\therefore f = 4 \, abkP \pm (\Delta f_1 + \Delta f_2) \tag{2.18}$$

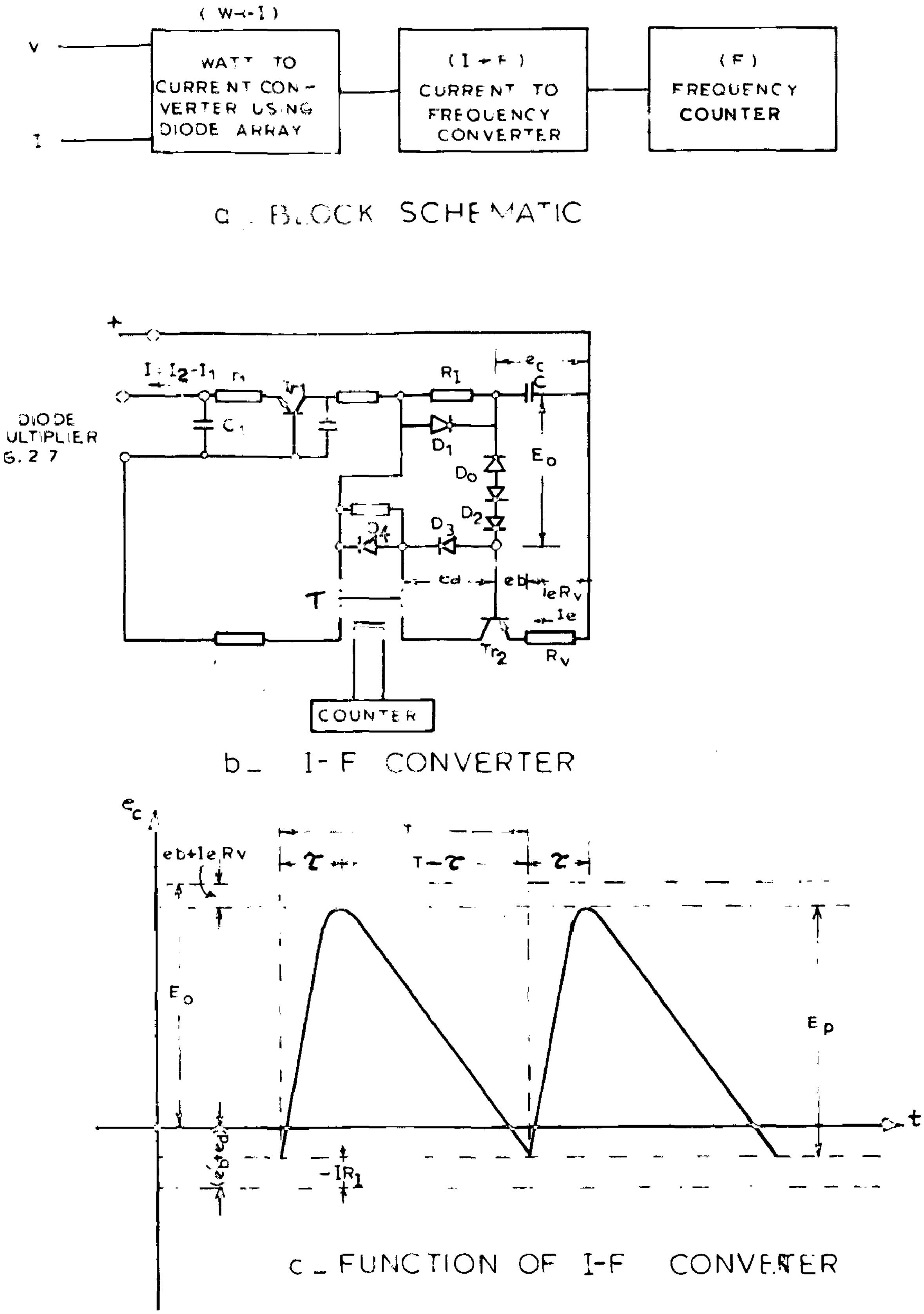
Hence the absolute maximum error in power measurement is $2\Delta f_M$ in terms of frequency since digital subtraction does not introduce error. Fig 2.11d shows the conversion error Δf versus d.c input voltage. The d.c to a.c transfer error is less than 0.05% for input voltage frequency ranging from

20 to 80 k Hz.

Due to direct digital feedback there is analog to digital conversion and the square law relationship between the input voltage and the output frequency does not depend on the intrinsic characteristics of the thermal units but only on a close matching of the input and feedback units, provided k is constant. Linearity and stability of error amplifier and VCO do not affect the accuracy of the conversion since they belong to the forward path of a feedback system. The use of thermal devices makes the instrument suitable for d.c as well as a.c with wide band disregarding the signal waveforms.

(b) Using diode array

(i) Principle: There are two converters W-I and I-F as shown in Fig 2.12a. W-I converter works on the quarter-square principle already described in section 2.3.2(b) and the I-F converter works on the method of cpacitor charge and discharge. The current difference $I = I_2 - I_1$ flows through the capacitor C and the filtering circuit T_{r1}, r_1, C_1, so that the charging voltage decreases. When the voltage across the capacitor C reaches a constant value, the switching transistor T_{r2} operates (switches on) and the capacitor C is instantaneously charged by an impulse voltage from the feedback pulse transformer T. Feedback pulse is generated by the pulse transformer T when T_{r2} switches on, and the peak of the pulse is cut by the Zener diode D_e. Therefore the charging peak voltage of the capacitor C is constant, independently of the



'G. 2.12 ENERGY METER USING DIODE ARRAY

pulse frequency. Nonlinearity caused by the feedback pulse width and the effect of DC supply voltage variation are reduced by the resistors R_I and R_v respectively.

If E_o = Zener voltage containing D_o and D_2

e_b = emitter base voltage drop of T_{r2}

Maximum charging voltage, $e_{max} = E_o - e_b - I_e R_v$

Minimum voltage level at which T_{r2} switches on and the performance terms over again = $e_{min} = -(e_b' + e_d - IR_I)$

e_b' = emitter base voltage drop of T_{r2} at the moment of begining to switch on.

e_d = voltage drop of diode D_3.

Peak to peak voltage $E_p = e_{max} - e_{min} = \frac{E - IR_I}{1}$

where $E = E_e - e_b + e_b' + e_d - I_e R_v$

As shown in Fig 2.12c, charging period τ is short and constant and the discharging period $T - \tau$ is inversely proportional to I,

$$\therefore \quad I(T-\tau) = C\,E_p = C(E - I\,R_I) \tag{2.19}$$

$$\text{or,} \quad I = C\,E/T-\tau+CR_I \quad = \frac{CE}{1-(CR_I-\tau)F}\,.F \tag{2.20}$$

where $F = 1/T$, R_I is so adjusted that $CR_I = \tau$

$$\therefore \quad I = C\,E\,F \quad \text{or} \ , \ F = I/CE \tag{2.21}$$

i.e., $F \propto I$

In Fig 2.12b, D_1 is for passing the charging current, D_2 is for temperature compensation, D_3 and D_4 protect T_{r2} from the strong pulse generating when T_{r2} switches off. Pulses proportional to power are counted after suitably dividing them in a divider.

(ii) Error analysis and comments: The W-I converter used (Fig 2.7) has some errors given as :

$$\epsilon = \epsilon_W + (\theta_I - \theta_V) \tan \phi + \frac{a\theta}{k\cos\phi I_L} + \frac{bI_L}{kV\cos\phi} \qquad (2.22)$$

where, ϵ_W = Full scale errors

(θ_I and θ_V = Phase angle error of CT and PT respectively.

ϕ = phase angle between voltage V and the current I_L

k = constant = $\frac{I}{VI_L\cos\phi}$

a,b = Degree of unbalance of e_V and e_I respectively. Error due to each term can be determined both theoretically and practically.

Maximum error of W-I converter has been reported to be +1% and that of I-F converter as -0.5%. Temperature error lies within +1% and error due to voltage variation lies within - 0.5%. Only prototype has been made and it is yet to go for mass production. The meter shows accuracy well within the limits of general purpose meter and there is scope for its mass production with thin film technique.

(c) Using direct P-f converter(9)

(i) A power to frequency converter is made by using a V-F converter with an inverse F-V conversion in the feedback. The transfer function of the instrument can be put as, $f = k_1 x / V_R T_M$ (2.23)

where, f = output frequency

x = analog input quantity

V_R = value of internal reference voltage

T_M = duration of monostable state

k_1 = proportionality constant.

By introducing the second input signal y into the monostable circuit in a manner that inversely modulates T_M as,

$$T_M = k_2/y \qquad (2.24)$$

From (2.23) and (2.24) $$f = \frac{k_1 xy}{V_R k_2} = kxy \qquad (2.25)$$

Hence a signal proportional to xy can be obtained without using multiplier.

Introducing, in place of input signals x and y, the sinusoidal load current and voltage,

$i(t) = I_M \sin(wt - \phi)$, $v(t) = V_M \sin wt$ respectively the meter can be realised. The schematic diagram of the V-F with F-V feedback is shown in Fig 2.13 (p-60)

(ii) Error analysis and comments: Errors are due to offset and drift voltages as well as bias and leakage currents. Combining all, relative error can be expressed as

$$\frac{\Delta f}{f} = \frac{\Delta I}{I}$$

where Δf is error in frequency, I, the measured value of load current, and ΔI error current present at the input of the amplifier. Considering typical bias currents and offset voltages, as well as their temperature and time variations, class 2 stated accuracy can be maintained over a maximum load range of 1:50.

Reported quantitative errors of the meter are as under:

Item	Variation	Within Error Limits
Current	10-500% at p.f = 1	1%
	20-500% at p.f=0.5 lagging	1.5%
Voltage	± 10%	0.6%
Frequency	± 5%	0.05%
Temperature	0-40°C	0.05%/°C
External magneticfield	0.5mT	none

In the proposed meter significant reduction of components has been suggested with the elimination of the multiplier. Its cost is being claimed to be competitive with conventional meters of similar accuracy. Error limits of the meter suggests it to be suitable for a general purpose meter. The temperature error is rather high.

CHAPTER 3

SOLID STATE ENERGY METERS DEVELOPED

For developing a kWh meter, Hall multiplier is chosen as the wattmetric transducer. A variable transconductance type multiplier has been used to make a kVAh meter. In both the cases, a V-F converter will quantise the transducer output. To start with the details of transducers are being discussed.

3.1 Transducers

3.1.1 Wattmetric transducer

(i) Principle: Temperature compensative type Hall Multiplier No HM 3050 (refer Appendix - I) has been used. The basic principle of the multiplier is based on well known Hall Effect which states that 'when a magnetic field is applied at right angles to a current in a particular medium, an electric field is setup in a mutually perpendicular direction tending to direct the path of the current in that direction and the magnitued of which at any instant depends upon the product of the corresponding current and the applied magnetic field'. If the two quantities to be multiplied together are made proportional instantaneously to voltage and current in a circuit the time average of the Hall output e.m.f is a measure of the time average power carried by the circuit.

If i_x = Instantaneous value of control current

b_z = Instantaneous value of uniformly distributed flux density perpendicular to the current i_x in the plate

Then Hall electric field at rt∠ to both b_z and i_x $e_H = RJb_z$

where, R = Hall coefficient

J = current density = i_x/Sl

In case, $i_x = \sqrt{2}\, I_x \sin wt$

$b_s = \sqrt{2}\, B_s \sin(wt - \theta)$, where I_x, B_s are r.m.s values.

V_H = Mean($e_H S$) = Mean$\left[\frac{R b_s i_x}{l}\right]$, V_H is r.m.s value of e_H.

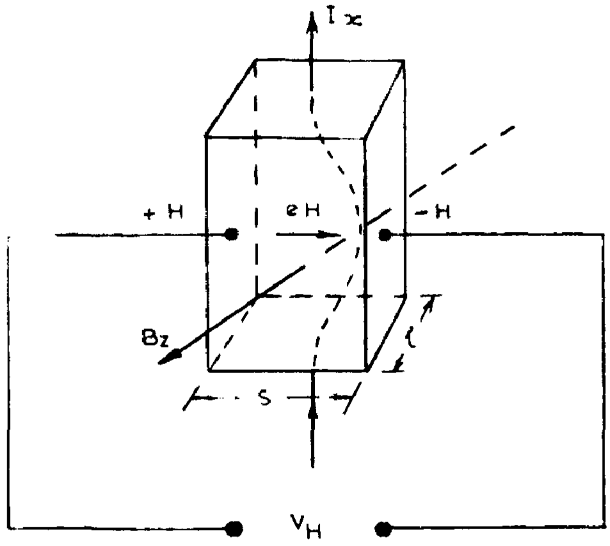
$$= \frac{R B_s I_x \cos\theta}{l} \qquad (3.1)$$

If arrangements are made such that B_s and I_x are proportional to V and I and $\theta = \phi$ i.e., phase angle between V and I, then it can measure true average power in an a.c. circuit. In that case both control current and field are sinusoidally time varying with same frequency and a phase angle ϕ existing between them. The no load output voltage can be expressed as

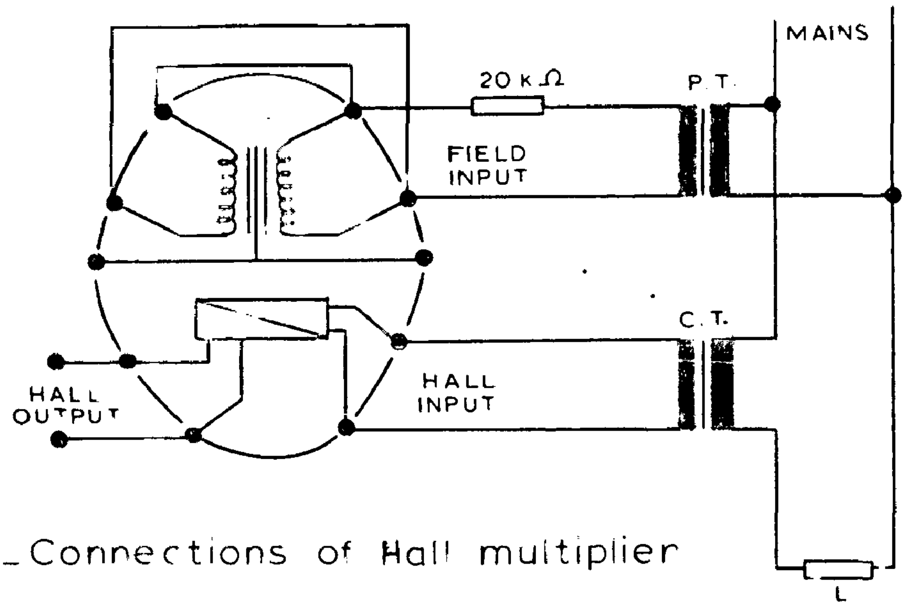
$$V_{HO} = KI \sin wt . V \sin(wt-\phi)$$
$$= \frac{KVI}{2}\left[\cos\phi - \cos(2wt-\phi)\right] \qquad (3.2)$$

Result is a d.c output with a superimposed a.c of double frequency.

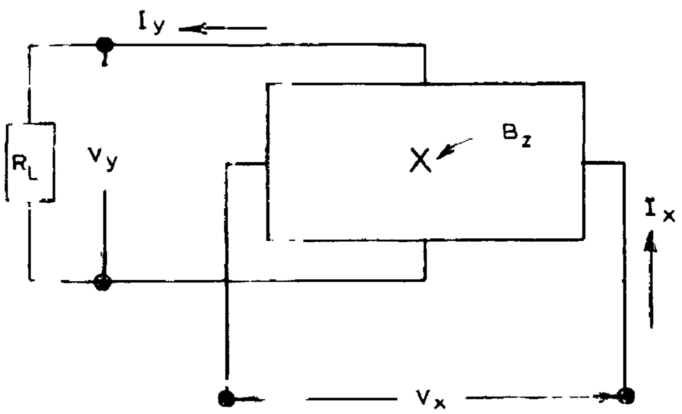
(ii) Working details: The inside detail of Hall Multiplier used is shown in Fig.(3.1b). Voltage is applied to the field coils in parallel such that current in it does not exceed 30mA. In order that the multiplier measures ture power, there should be nophase difference between the voltage applied to the field coils and the field produced by it. That the reactance of the field input is given as 40,000 Ohms/kHz i.e. 2000 Ohms for 50 Hz where as input resistance is only 500 Ohms



a _ Hall effect



b _ Connections of Hall multiplier



c _ Loading of Hall crystal

G.3.1 _ DETAILS OF HALL MULTIPLIER

this makes the circuit highly inductive for which there is a phase difference between the voltage applied and field produced by it. To overcome this, a high resistance of the order of 20 k Ohm is put in series with it. Hence total input impedance becomes 7440 Ohms. Now voltage upto 220V can be directly put across it for which current will not exceed 30mA. But the standard output of a P.T. 110V is used across the field coil so that current through it also remains within safe limit. In the Hall input circuit the load current is allowed to flow through a C.T. This current should not exceed 300 mA. As a result of the above arrangement a small d.c voltage upto 200mV is obtained from the Hall output which is further processed in the V.F-converter after amplification.

(iii) Error analysis: Two types of errors can occur in Hall Multiplier which can be explained as follows:

(a) Loading error: Well known equations for a Hall Multiplier (Fig.3.1c) are given as

$$V_x = R_{xx}I_x + R_{xy}I_y \qquad (3.3)$$

$$V_y = R_{yx}I_x + R_{yy}I_y \qquad (3.4)$$

where, R_{xx} = Resistance in control direction

R_{xy} = Mutual resistance = $-R_{yx}$ = KB_z

R_{yy} = Resistance in load current direction

If the load resistance is R_L then,

$$V_y = -I_yR_L \qquad (3.5)$$

From (3.4) and (3.5), $I_y = \frac{I_x R_{xy}}{R_{yy} + R_L}$ (3.6)

From (3.3), $V_x = R_{xy} I_y + \frac{I_y (R_{yy} + R_L) R_{xx}}{R_{xy}}$ (3.7)

$$\text{or} \quad I_y = \frac{V_x R_{xy}}{R_{xx}(R_{yy} + R_L) + R_{xy}^2}$$

$$= \frac{V_x k B_z}{R_{xx}(R_{yy} + R_L)} \left[1 - \frac{k^2 B_z^2}{R_{xx}(R_{yy} + R_L)} + \cdots \right] \qquad (3.8)$$

From (3.8) it is observed that I_y is not linearly dependent on $V_x k\,B_z$ and this is known as loading error. This error is eliminated by measuring V_y with respect to change in I_x. This can be shown as

$$V_y = I_y R_L = \frac{(I_x R_{xy}) R_L}{R_{yy} + R_L} = \frac{I_x k\,B_z R_L}{R_{yy} + R_1} \qquad (3.9)$$

since $R_{yy} \ll R_L$, (because $R_{yy} = 10$ Ohms, $R_L = 1\,M\Omega$)

Here R_L is input impedance of the operational amplifier used for amplifying the Hall output. From (3.9) it is observed that $V_y \propto I_x k\,B_z$ which is a linear relation between V_y and $I_x B_z$, and this is desired.

(b) Magnetic field error: If the impressed voltage to the magnetic field circuit is $V_1 \sin wt$, then

$$B_z = \frac{V_1 L'}{AN(w^2 L^2 + R^2)^{1/2}} \sin(wt - \phi) \qquad (3.10)$$

where, $L' = \frac{\mu_0^2 N^2 A}{(l_{Fe}/\mu_r) + l_g}$, $\tan\phi = \frac{wL'}{R}$

L' = Inductivity of coil

R = Resistance of the input of Magnetic field coil

A = core cross section

N = No of turns in winding

l_{Fe} = Length of iron core

l_g = Length of air gap

μ_0 = Free space permeability,

μ_r' = Relative permeability of iron core

Quantum of error introduced due to magnetic field depends on the value of ψ which has to be made negligibly small for making B_z, the exact replica of the impressed voltage. ψ is reduced by making $\omega L' \ll R$. As can be referred to the Appendix -I, manufacturers have claimed the value of ψ as 3°/KHz i.e., 0.15° for 50Hz. This has been further reduced by making $R = 10\omega L'$.

3.1.2 VA Transducer

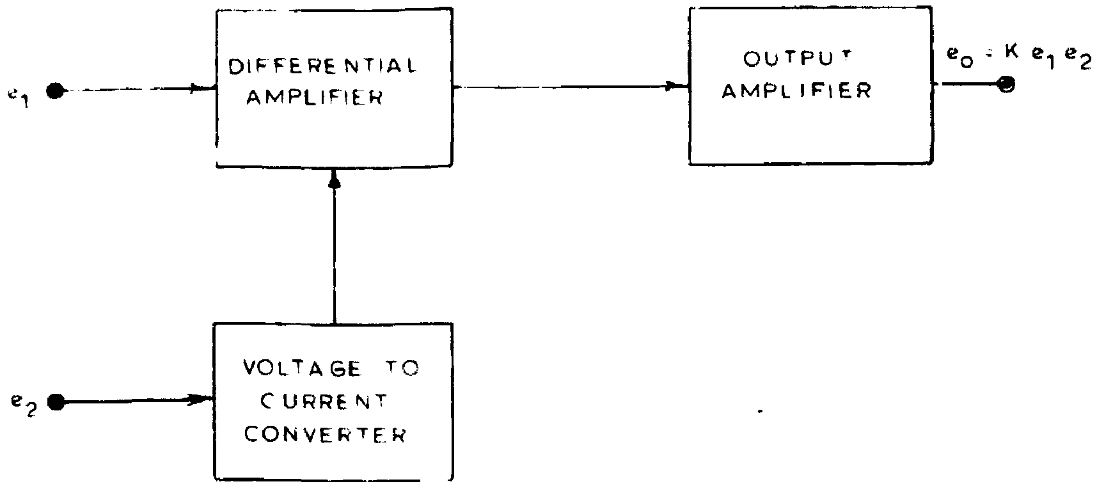
(i) Principle: With reference to the Fig 3.2b, A mathematical expression can be derived for illustrating the principle of the transducer. Current I_1 can be expressed in terms of V_{be1}, by the diode VA characteristics,

$$I_1 = I_{se} \frac{qV_{be1}}{kT} \tag{3.11}$$

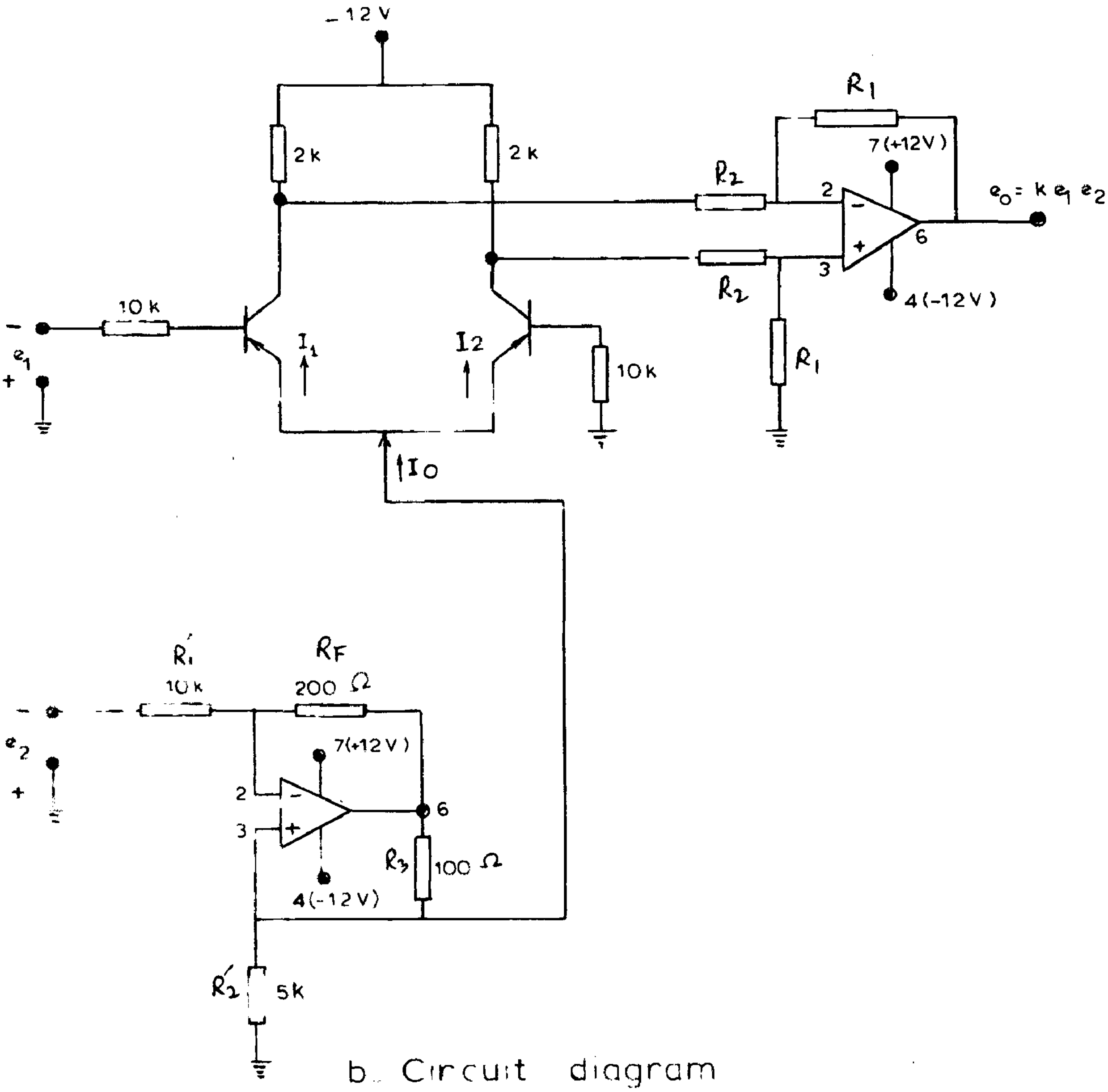
where, $I_{se} = -I_{EO}/(1-\alpha_N \alpha_I)$

α_N and α_I = Normal and inverted mode C.B gains

From (3.11) $$\frac{\Delta I_1}{\Delta V_{be1}} = \frac{q}{kT} I_1 \tag{3.12}$$



a _ Block schematic



b. Circuit diagram

FIG. 3.2 _ VARIABLE TRANSCONDUCTANCE TYPE MULTIPLIER

Since, $I_o = I_1 + I_2$ and $I_1 = I_2$(assuming a perfectly matched pair).

$$\Delta I_1 = \frac{q}{2kT} I_o \Delta V_{be_1} \qquad (3.13)$$

and, $$\Delta I_2 = \frac{q}{2kT} I_o \Delta V_{be_2} \qquad (3.14)$$

From (3.13) and (3.14), $\Delta I_1 - \Delta I_2 = \frac{q}{2kT} I_o(\Delta V_{be_1} - \Delta V_{be_2})$

or, $$\Delta I_1 - \Delta I_2 = C\, I_o e_1 \text{ (C = constant)} \qquad (3.15)$$

Because, $\Delta V_{be_1} - \Delta V_{be_2} \propto e_1$

But, $(\Delta I_1 - \Delta I_2)R_c = \Delta E$

or, $$\Delta E = C\, I_o e_1 R_c = \text{Differential collector voltage.} \qquad (3.16)$$

and $\therefore$ $e_o = \Delta E \frac{R_1}{R_2} = CR_c I_o e_1 \frac{R_1}{R_2} = K\, I_o e_1$

since, $$I_o \propto e_2,\; e_o = K' e_2 e_1 \qquad (3.17)$$

Hence the output voltage is proportional to the product of e_1 and e_2. The method is known as variable transconductance, because transconductance is given as,

$$g_m = \frac{\Delta I_1 - \Delta I_2}{\Delta V_{be_1} - \Delta V_{be_2}}$$, which is varied by changing the input e_2 as can be seen below,

$$g_m = \frac{q}{2kT} I_o \qquad \text{(from Eq. 3.15)}$$

where, I_o is varied by e_2.

Qualitatively the above can be summed up as, the differential collector voltage in proportional to the product of e_1 and e_2. The differential input Op amp provides single ended output e_o after amplification.

For providing a current proportional to the voltage e_2 a V-I converter is used, which acts as a source of current with high internal impedance. In Fig. 3.2b,

$$i_L = \frac{-e_2'}{R_2'} \quad , \quad \frac{R_3}{R_2'} = \frac{R_F}{R_1'} \qquad (3.18)$$

i.e., a grounded load is being supplied by the V-I converter. R_1' and R_2' should be chosen to draw small currents and R_F and R_3 has to be made small to minimise voltage drops. A mismatch of ratio of (3.18) may decrease the internal impedance of the source.

(ii) Circuit design: Two similar PNP transistors were chosen for the differential applifier. Collector resistances were made 2k each for limiting the collector currents to few mA. Base resistances were chosen as 10k each for making the base currents less than 1mA with e_1 = 5V. Similarly, for the V-I converter, the ratio of $R_3/R_2' = R_F/R_1$ was kept 1/50, so that current drawn (with e_2= 5V) can be less than 1mA and consequently voltage drops are minimised by making R_3 = 100 Ohms and R_F = 200 Ohms. Transistors of differential amplifier should remain in the active range for good linearity.

3.2 Voltage to frequency converter

3.2.1 Principle

In the preceding section, it was observed that transducers are converting the tariff quantity into proportional small d.c voltages which has to be converted into a linearly proportional train of pulses to be counted in a counter. The principle of this V-F converter is based on charge compensation method. The multiplier output is allowed to charge C of the integrator until a threshold voltage is reached at the level detector which triggers the monostable. Monostable emits a pulse of short duration which discharges the capacitor i.e., net charge flow at C is zero and again this cycle repeats itself. So a train of pulses from the monostable output proportional to the voltage fed at R_1 is obtained. Refering to the Fig 3.3a&b

If I_1 = Input current = e_1/R_1

I_2 = current through R_D due to MMV = e_o/R_D

$$\therefore \quad I_1 t = -I_2 t_D \tag{3.19}$$

$$\text{or,} \quad \frac{e_1}{R_1} t = -I_2 t_D \quad \text{or,} \quad t = -\frac{I_2 t_D R_1}{e_1}$$

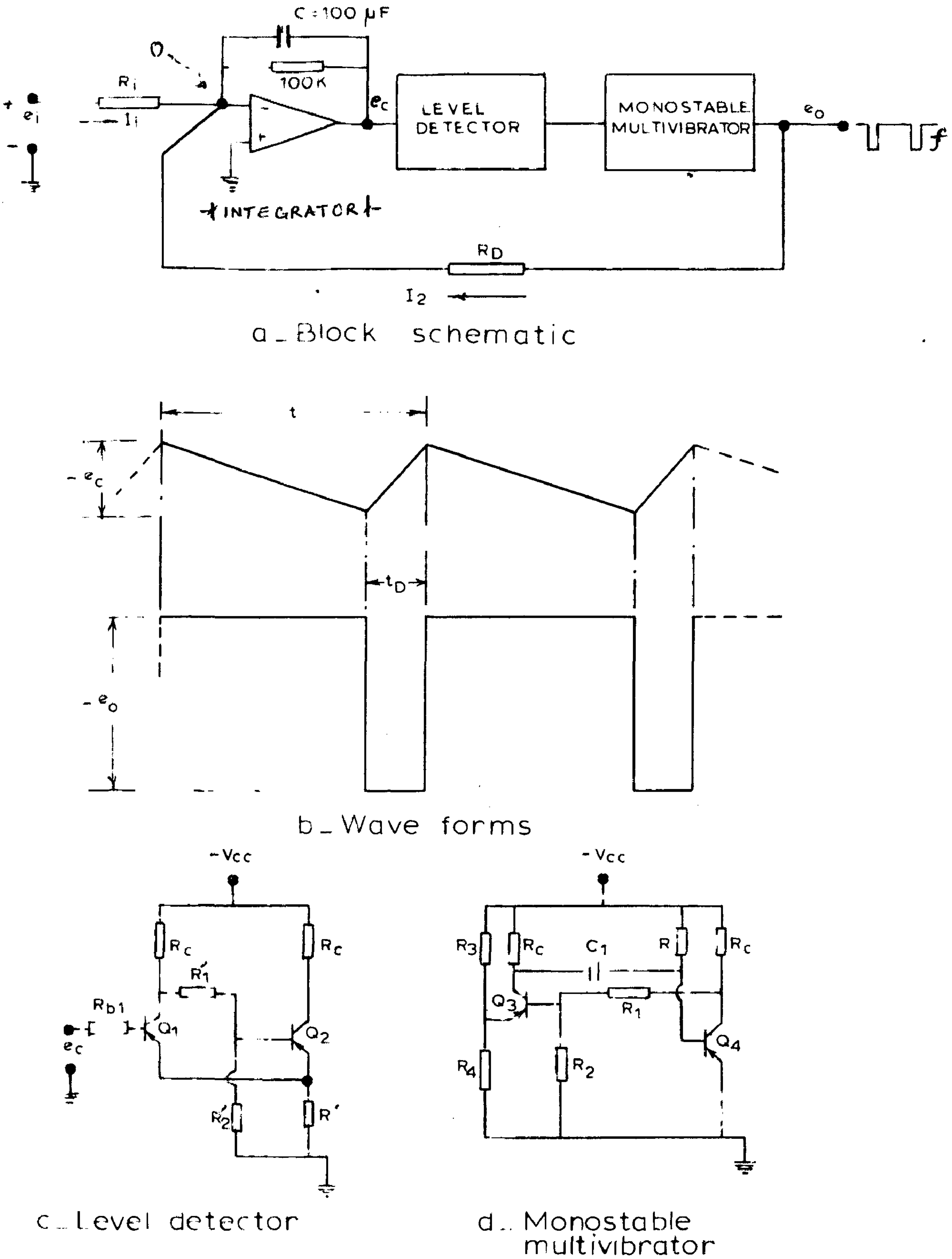
$$\text{or,} \quad f = \frac{1}{t} = -\frac{e_1}{I_2 t_D R_1} \tag{3.20}$$

From (3.20) it is seen that f is linearly proportional to e_1 because I_2, t_D and R_1 are constants

Voltage level of integrator output, $e_o = -\frac{1}{R_1 C}\int_0^t e_1\, dt$

$$= -\frac{e_1 t}{R_1 C} \tag{3.21}$$

While calculating R_1 and C equations (3.20) and (3.21) are to



a _ Block schematic

b _ Wave forms

c _ Level detector

d _ Monostable multivibrator

FIG 3.3 VOLTAGE TO FREQUENCY CONVERTER

be considered such that

$$e_i = \frac{-I_2 t_D R_i}{t} \quad \text{from (3.20)}$$

$$e_i = \frac{e_c R_i C}{t} \quad \text{from (3.21)}$$

$$\therefore \frac{I_2 t_D R_i}{t} = \frac{e_c R_i C}{t} \quad \text{or,} \quad I_2 t_D = e_c C \qquad (3.22)$$

For a particular e_i range, values of different parameters can be calculated for obtaining a required frequency.

3.2.2 Circuit Design

Step I: Determination of t_D

If $I_i/I_2 = -t_D/t = 1/4$, then $4t_D = t$, and pulses of width t_D can be distinguished. I_i can be limited to 1mA, which will make $I_2 = 4$mA. Then $R_i = e_i/1\times10^{-3} = 5$k Ohms, assuming $e_i = 5$V. Similarly $R_D = e_o/I_2 = 12/4I_i = 3$k Ohms. In order to obtain a frequency of 20 pps with $e_i = 5$V, $t_D = e_i/I_2 . R_i . 20 = .0125$sec. Hence the monostable should be designed with a time period of .0125 sec. and R_D should be 3k Ohm. (Used value = 2.2k)

Step II: Determination of C

From (3.22) $I_2 t_D = e_c C$, here e_c can be fixed at a level of 0.5V, so that, $C = I_2 t_D/e_c = 100\mu F$. (Used values = 100µF)

Step III: Design of a level detector with a minimum threshold of 0.5V. (Refer Fig. 3.3c).

$$\frac{V_{cc} \times R'_t}{R_c + R'} = 0.5 \quad \text{i.e.} \quad R' = 90 \text{ Ohms} \quad (\text{Used value} = 68\,\Omega)$$

$$\frac{R_1' + R_2'}{12} = \frac{R_2'}{2.5}$$, i.e., $R_1' = 3.8\ R_2'$

Used values ($R_1' = 10k\Omega, R_2' = 39k\Omega$)

Step IV   Design of a Monostable with time period of .0125 sec:(Refer Fig 3.3c)

R_c are fixed at 2.2 k by assuming a I_c(sat) of 5.5mA. R is taken as 100k so that it can allow sufficient current to the base of Q_2 to send it into saturation.

$\therefore$ 0.7 RC = 0.0125 , C' = 0.175 µF (Used value = 0.22µF)

For Q_3 'ON' and Q_4 'OFF' (Unstable state)

$$\frac{V_{cc} - \left[V_{be1(sat)} + 2\right]}{R_1 + R_c} = \frac{I_{c(sat)}}{min} + \frac{\left[V_{be1(sat)} + 2\right]}{R_2} \qquad (3.23)$$

and for Q_3 'OFF' and 'Q_4' ON (Stable state)

$$\frac{V_{cc}}{2 + V_{be1(off)}} = \frac{R_c + R_1 + R_2}{R_2} \qquad (3.24)$$

R_3 and R_4 are chosen to make the emitter bias of Q_3 as 2V. By assuming $V_{Be(sat)} = -0.7V$, $V_{be(off)} = 0$ (for S_1 PNP transistor) R_1 and R_2 are determined as (from 3.24 and 3.23)

$R_1 = 170\ k\Omega$, $R_2 = 50\ k\Omega$ (Used values $R_1 = 160$ k, $R_2 = 51$ k)

3.2.3   Test Results

After assembling the circuit, a varying d.c voltage of known magnitude was applied to R_1 and frequency of pulses

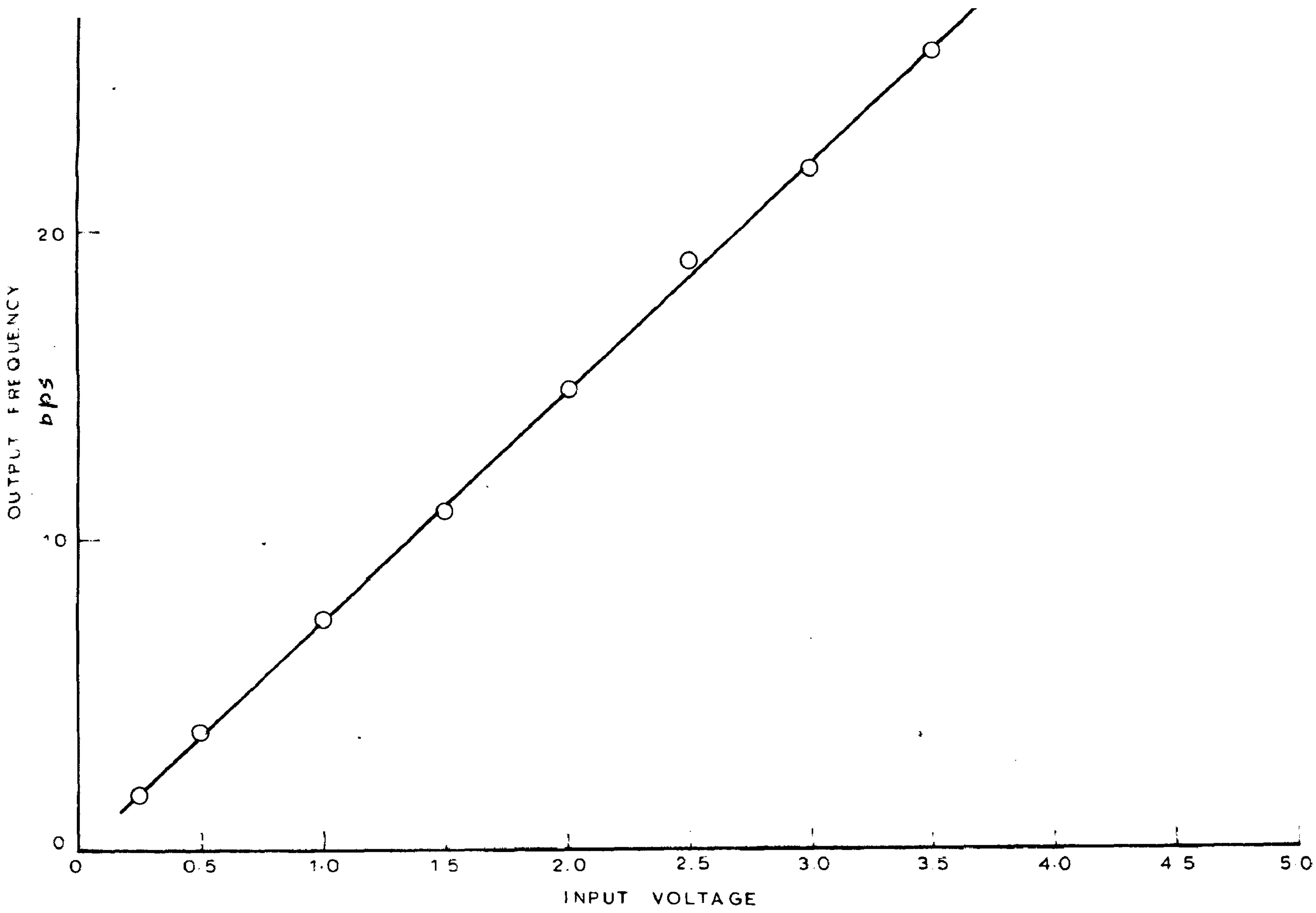


FIG. 3.4 _ RESPONSE OF V-F CONVERTER

at the monostable output was observed in oscilloscope as well as counted in an electronic digital counter. A mechanical counter was connected to the output as shown in Fig 3.5b to observe its reponse. It responded well but electronic counter was used for testing purpose.

It can be observed from the results in Fig 3.4 that linearity response of the V-F converter is quite good. Possibility of error is due to offset voltage appearing at the output of Op amp of the integrator. So it is subjected to a linearity error of the order of V_{off}/R_i (V_{off} = offset voltage) because V_{off} varies with input. Suitable arrangements can be done to compensate this voltage.

Sensitivity of the V-F converter comes out to be about 7pps/V. Since minimum starting level of V-F converter was designed to be 0.5V, for shifting it to 0, a five potential was applied to the input as shown in Fig. 3.5b.

3.3 kWh Meter

3.3.1 Block schematic

Principle of operation of the meter can be explained from the block schematic diagram shown in Fig 3.5a. After conditioning, both voltage and current signals are fed to the Hall multiplier. Its output goes to the V-F converter after amplification. V-F converter output pulses (proportional to power) counted for a particular period gives the amount of energy used during that period.

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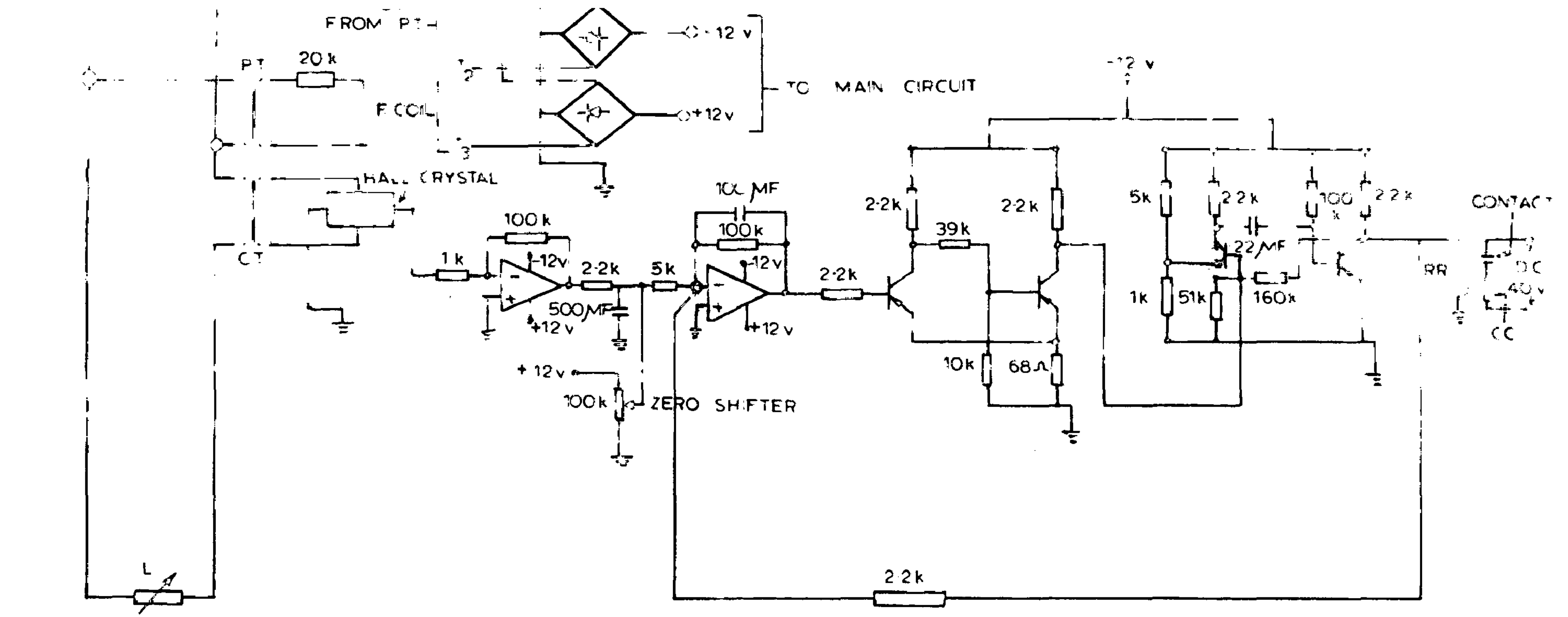
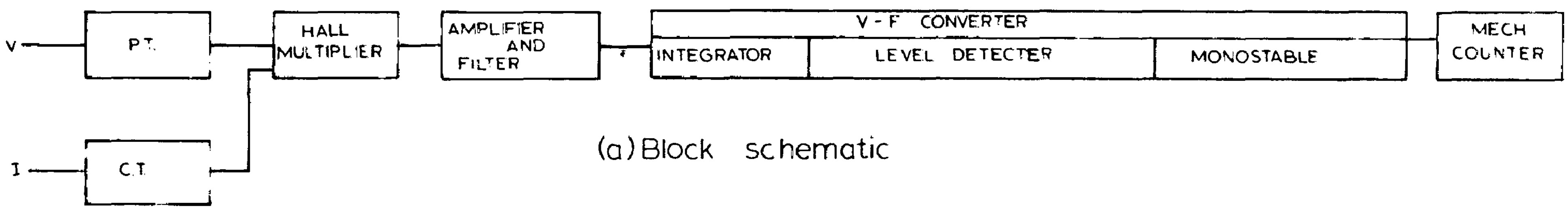


(b) Circuit diagram



(a) Block schematic

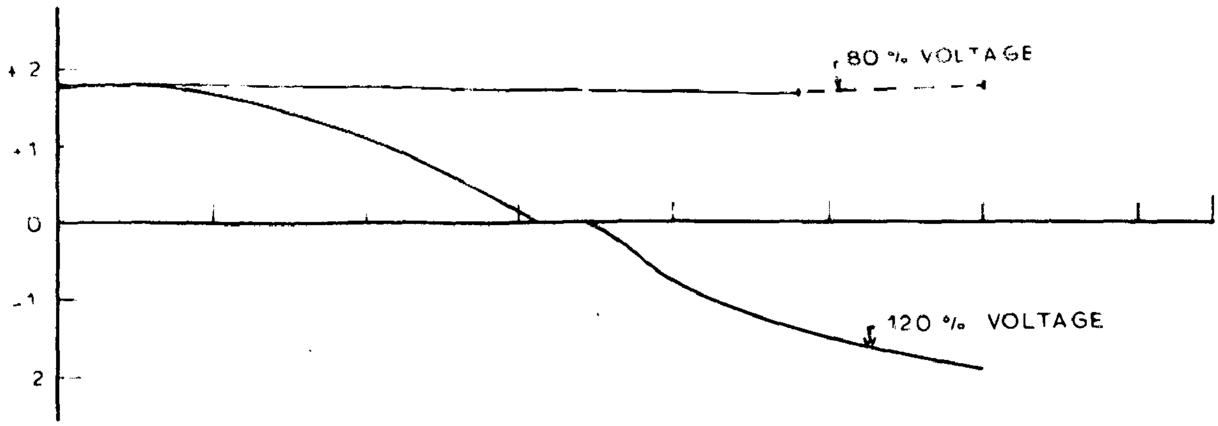
FIG.3·5_ENERGY METER (kwh)

3.3.2 Complete circuit

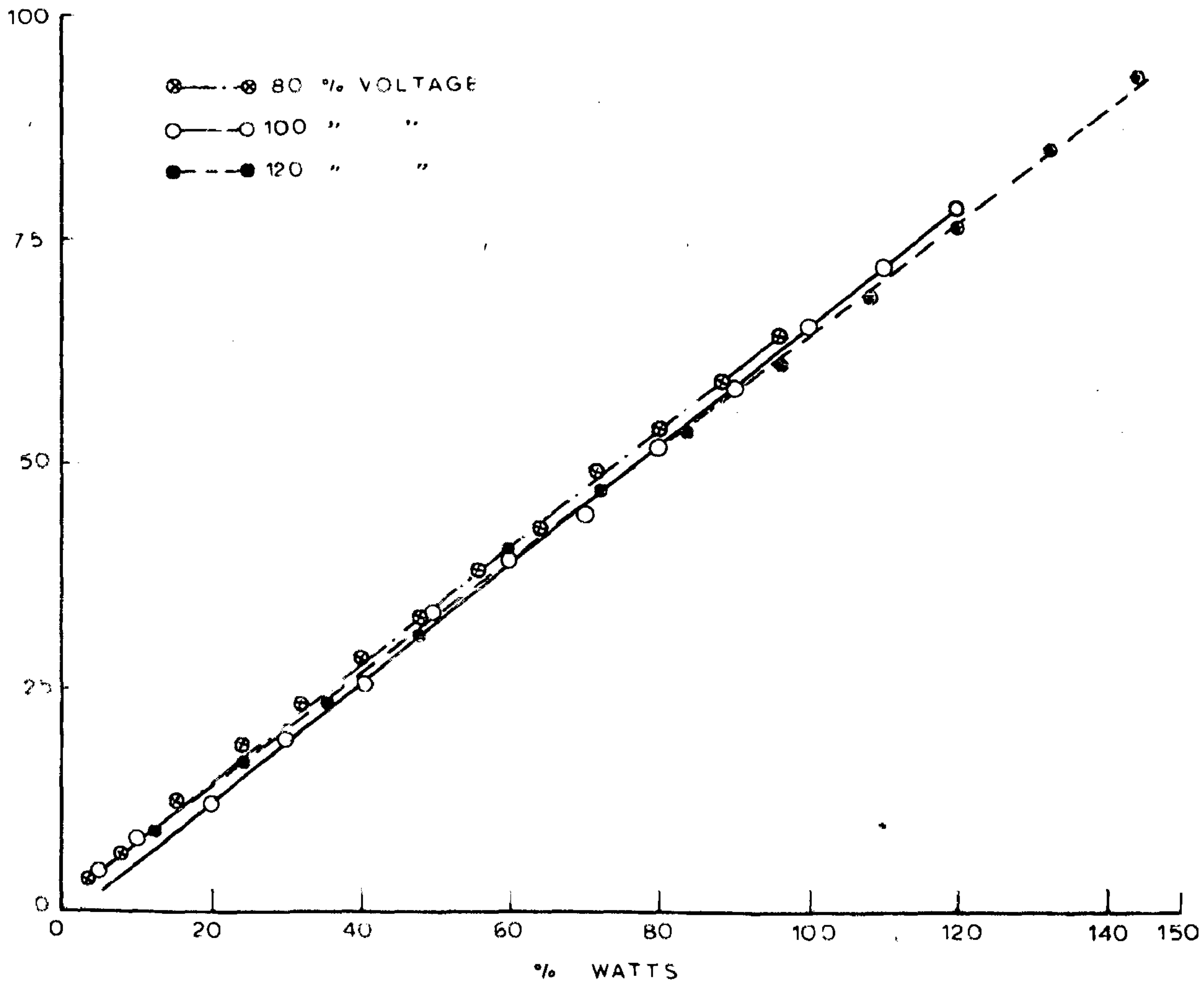
Complete circuit of the kWh meter is shown in Fig3.5b. Hall output voltage is amplified 100 times and then 100c/s a.c component is by passed through the 500μF capacitor as a result of which only a d.c voltage of the order of 0-5V is obtained. This d.c voltage is fed to the V.F. converter at a point, of which the potential is adjusted to a suitable positive value by a 100k preset pot as shown. The output of V-F converter is tapped from the collector of Q_4 through the read relay. D.C. supplies of ± 12V for the circuit and + 40V for the counter is to be obtained by rectifying, filtering and stabilising the small a.c voltages tapped from the voltage signal conditioning transformer.

3.3.3 Test Results

The meter was tested with a fictitous load. Before applying low intensity signals to the Hall multiplier phase angle between voltage and current was adjusted by means of a phase shifter and a phase angle meter. At 80, 100 and 120% of the rated voltage i.e., 110V, different sets of readings were taken with load current varying between 5-120% of rated value. Power factor was fixed at unity, 0.5 Lagging and 0.5 Leading.respectively for the three sets. Results are plotted in Fig3.6a&3.7a. Few each power factor, the variation of meter reading with change in voltage has been brought out. Then the error observed is put separately in a graph (Fig3.6b&3.7b) showing thereby percentage error in terms of Full deflection of the meter. This has been determined by keeping the meter reading

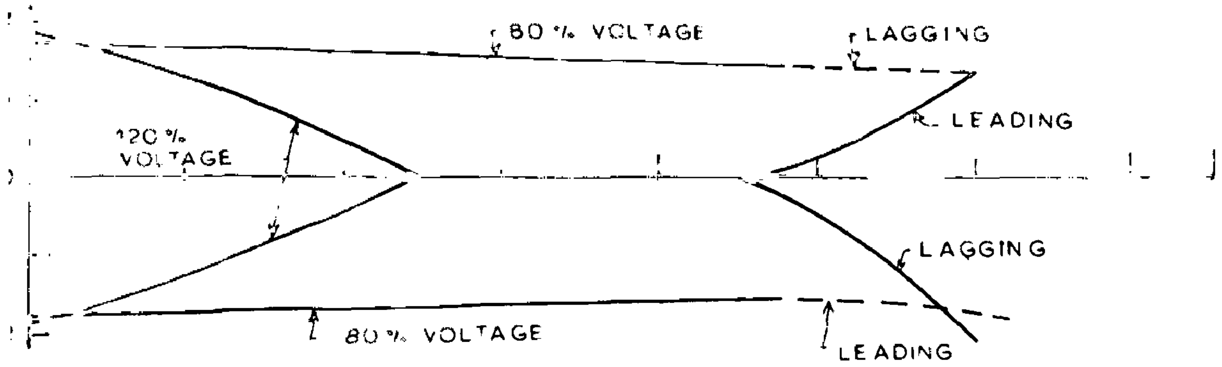


b _ Variation of error with voltage

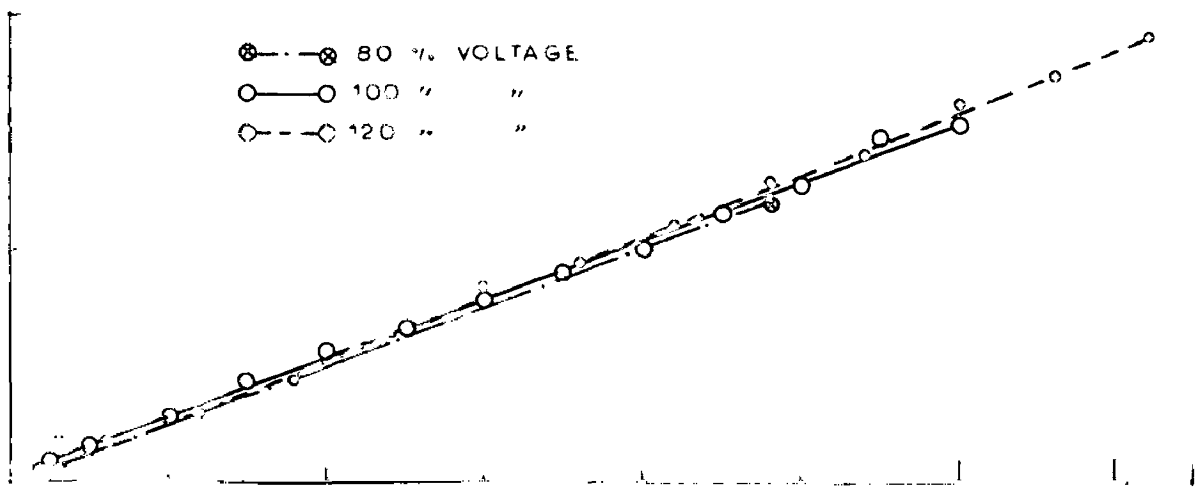


a _ Variation of meter reading with voltage

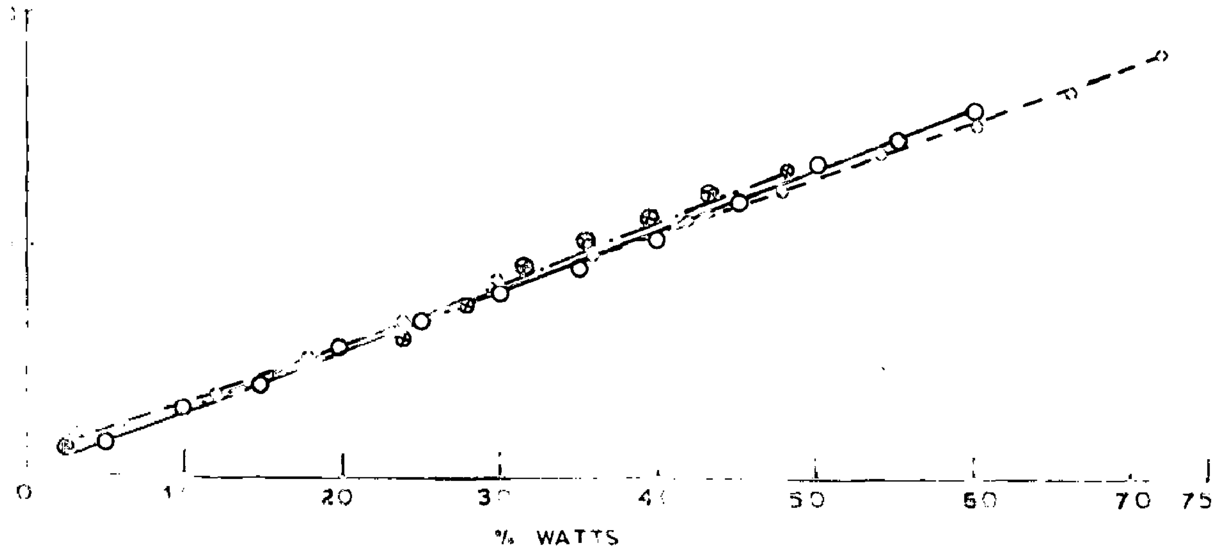
IG.3.6 _ METER RESPONSE WITH VARYING VOLTAGES AT UNITY p. f. (kWh meter)



Variat on of error with voltage at 0·5 p f.



Variation of meter reading with voltage (p f leading)



...ation of meter reading w.th voltage (p. f. Lagging)

/ METER RESPONSE WITH VARYING VOLTAGES AT 0·5 POWER FACTOR at 100% rated voltage as the reference. For convenience in studying the errors, all inputs to the meter has been plotted as % watts in x-axis and the corresponding % F.S.D. in y-axis. Error limits observed are between ±2% maximum in each case. It is seen that error at 80% voltage is steady but at a higher level where as at 120% voltage, it slowly becomes zero from maximum. Effect of change of p-f from 0.5 Lagging to 0.5Leading is a shift in error nature only and not in its magnitude. Error limit is within that of a general purpose meter. It can be brought down considerably with the use of an error compensated C.T. as shown in Fig 3.10 . Results can be further improved by using precision instruments for testing.

3.4 kVAh Meter

3.4.1 Block Schematic

Block schematic ofthe meter is shown in Fig 3.8 . Both voltage and currents are sent to the VA multiplier inform of proportional small d.c voltage. Output from the VA multiplier is fed to the V-F converter, the output of which is counted in an electronic or mechanical counter.Count of pulses for a given time gives the energy i.e. kVAh for that period.

3.42 Complete Circuit

The output of VA transducer (Fig 3.2) is a d.c voltage of the order of 0-5 V. This can be made higher if need be. This output is proportional to VA of the circuit and is fed to the VF converter for integration. Except for the transducer part the scheme remains same as that of kWh meter.

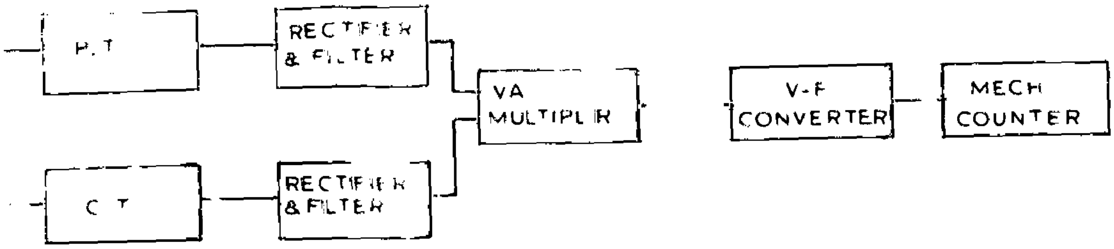
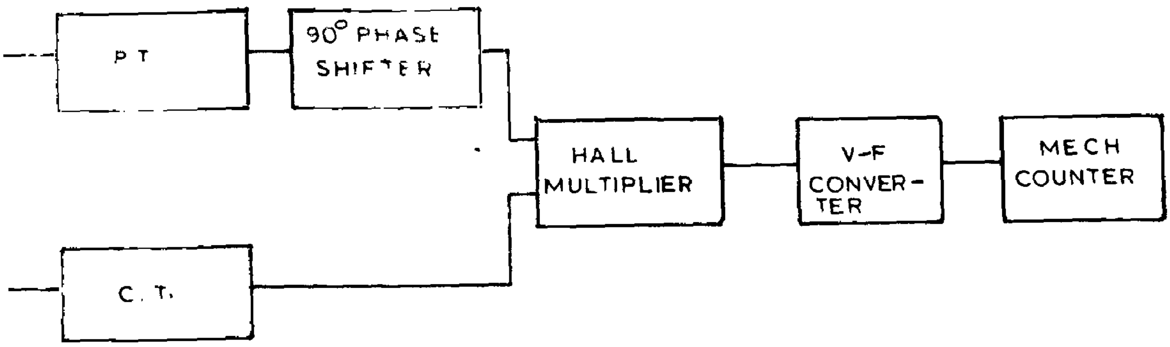
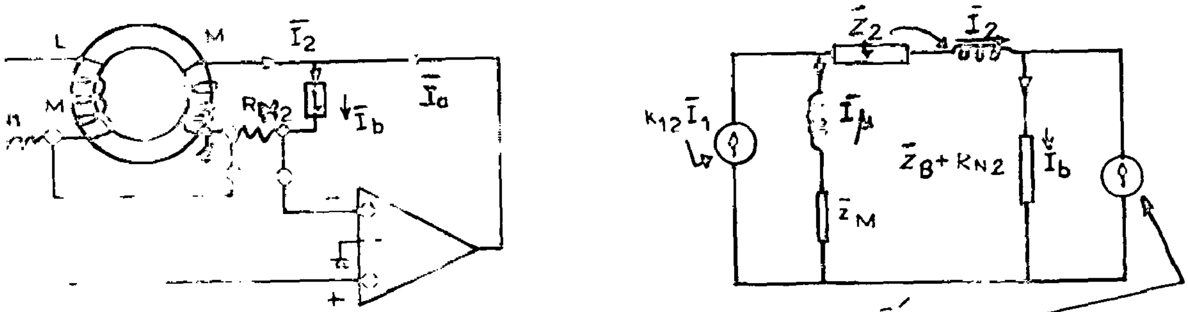


FIG. 3.8. BLOCK SCHEMATIC OF kVAh METER



IG. 3.9 _ BLOCK SCHEMATIC OF kVArh METER



ircuit diagram

$\frac{R_{N2}}{R_{N1}}$ = Desired Nominal Ratio of C.T. $I_a = \frac{GRN_2 \bar{I}_\mu'}{GRN_2 + 1}$

b- Equivalent ckt.

$\bar{I}_\mu'$ = C.T. exciting current

K_{12} = Inverse of Nominal Ratio

GR_{N2} = Factor by which secondary self inductance is increased.

$\bar{Z}_B$ = burden impedance ; X_2 = Leakage.

G 3.10 . ERROR COMPENSATED C.T.

3.4.3 Test Results

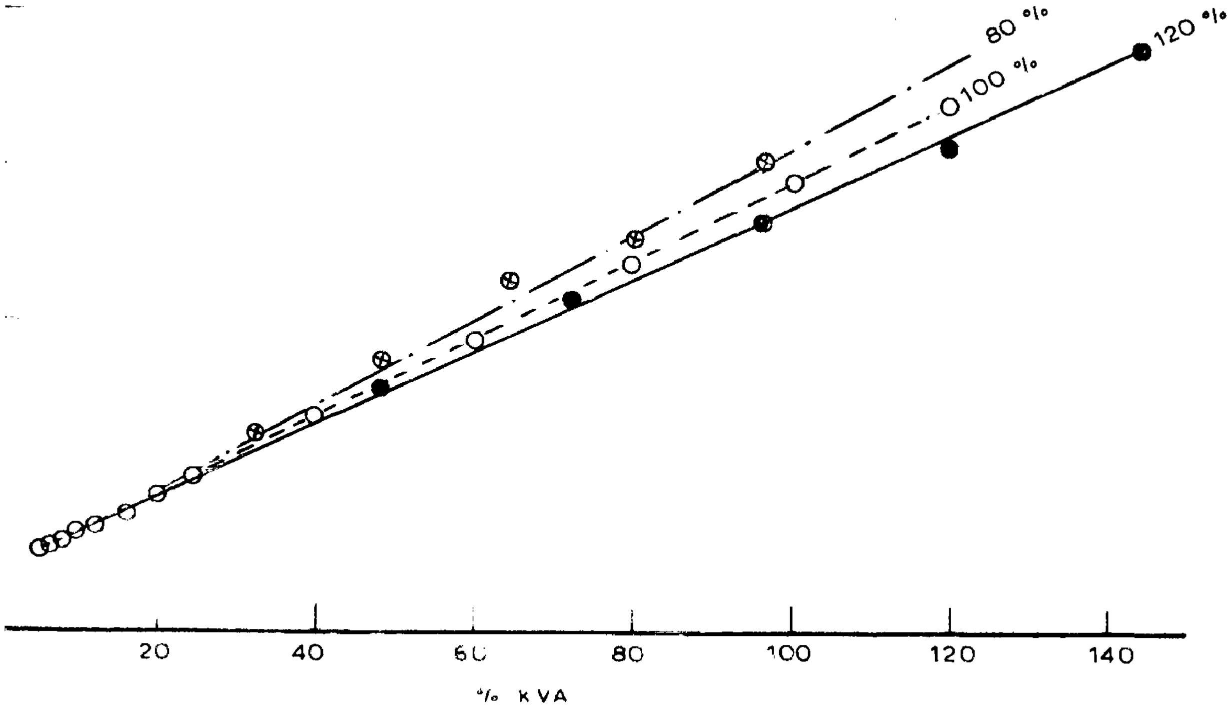
Referring to the Fig 3.2 e_1 is made proportional to voltage signal and e_2 is made proportional to current signal. The meter is tested with fictitous load. At 80,100 and 120% of rated voltage i.e., 110, meter output was recorded with load current varying between 5-120% of rated value. Three sets of curve were obtained as shown in Fig 3.11 . These are plotted as % F.S.D of the meter against %kVA. Error limits are within ± 5 %. It is large because of obvious mismatch between the transistors of differential amplifier. This can be reduced by using matched pairs available in IC form.

3.5 KVArh Meter.

Before impressing the voltage proportional to line voltage to the magnetic field coils of the Hall multiplier, it has to be passed through a 90° phase shifting circuit for measuring kVAr. Block schematic is shown in Fig 3.9 . Any standard circuit for 90° phase shifting can be used here. Since the Hall multiplier is giving satisfactory result otherwise, equally good result is expected with a phase shifting circuit. Accuracy of the meter will depend on the stability of the phase shifter.

3.6 Steps for Making Prototypes.

Sufficient background is created with the development of meters described in previous section for developing suitable prototype. Apart from improving the transducers and the V-F converter, following steps should be taken to make a prototype of each meter.



3.11 RESPONSE OF KVAh METER WITH VARYING VOLTAGES

3.6.1 Making an error compensated C.T as shown in Fig 3.10.

Principle of this can be read as under.

A is a differential input amplifier whose output current I_a is proportion to the input voltage signal. The current I_b through the load is the sum of the currents I_2 and I_a, where I_2 is the current through the secondary winding of the C.T. If I_b forms the correct fraction and has the correct phase position, the differense voltage appearing across the input of the amplifier would be zero. With a sufficiently large gain, the output current I_a of the amplifier is adjusted in magnitude and phase position until I_1/I_b approaches the normal ratio, thus reducing the errors in the transformation ratio as seen from the load.

3.6.2 Making of a combined potential transformer and d.c Power supply unit.

Details of it can be worked out based on the idea given in Fig 3.10. Suitable arrangements should be done to rectifiy, filter and stabilise the signal picked up from the transformer. It should be properly enclosed in an enclosure. Care should be taken to make thewhole thing compact and light.

3.6.3 Design and fabrication of a mechanical counter to

To count the pulses a suitable mechanical counter has to be evolved which can count upto 30 pulses per second. It should be comparable in cost with the existing counters in conventional meters.

CHAPTER 4

SOLID STATE DEMAND METERS DEVELOPED

Though, there are two types of demand meter i.e. Lag and Integrating type but the Integrating types are most widely accepted. Some attempts have been made to electronically handle the outputs of conventional demand meters, but so far all electronic type demand meter has not come up. An attempt has been made to develope all electronic demand meters one each of Integrating and Lag type. Lag type is made in a manner such that it can become more popular than the existing types.

4.1 Integrating Type Demand Meter

4.1.1 Block Schematic

As observed in chapter 3, number of pulses proportional to energy to be measured are available from the V-F converter. If these pulses are counted for every 30 mts and the higher value is retained, then it will do the job of the existing Integrating type demand meter. Block schematic of the instruments is shown in Fig 4.2 . Pulses from the energy meter simultaneously come to two Binary counters and a mechanical counter. The mechanical counter and BC-II will receive these pulses provided the AND gates are open i.e. an output is available from the comparator. The comparator is so designed that it gives an output only when the Binary counter I and II are having equal counts. There is a clock pulse generator which produces a pulse for every 30mts to reset the BC-I. To start with, say, all the three counters are reset to'0' and they will be counting pulses, because the comparator is keeping the AND gates open. After

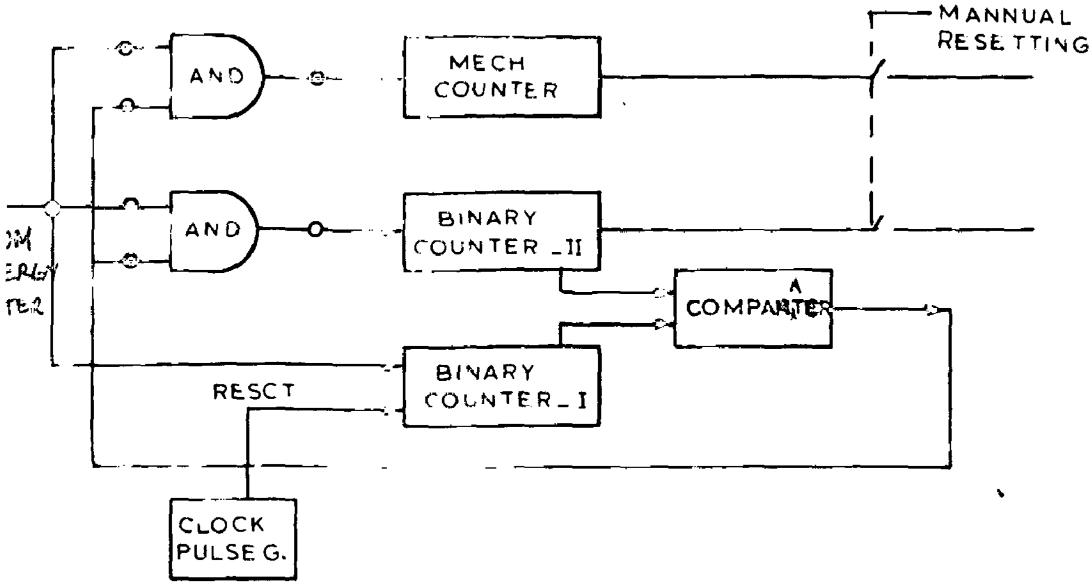
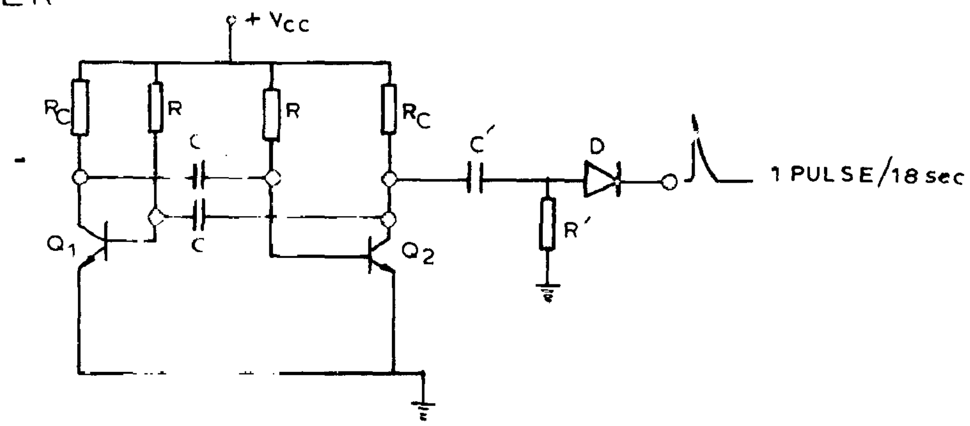
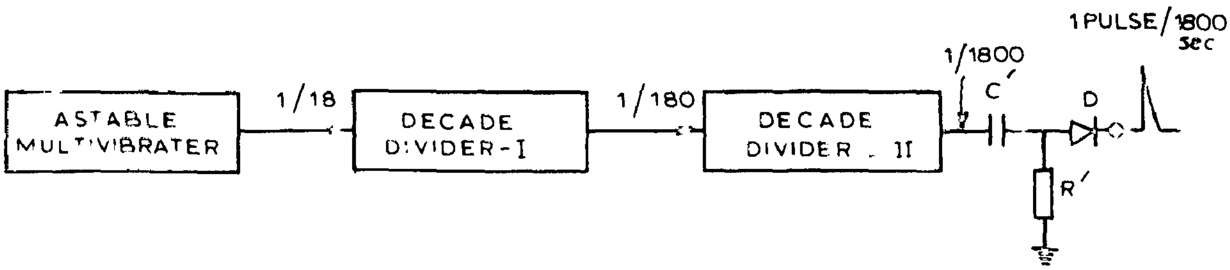


FIG.4.2 BLOCK DIAGRAM OF INTEGRATING DEMAND METER



a_ Astable multivibrator for C.P.G.



b_ Pulse revaluator

FIG. 4.^ .. CLOCK PULSE GENERATOR

30 mts, theBC-I receives a clock pulse and gets reset to '0', this makes the comparator output also '0' and now BC-II and mechanical counter will not receive puses. For the next 30 mts, if the number of pulses exceeds the number already recorded in BC-II in the previous demand interval i.e., if the demand increases, then at some instant, count of BC-II will be equal to BC-I and from this instant onwards the comparator will give output to keep the AND gates open and allow the BC-II and mechanical counter to count the pulses till the BC-I is reset after 30 mts. In case the demand is below that recorded in the previous interval, comparator willl not give output and pulses will not be further recorded in mechanical counter as well as BC-II. Thus the BC-II and mechanical counter will retain the maximum number of pulses received in any particular demand interval. BC-II and Mechanical counters can be reset manually as and when required by the meter reading authority.

4.1.2 Circuit Details

(i) Clock pulse generator

A clock pulse generator is required which will emit per 1800 sec. one pulse of short duration and voltage high enough to reset the counters. Output of a free running Astable multivibrator can be used after suitably differentiating. Time constant of a free running Astable Multivibrator can be expressed as $T = 1.38\ RC$. Value of R is limited by the fact that it should be able to supply the base current to the transistors. For a 12 V supply R can be around 120kΩ assuming 2mA as I_c(sat) and

β_{min} = 20. Then for T = 1800 sec., Value of C = 10,800μF. It is difficult to get such a capacitor and even if it is obtained it will have very large leakage. The pulse stretching of the AMV output can be done through available frequency dividers. These are normally in the rangeof divide by 10,12 or 16. Most convinient is to use a divide by 10 divider. In order to obtain a pulse per 1800 sec. 2 decade dividers can be used after an AMV of 18 sec. duration (Fig4.1b). This will keep the values of R and C in AMV within available limits. Hence for obtaining pulses of 18 sec. duration from AMV C = 108.6μF (Used value 100μF). For this value of C, R comes to be 130.5kΩ Ohms(Used value 150k). To differentiate the +ive pulses obtained from the Astable Multivibrator a differentiator with C_1 = .22μF and R_1 = 5.6k, which will make the pulse width about 12.32 m sec. Ultimately a reset pulse is obtained every 30 mts which will reset only BC-1.

(ii) Binary Counters I and II

Binary counters of any type can be used here but the selection criteria should be such that minimum number of counters can count the maximum number of pulses expected within 30 mts. Out of the available counters the divide by 16 is most economical to be used but since it was not available, design had to be done with divide by 12 counter, the details and truth table of which are shown in Fig 4.4 and Appendix III. If the pulses are directly taken from the V-F converter they will number 30 x 1800 = 54,000 maximum in 30 mts. For this suitable counting circuits are to be designed with minimum number of counters.

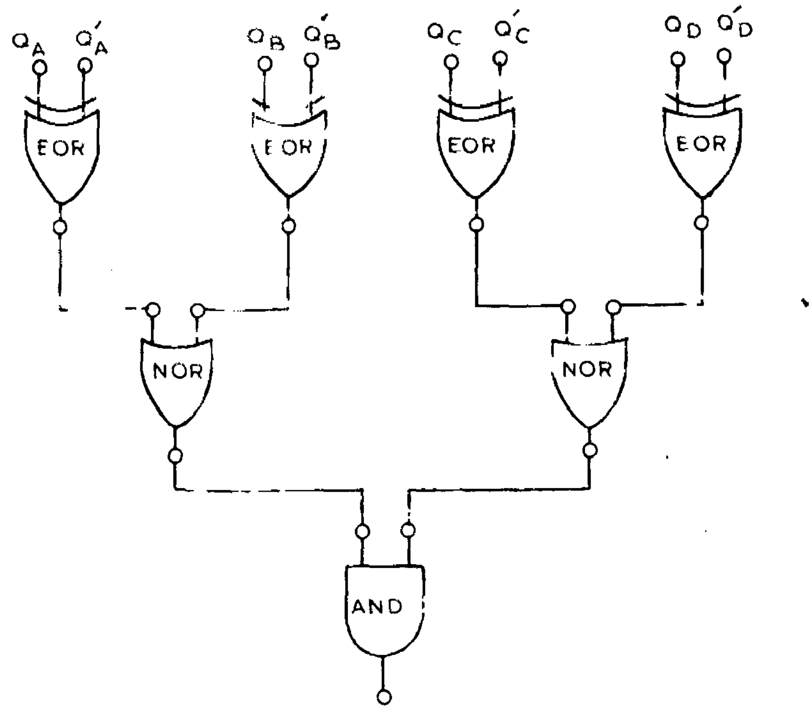
(iii) Comparator

A bit to bit comparator for the two counters has been designed. This can be used with any type of binary counter having Flip Flops. Output from each set of binaries have been taken to Exclusive OR gates and then to NOR and AND gates as shown in Fig 4.3 . From the truth tables of these gates, it is clear that an output will be available at the AND gate only when, $Q_A = Q'_A$, $Q_B = Q'_B$, $Q_C = Q'_C$, $Q_D = Q'_D$ and in no other condition. For instance $Q = Q' = 1$ or 0 in any case of equality and for both these conditions XOR gate will give 0 output which are going to NOR gates. NOR gates will always give 1 output which are going to AND gate which will give 1 output only when both inputs are 1.

Since XOR gates were not available, these had to be made out of AND and NOR gates as shown in Fig4.3c. Quard two input gates are available for convinientlly carryingout the operations desired by the comparator.

4.1.3 Test Results

In the absence of sufficient number of ICs only the basic principle of operation has been tested by fabricating a part of the circuit in printed circuit board. Since the counting capacity of the counters used is only 11 at a time, very slow pulses for short duration were sent to counter I and II after resetting them to '0'. Then by observing the outputs at $Q_{A,B,C,D}$ of each counter by means of a voltmeters counts



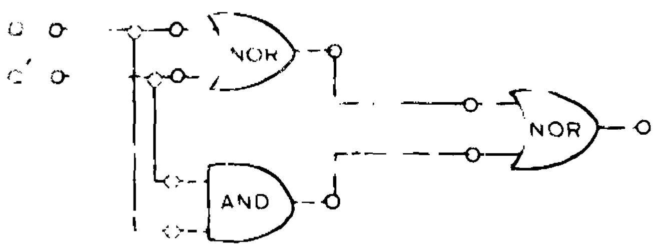
a_ Bit to bit comparison of 2 counters

EOR		
INPUT		OUTPUT
0	0	0
0	1	1
1	0	1
1	1	0

NOR		
INPUT		OUTPUT
0	0	1
0	1	0
1	0	0
1	1	0

AND		
INPUT		OUTPUT
0	0	0
0	1	0
1	0	0
1	1	1

b_Truth tables



c_ AND & NOR Combination for EOR gate

FIG 4.3 _COMPARATOR DETAILS

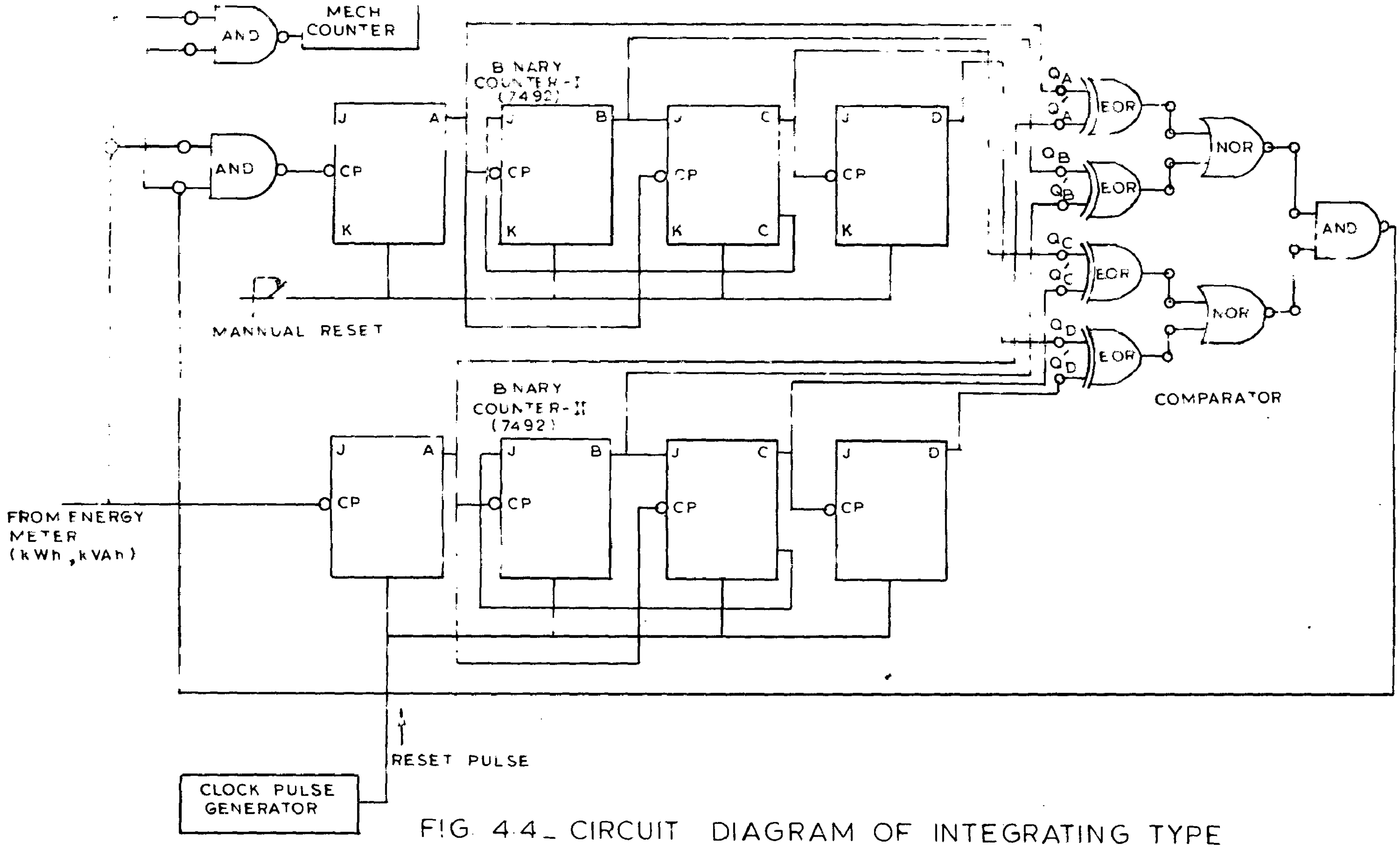


FIG 4.4_ CIRCUIT DIAGRAM OF INTEGRATING TYPE DEMAND METER

were determined. Counter I was reset and after this, counts of counter-II were found to be intact. Then some more number of pulses were sent to the system than already stored at counter II. Booththe counter were observed to be advancing together. Once again counter I was reset and counter II was found to be storing the maximum number of counts received so far. The summary of the above can be seen in the table below.

	Counter-I				Counter II			
	Q_A	Q_B	Q_C	Q_D	Q'_A	Q'_B	Q'_C	Q'_D
Starting point	0	0	0	0	0	0	0	0
Counts after the receipt of 1st set of pulses'5' in number	1	0	1	0	1	0	1	0
Counts after 1st reset of counter I	0	0	0	0	1	0	1	0
Counts after 2nd set of pulses'5' in number	1	0	1	0	1	0	1	0
Counts after the 7th pulse	1	0	0	1	1	0	0	1
Counts after 2nd reset of counter I	0	0	0	0	1	0	0	1

Apart from the above check of the system outputs of counters I and II at $Q_{A,B,C,D}$ where observed in oscilloscope by giving a train of pulses at the input, and were observed to be same in nature indicating thereby that both are counting together.

4.2 Lag Type Demand Meter

4.2.1 Block schematic

Principle of the meter can be explained by means of the Fig 4.5a. The output from the Watt or VA to voltage converter goes to a Lagging circuit which reaches 90% of the subjected value in 30 mts. The output of the Lagging circuit is measured by a moving coil meter through an impedance matching circuit.

4.2.2 Circuit details

The time lag between the occurance of a load and the corresponding instrument reading is obtained by charging a condenser through a resistance. The condenser is charged from the d.c voltage proportional to the demand obtained from the appropriate transducer. The charging time constant is so adjusted as to charge the condenser to 90% of the prospective final value in 30 mts. Votage across the condenser is measured by a high input impedance meter. The meter retains an indication of the maximum deflection attained during the assessment period which represents the MD in KVA of kW as the case may be. The time constant τ of charging and discharging of the condenser is decided by the equation

$0.9 = 1 - e^{-1800/\tau}$, which gives τ = 783 secs.

i.e., RC = 783 secs., R and C are fixed as 780k and 1000μF which makes τ = 780 secs. FET is used here in common drain configuration. R_1 is chosen as 15k to limit the current of FET.

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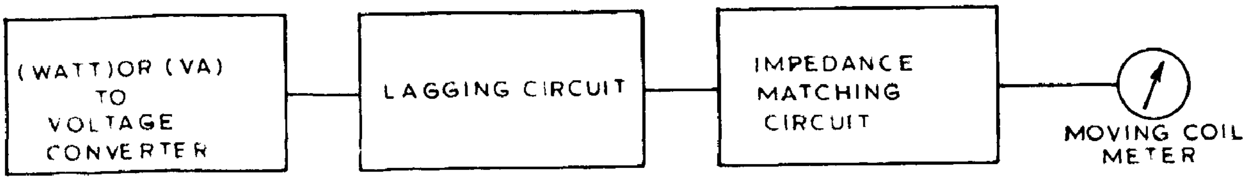
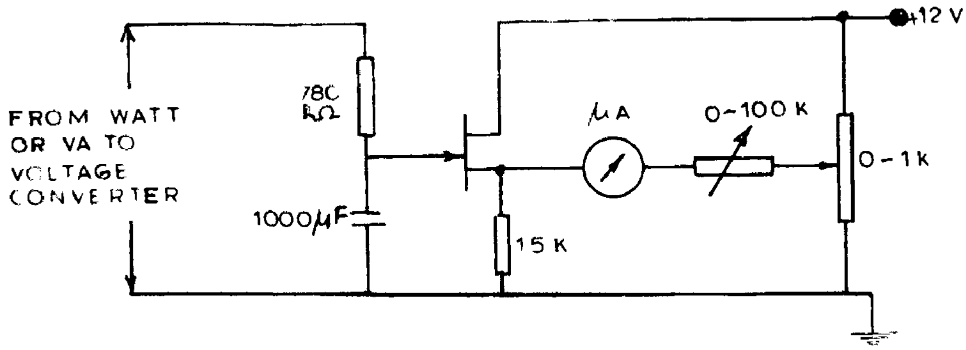
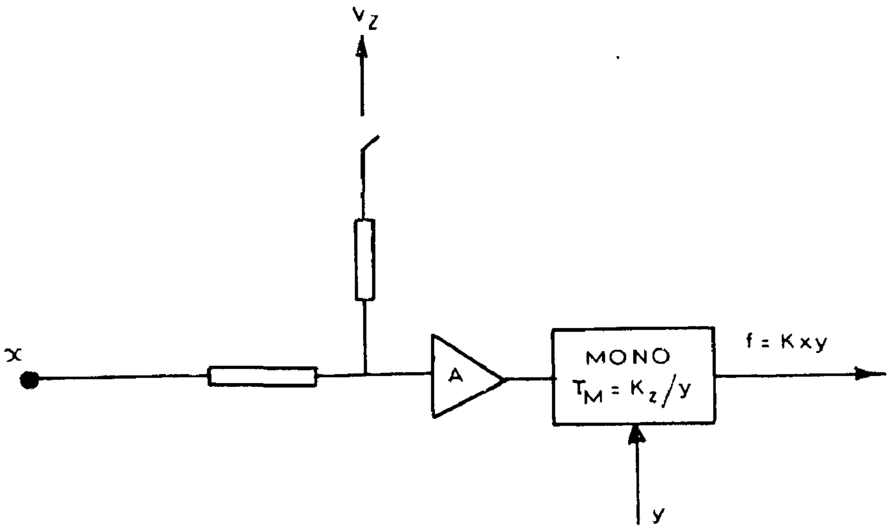


a _ Block schematic



b _ Circuit

FIG 4.5 _ LAG TYPE DEMAND INDICATOR



. 2 13 _ SCHEMATIC OF V-F WITH F-V FEEDBACK

R_2 is a variable high resistance so chosen that only 50µA current flows through the meter. R_3 is for zero adjustment of the meter.

4.2.3 Test Results

The meter was tested with four types of load variation such as steady, stepped, peak and stepped rising and falling. This ensures that the meter when subjected to actual loading, will work satisfactorily. The Lagging circuit was fictitiously loaded from a d.c source and a stop watch was used to record time intervals at which the µA readings were noted at every 3mts intervals. Readings are given in Appendix VII Theoretical meter response is compared with practical values obtained in Fig4.6&7. Maximum error comes to be ±1%. The practical curves is drawn through the mean positions of points obtained from actual reading.

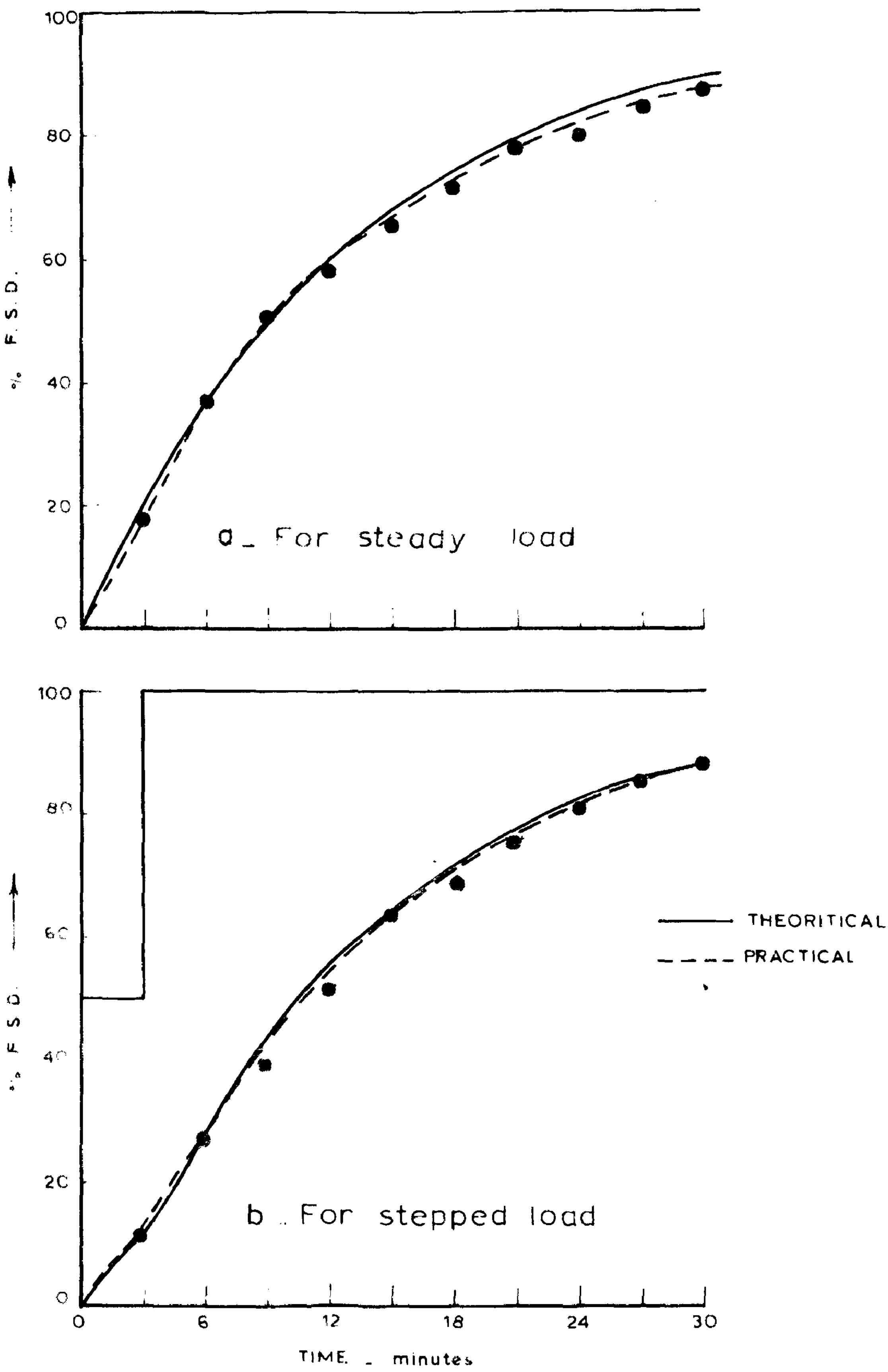


FIG 4.6 _ RESPONSE OF LAG TYPE DEMAND INDICATOR

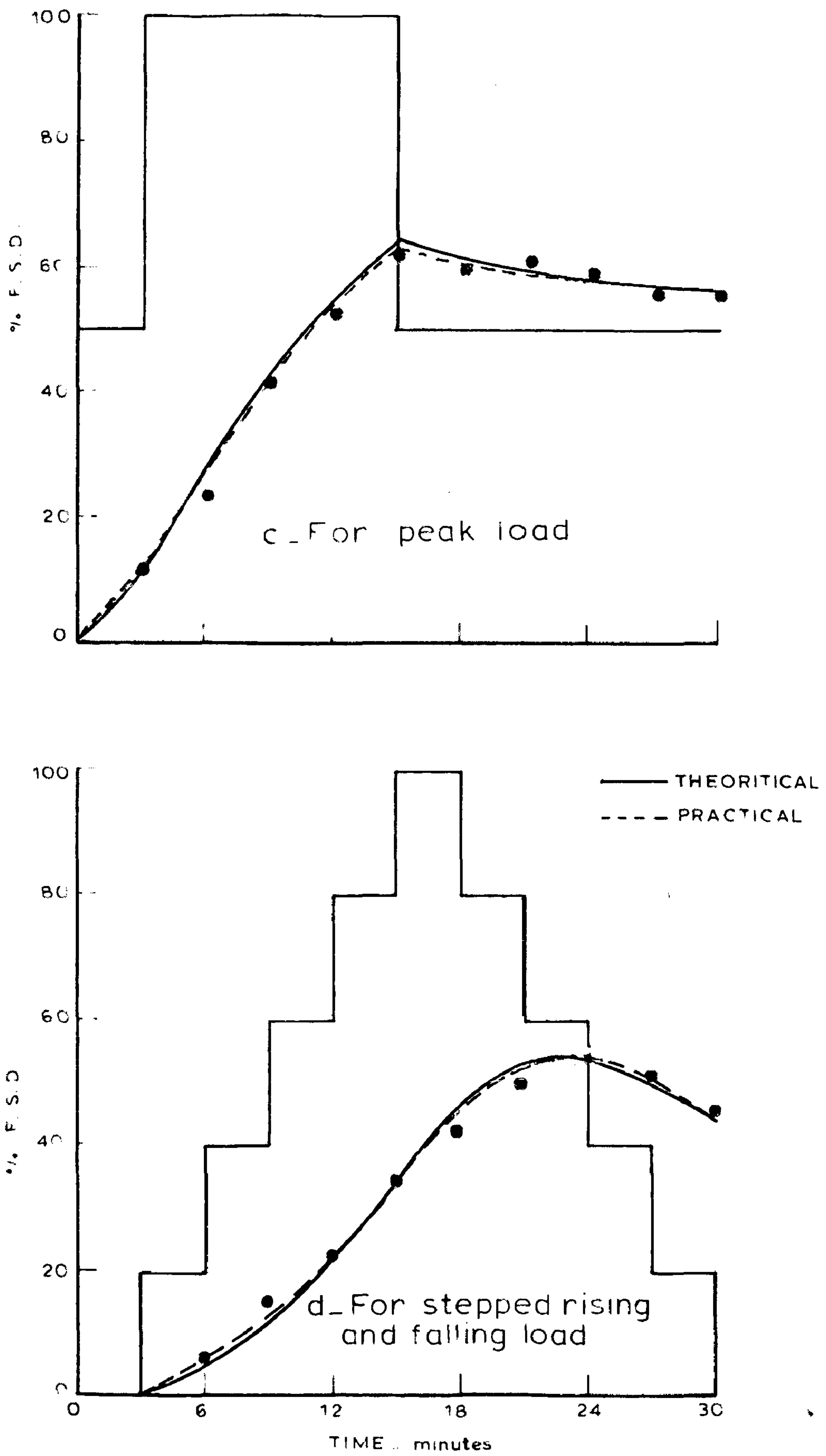


FIG. 4.7_ RESPONSE OF LAG TYPE DEMAND INDICATOR

CHAPTER 5

TARIFF DATA SENSING AND MONITORING

After the metering of tariff quantity, it has to be transmitted to the supplier's premises for billing as well as operational and planning purposes. Conventional method is to manually record the readings at consumer's premises. Though not in this country, extensive efforts have been made abroad for remote sensing and monitoring of tariff data. There are two basic approaches regarding this i.e., either there is remote sensing and recording of data from time to time or there is continuous monitoring of the same. Latter is more useful for operational purposes. Most of the methods use solid state devices. A very comprehensive review of the basic principles involved in few schemes, is being presented here. So far no universally acceptable method could be evolved but only proposals have been tested on small scale.

5.1 Basic Requirements

The problem of remote sensing and monitoring of tariff data can be broken up as:

(i) Encoding the informations of the meter reading and the consumer's identification.

So far, most of the schemes tried have to encode informations from conventional meters. This is principally done in two ways, like,(a) by attaching to meter register an encoding system which takes the form of a number of sliding contacts and (b) using an electro-optical array at each dial of meter register (c) using inductive senser with meter wheel.

(ii) Incorporating a signal sending function with the consumer's meter and providing a transmission channel between the consumer and the billing office.

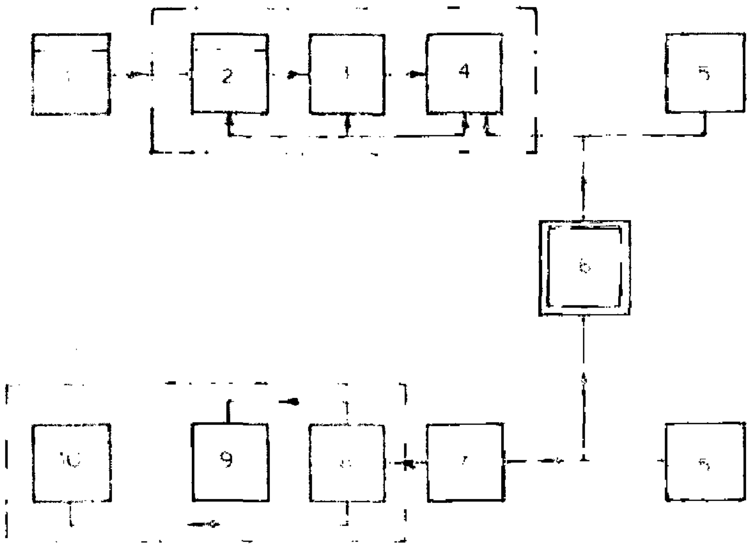
The signal sending function of the meter depends on the means of communication adopted. So far, several communication methods have been tried using (a) consumer's telephone line, (b) separate pilot wire, (c) suppliers transmission line and (d) Microwave transmission system. Various types of digital telemetries are used for data transmission under these methods.(

(iii) Providing a signal receiving equipment at the billing point which will accept and decode(or pass on) the signal sent by the consumer's meter to the billing equipment.

Basically signal receiver equipments are meant for digital data reception and store in a manner that the same can be used by a billing equipment. There are variation in the finer details of signal receivers according to means of communication adopted.

5.2 Remote reading of Maximum Demand Indicators using Telephone lines.(18)

Block schematic diagram of the system is shown in Fig 5.1. The readout register for the M.D. Indicator has facility to read and store monthly maximum demands for 12 consecutive months. Monthly maximum demand is read by this

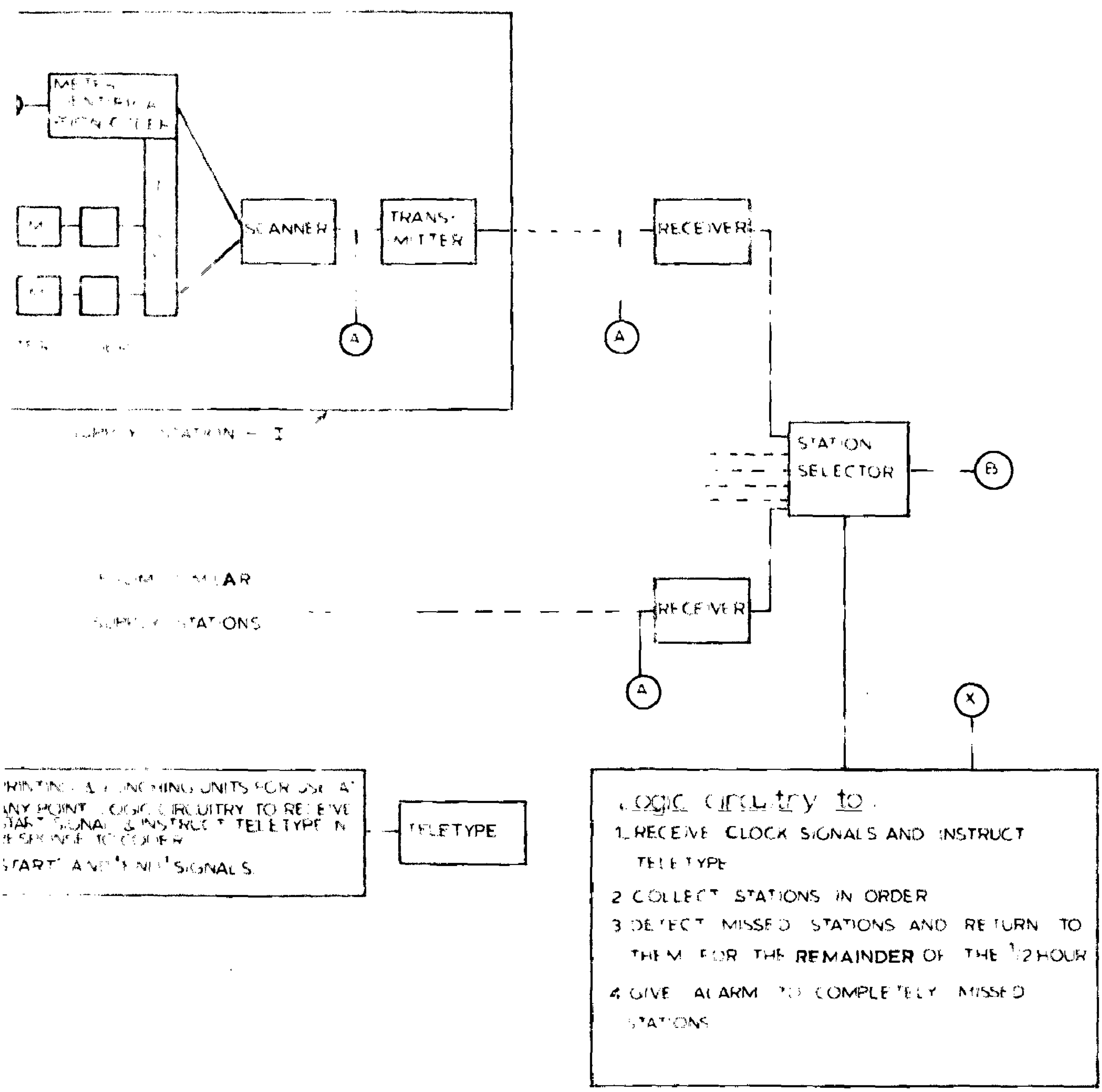


1_MILEAGE METER
2_READOUT REGISTER
3_STORE
4_CONTROL DEVICE
5_TELEPHONE
6_TELEPHONE CENTRAL STATIONS
7_RECEIVING DEVICE
8_RECEIVING STORE
9_ELECTRONIC INDICATORS
10_ELECTRIC TYPE WRITER

FIG 5.1 REMOTE READING OF MD WITH TELEPHONE WIRE system using telephone line network. During early morning hours of any fixed day in a month, the control device at the consumer's end is activated from the receiving end by sending signals through telephone lines. This control device interrogates the readout register and store and sends reply signal to the receiving device from the electronic indicators at the receiving end data can be typed in an electric meter manually. Similarly yearly MD can be also interrogated at the end of every year.

5.3 Continuous monitering of Tariff Data Using Supplier's special telemetering facility(14)

A block schematic diagram of the scheme is shown in Fig 5.2 . The system can either store half hourly demands from a Maximum Demand Meter or can take meter reading for every half hour. Either of these two informations can be stored in binary codes at the store. A free running scanner goes on continuously scanning stored data and meter identification code simultaneously and transmits the same at about 50 bauds over supplier's 120 Hz(voice frequency) special telemetering channel. Each cycle takes about 15secs to 2mts depending on the number of emands/readings transmitted. scanner will continuously send the information sfor half hour, after which it will reset and start sending new half hour information. At collecting point, a station selector will be connected to each transmission channel in turn every half hour and rest on it till a complete cycle has been received from each station.



ACCESS POINT TO CODES FROM INDIVIDUAL STATIONS

ACCESS POINT TO ALL CODES IN ORDERED SEQUENCE
THESE ACCESS POINTS CAN BE MADE AVAILABLE TO ANY USER WITH RECEIVING EQUIPMENT

START SIGNAL

FIGURE [illegible] SCHEMATIC OF A CONTINUOUS TARIFF DATA MONITORING SYSTEM

If a station is missed within the predetermined period, it will switch over to the next station and will return to its during remainder of the half hour period. The information is transmitted in some predetermined code under practice in digital telemetry.

System can be further extended for telemetering information about position of circuit breakers, current readings, voltage readings, transformer tap position and weather conditions for every half hour, by adding extra codes. These informations can be used for operational planning and ensuring system security.(The proposal seems to be theoritically sound but its actual success in operation is yet to be reported).

5.4 A Mobile data recorder using Microwave Transmission Technique.

A system or reading tariff meter using microwave communication technique has been developed by M/s Sangamo Electric Company,U.S.A(15). It is known as 'PURDAX' system. 'PURDAX' stands for public utility revenue data acquisition system. A vehicle, equipped with microwave transreceiver and a mini data recording unit is used in this system for interrogating meters fitted with matching microwave transreceiver. As the vehicle drives down the street, a µwave beam of frequency 929mHz radiated by the transmitting antenna sweeps along with it. There is a microwave receiver tuned to second harmonic frequency of 929 mHz(i.e.,.1858mHz) in the vehicle. Each meter

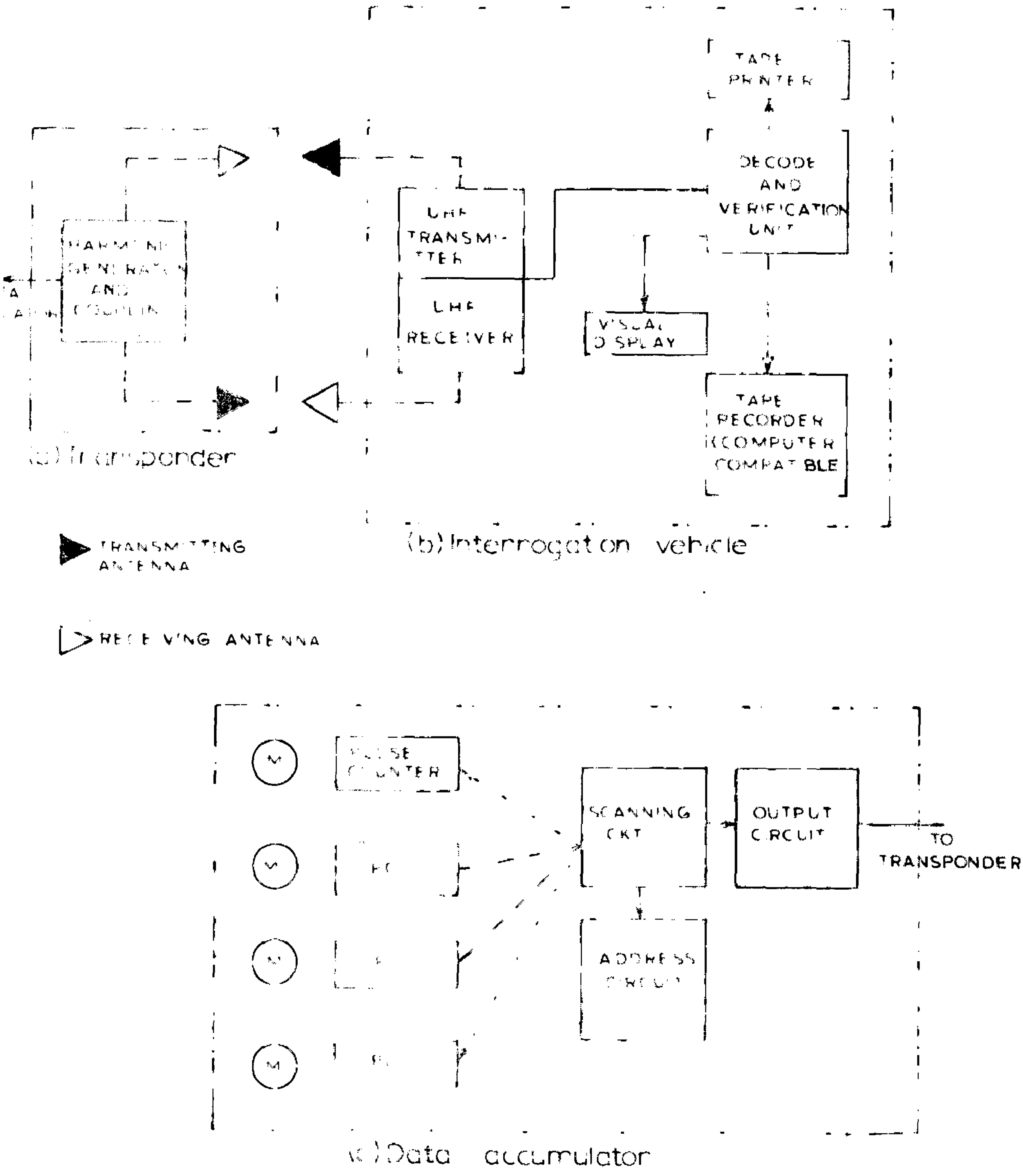


FIG 5.3 'PURDAX' SYSTEM

to be interrogated is equipped with a unit named transponder. Transponder consists of two antennas tuned to 929 MHz and 1858 MHz used for receiving and transmitting respectively. A communication link is established between the vehicle and subscriber's meter because some of the transmitted 929 MHz wave energy is transformed into 1858 MHz energy at the transponder which is received by the vehicle. A block schematic of the system is shown in Fig 5.3 . Energy transformation at the transponder takes place through a simple passive coupling network between antennas, consisting of a diode. By controlling the bias of the diode, the communication link between the vehicle and transponder can be either cutoff or established. Bias of the diode is controlled by the accumulator output which sends meter counts in form of diode bias voltage to the transponder. Signal transmission takes place with a very high frequency of several thousands per second. As shown in Fig(5.3b), data received at the vehicle is recorded in a tape.

Though still at a trial stage, the FURDAR system has certain advantages over existing methods of remote sensing of tariff data, like:

(a) It can be simultaneously used for all types of tariff meter i.e., electricity, gas, water etc.

(b) A single pair of frequencies can be used for interrogating all meters.

(c) No physical communication link is required between consumer's meter and interrogator.

(d) It can be independently carried on by the supplier without any collaboration with other authorities like P and T etc.

(e) All costly equipments are in the vehicle whereas consumer premises have simple and cheap equipments.

Overall cost/performance ratio of LUDAS can be compared with other existing methods after its extensive trials. It can read 100,000 meters per month through a single vehicle operating for single 8 hr shift in 5 days a week.

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

Some interesting conclusions are drawn from the review on the topic. At the same time, experience of laboratory work also is significant. With this in back ground scope of further work in the field could be brought into light.

6.1 Conclusions

6.1.1 Review work

After a glance at the fast pace of development in solid state tariff meters, several features of the same can be qualitatively put as follows:

(i) High linearity and accuracy over a wide range of loads.

(ii) Very low minimum driving current

(iii) Slightly affected by voltage, temperature and frequency deviations.

(iv) Unaffected by asymmetrical mains voltage condition

(v) Picks up active harmonic power with good accuracy

(vi) Vertically aligned mounting is not essential.

(vii) Very good long term stability

(viii) Same meter can be used for import and export records with suitable arrangements.

Review of the topic gives an impression that the development is taking place towards complete removal of conventional meters with solid state types but at the same time steps are also being taken to improve the conventional meter with use of solid state devices. More efforts are being now consentrated towards the development of solid state wattmetric transducers for energy meamurement as well as making prototypes of meters for trial tests.

After going through the various methods of remote sensing and monitoring of tariff data it seems that a technically feasible and economically viable solution can be made in this field. Experiences gained through several systems tried abroad can be useful in formulating a suitable system for Indian conditions

6.1.2 Author's work

After carrying out the development of some solid state tariff meters, possibilities of realising them with their salient features have become quite clear to the author. The field of energymeter development can be broken up as

(a) evolving wattmetric and VA transducers
(b) making suitable integrating system for the output of these transducers.

As observed by the author, the all compensated type Hall multiplier can prove to be an excellent wattmetric transducer because of the following facts: (i) It is a 4 quadrant multiplier which can be used for both import and export of energy.,(ii) Completely compensated for temperature variations, (iii) Voltage signal from a standard P.T(i.e.110V) need not be reconditioned for applying to the Hall multiplier. (iv) Multiplier is robust and compact. Along with these advantages there are some demerits also involved. These can be put as its high initial cost, and heavy weight. Although its size is not so big but whether it can compete with other electronic circuits in IC form or not, is an unsolved question at present.

The VA transducer tried is a simple analog multiplier. Out of all the available multipliers this type is the cheapest but also least accurate. But its accuracy can be considerably improved by a current rationing type multiplier based on the same principle[12], which can be made in IC form.

Voltage to frequency converter made is very simple type with an excellent linearity over the working range. Its range can be considerably increased with respect to input and output. i.e., for a small voltage range one can get wide variation of frequency or vice versa.

The higher limit of frequency range is limited by the fact that discharge current [redacted] supplied by the monostable should be atleast 3 to 4 times more thamt input current for obtaining distinct output pulses. Similarly, the lower limit is fixed by the fact that the input voltage should be sufficient to drive the charging current for the capacitor in the integrator.

The energy meters developed can be used for polyphase measurements also by using more than one multiplier and summing the output of each through a summing amplifier. A common V-F converter can be designed for integrating the amplifier output.

It will be a simulation of multielement conventional energy meter where torques due to each phase developed creates a final torque proportional to the total power consumed.

The Integrating type demand meter developed is based on the principle of counter comparison through gates. There is no need to have electronic display of outputs here, counters are only used for count comparison which can't be done through a mechanical counter.

Lag type meter made, contains all the required features but do not have the demerits of the existing termal types as shown below:

(a) It records KVA or kW demand as against only current variations recorded in thermal type.

(b) Scale is linear where as it is non linear for thermal type.

(c) It is cheaper and simpler than thermal type.

(d) It will require lesser maintenance.

(e) With tentalum electrolytic capacitor it will give higher stability of calibration than thermal type.

(f) It will impose a lower burden on the circuit.

Due to above merits it can probably be considered as an alternative to the existing integrating type demand indicator which are quite costly and requires more maintenance.

6.1.3 Possibilities of replacing the conventional meters

Comparison of cost/accuracy characteristics of conventional and solid state meters (Fig 1.3) reveals that at lower accuracy limit letter can not compete with the former. Whether the cost of low accuracy solid state meters can be brought down further or not is still an unsolved question. With the fast growth of integrated circuit technology there is ample scope of reducing the cost for mass scale production. Possibilities of replacing conventional metes with solid state alternatives depend on how efficiently it performs all the functions of conventional meters as well as how much it improves the measurement quality. Keeping these two function in background initial higher cost can be tolerated upto a compromising limit.

6.3 Suggestions for Further Work

In order that solid state meter developes faster towards a superior alternative, researches in the following fields have to be carried out.

(i) Signal Conditioning: Static meters are now available with internal current and voltage transformers for conditioning the signal to be handled by a printed circuit. Metering of tariff data is done both at the supplier's primary end as well as consumer's premises. In both cases there are possibilities of a centralised metering. Instead of generating the low level signal at each meter, possibilities can be examined of generating it at the primary circuit. In case of metering at a central place of a big modern power station the burden of cabling on the metering signal is considerable. There is a solution of this problem by putting the meter near the primary circuit and using impulsed

or coded signals. There can also be an explorat[illegible]
posibilities of using d.c analogue signals of h[illegible]
for this purpose.

(ii) Meter Housing: Future solid state meters can take the shape of plug in printed circuit cards housed in a box. Instead of connecting the meter with the circuit through wires it should be a modular system with plug in arrangements. Although sufficient progress has taken place in the field of modular instrumentation, it has to be applied in large scale to the field of tariff metering.

(iii) Output Display: Since all wearing parts have been done away with in static meters, there should be a move to replace the mechanical registers also with a suitable alternative. Long time magnetic storage devices used in electronic computers are too costly to be incorporated in tariff meters. But there is a scope for using data recording in magnetic tapes which can be directly fed to the computer. There is a school of thought that one should not have continuous display of counts in a tariff meter. In that case readings can be captured in a modular counter as and when required. But this thought does not contradict with the fact that meter readings should remain unchanged with the power failure. Some further work can be done towards developing a data storage device suitable for tariff meters.

***

APPENDIX B

Details of [illegible] 9030 Hall Multiplier

Magnetic field input (For parallel connection of field

Resistance, approx	R_f	500 Ohm
Temperature influence on	R_f	+0.3% per °C
Reactance, approx.	X_f	40,000 Ohm/MHz
Current rating	$I_{f\,nom}$	50 mA
Practical frequency range of	f_{max}	0.25 MHz

Hall Input

Resistance, approx at $I_f = 0$	R_{in}	2.5 Ohm
Temperature influence on R_{in} approx		+ 0.15%/°C
Magneto resistance at I_{fmax}	$\rho_{BH} I_f^2$	< 25% of R_{in}
Current rating	I_{nom}	550mA
Practical frequency range		d.c to 500kHz

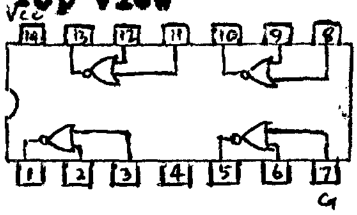
Hall Output

Resistance, approx	R_{out}	10 Ohm
Load resistance	R_L	50 Ohm
Temperature influence on V_H		
ambient 0°C to +50°C		< ± 0.5 %
" -25°C to +75°C		< ± 1 %
Output at nom. inputs	$V_H \sim I_f \times I_o$	> 200mV

APPENDIX II

Details of Quad 2-input 'NOR' GATE (7402)

Top view

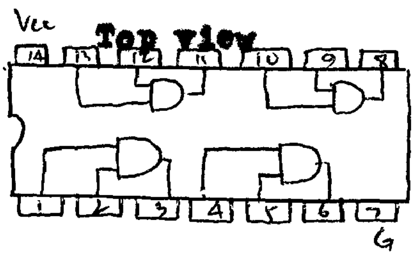


Recommended Operating conditions

Parameter	Min.	Typ.	Max.	Units
Supply voltage	4.75	5.0	5.25	Volt
Operating free air temperature range	0	25	70	°C
Normalized Fan output from each output			10	U.L

Details of Quad 2-input 'AND' GATE (4708)

Top view



Recomend operating conditions

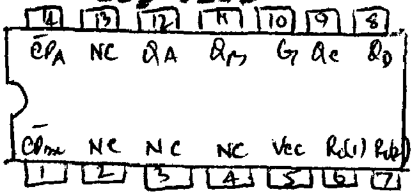
Parameter	Limits Min	Typ.	Max	Units
Supply voltage V_{cc}	4.75	5.0	5.75	Volts
Operating free air temperature range	0	25	70	°C
Normalised Fan out from each output,N			10	U.L

† U.L. = 40μA High/1.6mA Low

APPENDIX III

Details of divide by 12 binary counter (7492)

Top view



Recommended Operating Conditions

Parameter	Limits			Units
	Min	Typ.	Max.	
Supply voltage V_{cc}	4.75	5.0	5.25	Volts
Operating free air temp.range	0	25	70	^{o}C
Normalised Fan out from each output,N			10	U.L
Width of Input count pulse, t_p(in)	50			nos.
Width of Reset pulse	50			nos.

Truth Table

Count	Output			
	Q_A	Q_B	Q_C	Q_D
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	1	1	0	0
4	0	0	1	0
5	1	0	1	0
6	0	0	0	1

Contd...

APPENDIX V

Readings of kWh meter

Load current %	Output of Wattmetric transducer (At unity p.f)					
	At 80% Voltage		At 100% Voltage		At 120% Voltage	
	% Watts	Volts	% Watts	Volts	% Watts	Volts
1	2	3	4	5	6	7
5	4	0.10	5	0.10	6	0.20
10	8	0.30	10	0.30	12	0.40
20	16	0.50	20	0.50	24	0.70
30	24	0.70	30	0.80	36	0.90
40	32	0.90	40	1.00	48	1.20
50	40	1.15	50	1.30	60	1.60
60	48	2.35	60	1.60	72	1.90
70	56	1.55	70	1.80	84	2.15
80	64	1.70	80	2.10	96	2.40
90	72	2.00	90	2.35	108	2.70
100	80	2.15	100	2.60	120	3.00
110	88	2.30	110	2.90	132	3.40
120	96	2.60	120	3.10	144	3.70
			(At 0.5 p.f Lagging)			
5	2	0.10	2.5	0.10	3	0.15
10	4	0.15	5	0.20	6	0.30
20	8	0.20	10	0.30	12	0.40
30	12	0.30	15	0.40	18	0.50
40	16	0.40	20	0.55	24	0.70
50	20	0.50	25	0.65	30	0.85
60	24	0.60	30	0.80	36	0.95
70	28	0.70	35	0.90	42	1.10
80	32	0.90	40	1.00	48	1.20
90	36	1.00	45	1.20	54	1.40
100	40	1.10	50	1.35	60	1.50

APPENDIX IV

Readings of V-F Converter

Voltage	Frequency pps
0.25	2
0.5	3.8
1.0	7.5
1.5	10.8
2.0	14.8
2.5	19
3.0	22
3.5	25.8
4.0	29
4.5	29
5.0	29

APPENDIX V

Readings of kWh meter

Load current %	Output of Wattmetric transducer (At unity p.f)					
	At 80% Voltage		At 100% Voltage		At 120% Voltage	
	% Watts	Volts	% Watts	Volts	% Watts	Volts
1	2	3	4	5	6	7
5	4	0.10	5	0.10	6	0.20
10	8	0.30	10	0.30	12	0.40
20	16	0.50	20	0.50	24	0.70
30	24	0.70	30	0.80	36	0.90
40	32	0.90	40	1.00	48	1.20
50	40	1.15	50	1.30	60	1.60
60	48	2.35	60	1.60	72	1.90
70	56	1.55	70	1.80	84	2.15
80	64	1.70	80	2.10	96	2.40
90	72	2.00	90	2.35	108	2.70
100	80	2.15	100	2.60	120	3.00
110	88	2.30	110	2.90	132	3.40
120	96	2.60	120	3.10	144	3.70
			(At 0.5 p.f Lagging)			
5	2	0.10	2.5	0.10	3	0.15
10	4	0.15	5	0.20	6	0.30
20	8	0.20	10	0.30	12	0.40
30	12	0.30	15	0.40	18	0.50
40	16	0.40	20	0.55	24	0.70
50	20	0.50	25	0.65	30	0.85
60	24	0.60	30	0.80	36	0.95
70	28	0.70	35	0.90	42	1.10
80	32	0.90	40	1.00	48	1.20
90	36	1.00	45	1.20	54	1.40
100	40	1.10	50	1.35	60	1.50

APPENDIX V(CONTINUED)

1	2	3	4	5	6	7
110	44	1.20	55	1.45	66	1.70
120	48	1.30	60	1.60	72	1.80
		(At 0.5 p.f Leading)				
5	2	0.08	2.5	0.2	3	0.2
10	4	0.15	5	0.3	6	0.4
20	8	0.10	10	0.4	12	0.5
30	12	0.20	15	0.5	18	0.6
40	16	0.35	20	0.6	24	0.7
50	20	0.5	25	0.7	30	0.8
60	24	0.6	30	0.8	36	0.9
70	28	0.7	35	0.9	42	1.1
80	32	0.8	40	1.0	48	1.3
90	36	0.9	45	1.15	54	1.4
100	40	1.0	50	1.30	60	1.6
110	44	1.1	55	1.45	66	1.7
120	48	1.2	60	1.5	72	1.9

APPENDIX - VI

Readings of kVAh meter

Load current %	Output of VA transducer with varying voltages					
	80%		100%		120%	
	%kVA	Volts	%kVA	Volts	%kVA	Volts
5	4	0.40	5	0.5	6	0.6
20	16	0.75	20	1.0	24	1.0
40	32	1.25	40	1.4	48	1.55
60	48	1.75	60	1.8	72	2.10
80	64	1.22	80	2.4	96	2.60
100	80	2.5	100	2.9	120	3.10
120	96	3.0	120	3.4	144	3.70

APPENDIX-VII

Readings of Lag type demand indicator

Time mts	µA-Reading			
	Type of Load			
	Steady	Stepped	Peak	Stepped rising and falling
3	9	5.5	6	-
6	18.5	13.5	11.5	3
9	25.5	19	21	7.5
12	29	26	26	11
15	32.5	32	31	17
18	36	34	30	21
21	39	38	30	25
24	40	40	29.5	27
27	42.5	42	28	25.5
30	44	44	28	23

APPENDIX_VIII

Theoritical response of Lag type demand indicator

Time mts	Output of Lagging circuit in Volts (keeping 4V =100%)			
	Type of Load			
	Steady	Stepped	Peak	Stepped rising and falling
1.5	-	0.22	0.22	-
3.0	0.82	0.41	0.41	-
4.5	-	0.80	0.80	0.08
6.0	1.47	1.15	1.15	0.16
7.5	-	1.46	1.46	0.32
9.0	1.99	1.73	1.73	0.46
10.5	-	1.98	1.98	0.67
12.0	2.41	2.20	2.20	0.86
13.5	-	2.40	2.40	1.15
15.0	2.72	2.57	2.57	1.34
16.5	-	2.72	2.50	1.63
18.0	2.99	2.87	2.40	1.89
19.5	-	2.99	2.38	2.03
21.0	3.20	3.10	2.36	2.16
22.5	-	3.20	2.32	2.18
24.0	3.36	3.29	2.28	2.20
25.5	-	3.36	2.24	2.14
27.0	3.49	3.43	2.20	2.08
28.5	-	3.49	2.16	1.94
30.0	3.60	3.55	2.12	1.81

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