C. P. STEINMETZ.
ALTERNATING CURRENT ELECTRIC METER.
(Application filed Apr. 28, 1902.)

INVENTOR:
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WITNESSES:
Abi Elgin
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To all whom it may concern:

Be it known that I, CHARLES P. STEINMETZ, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Alternating-Current Electric Meters, (division of my prior application, Serial No. 669,901, filed February 11, 1898,) of which the following is a specification.

In alternating-current systems in which power is supplied to inductive translating devices—for example, such as induction-motors—a part of the current is almost invariably wattless—that is, it does not represent power delivered. Nevertheless, since wattless currents represent power consumed on the lines and in transformers, because of the C.R. loss, and since such currents consume generator capacity it is fair that a charge be made, though perhaps at a smaller rate than the rate charged for actual power delivered for this loss in the system, since such a charge would form a check on customers using motors too large for the work demand upon them and running therefore at light loads with consequent excessive lagging current. Moreover, the fact that some charge is made for wattless current constitutes an inducement for customers to cut out of circuit entirely except when in actual use all inductive apparatus, such as transformers or motors, which take at no load an excessive lagging current.

It is the object of my invention to provide a meter recording not only the power delivered, but also a part at least of the power lost on the line due to the lagging or wattless currents. I accomplish this object by producing in some of the actuating-coils of a meter, such as the Thomson recording-wattmeter or an induction wattmeter or whatever type may be preferred, a relative inductive reactive effect and a resultant relative shifting of the magnetomotive forces, which act on the armature to cause it to actuate the registering or indicating mechanism. In a Thomson recording-wattmeter, for instance, by properly adjusting the relative amount of reactance and non-inductive resistance in the potential circuit of the instrument the amount of lagging currents recorded can be adjusted as desired, and consequently a corresponding rate of charge can be established.

The power in an alternating-current circuit is equal to volts into amperes multiplied by the cosine of the phase angle between the volts impressed on the circuit and the current flowing. The readings in a recording-wattmeter are proportional to the current in the potential circuit—that is, the current due to the difference of potential across the mains into the main current multiplied by the cosine of the angle of phase difference between these two currents. Moreover, if the potential circuit is in phase with the impressed volts, the reading of the wattmeter will be proportional to the power.

I have found that if we insert in the potential circuit of the wattmeter a suitable inductive retrace and adjust it so as to cause the magnetism due to the current in the potential circuit to lag, say, twenty degrees behind the phase which it would have were the instrument to register the actual energy consumed, and then so adjust the wattmeter as to read correctly at non-inductive load by properly proportioning the windings or adjusting the recording or registering mechanism, the reading of the instrument will not be volts by amperes by cosine of the phase angle between the impressed volts and the resultant amperes, but will be volts by amperes by cosine of an angle twenty degrees less than the angle of lag in the circuit. The cosine of this angle is obviously greater than the cosine of the phase-angle itself.

For example, suppose the lag of the current due to the inductive load is twenty degrees. Then the power delivered is volts by amperes by cosine of the angle of twenty degrees, the cosine of twenty degrees being .94—that is, in this instance, the actual power delivered is slightly less than the apparent power.

Let us consider what would be the readings of the instrument when a device having inductance or an inductive resistance is included in the potential circuit of the wattmeter. It is evident if the instrument is not readjusted that it will register less than the en-
ergy consumed in the circuit, since the energy consumed with a non-inductive load on the circuit is volts by amperes, while the readings of the instrument would be volts by amperes by .94. Therefore the instrument should be readjusted to give at non-inductive load the same reading—that is, volts by amperes—as if the inductive resistance was omitted from the potential-current circuit. The instrument is therefore made to read higher than the equation would make it read in the ratio which unity bears to the cosine of twenty degrees. Suppose the main-line current lags by \(x\). Then the difference of phase between the current in the main line and that in the potential circuit is \((x^\circ - 20^\circ)\) and the equation would give, for the meter-registration, volts by amperes by \(\cos (x^\circ - 20^\circ)\); but as the meter has been readjusted, as above described, it results that its reading would be volts by amperes by \(\frac{\cos (x^\circ - 20^\circ)}{\cos 20^\circ}\).

With the reactance causing a lag of twenty degrees in the potential circuit, the instrument being adjusted to read correctly at non-inductive loads, the reading of the instrument will be at twenty degrees load lag, volts by amperes by \(\frac{\cos (20^\circ - 20^\circ)}{\cos 0^\circ}\), or volts by amperes by \(\frac{\cos 0^\circ}{\cos 20^\circ}\) or \(\frac{\cos 20^\circ}{\cos 20^\circ}\). 1.064, so that the instrument will register a small percentage over what it would register with the inductance eliminated from the potential circuit, and therefore there would be a small charge for wattless current at a time when the lag caused by load is relatively small. If the lag of the current is comparatively great—for example, say sixty degrees—the power of the circuit is one-half the volts by amperes, since the cosine of sixty degrees is one-half. The reading of the instrument would be in this case volts by amperes by \(\frac{\cos (60^\circ - 20^\circ)}{\cos 20^\circ}\), or volts by amperes by \(\frac{\cos 40^\circ}{\cos 20^\circ}\) or volts by amperes by .83. In this case it will be apparent that the instrument registers about 1.66 times the actual power delivered. In this case the charge for wattless currents is evidently almost two-thirds of the charge for energy-current. If the lag of the circuit is eighty degrees, then the instrument will indicate volts by amperes by \(\frac{\cos 20^\circ}{\cos 20^\circ}\), which is volts by amperes by .94—that is, the instrument instead of charging .71\(\frac{\times}{\times}\) times the volt amperes charges .54 times the volt amperes. In this case the charge is for the actual power and for something over one-third of the wattless currents.

By adjusting the relative amount of inductance in the potential-current coils of the wattmeter we can vary the readings of the instrument so as to charge at different rates of increase according to different adjustments made. By cutting out entirely the inductive resistance or reactance we can change the instrument back into a wattmeter of the ordinary type, which registers simply the actual power supplied, in which case the reading of the recording-wattmeter becomes again potential current by main current by cosine of the angle between the two. By properly adjusting the non-inductive and inductive resistance of the potential circuit of the wattmeter in different proportions we get different readings, so that the instrument when combined with a regulable inductive and a regulable non-inductive resistance in its potential-current circuit becomes a multiplex wattmeter—that is, a meter capable of giving different readings in accordance with the relative amount of reactance in its potential-current circuit. The same principle can be applied to any recording-wattmeter based on the mutual action of potential-current coils and the main current-coils. For instance, in the induction wattmeter where the currents in the two coils are approximately ninety degrees separated from each other and act on an armature wound with closed coils or on simply a disk of conducting material in which eddy-currents are generated the same effect may be secured by making the potential-current lag more than ninety degrees behind the impressed electromotive force, as by producing an inductive reactive effect in certain of the coils of the instrument, and by adjusting this inductive effect various readings may be obtained.

It results from a motor constructed as described that a customer may be given a certain discount for taking leading currents; but this is not objectionable, since such currents tend to raise the power factor of the system.

Referring to the drawings, Figure 1 illustrates my invention in connection with a Thomson recording-wattmeter, in which A B represent constant-potential mains supplied with energy or through intermediation of transforming apparatus; and Fig. 2 represents diagrammatically the application of my invention to an induction-wattmeter. In Fig. 1, A' indicates the armature-coils of the wattmeter, and K K' indicate the field-magnet coil of the wattmeter, here shown as of a usual and well-known construction. X is the shaft which carries the armature-coils, supported in the usual manner in adjustable jewel-bearings. M is the damping-disk acted upon by the permanent magnets M' M'. LL are incandescent lamps or other similar devices arranged in multiple on the constant potential circuit A B. C is the commutator of the armature, upon which rest brushes C', by which commutator and brushes a current in multiple with the mains A B and corresponding in magnitude and phase to the electromotive force impressed on the translating devices may be supplied to the coils A'. D represents any of the well-known forms of registering mechanism, such as a train of gear...
ing with indicating-dials. R is an adjustable non-inductive resistance of any well-known type, and R is an inductive resistance or reactance device, such as is involved in my invention. It will be noticed that this reactance device is adjustable. The points of contact of the coils over which the switches pass are connected at such points of the winding of the inductive resistance with relation to the non-inductive resistance, the instrument, and the circuit in which it is connected as to permit the adjustment which renders my apparatus a meter of the multiple-rate type. By placing the switch-arm S on the second contact, as shown, enough of the coils of the inductive resistance will be in circuit with the armature A and potential circuit P to cause a lag of the current in the armature of, say, twenty degrees. When placed on the next contact to the right, a lag of thirty degrees would be produced in the armature-circuit, and so on.

Turning to Fig. 2, which illustrates, as I have stated, my invention in connection with an induction-wattmeter in outline, T represents a transformer through which energy is supplied at constant potential and lowered pressure to the circuit A B, in which are arranged incandescent lamps or other translat ing devices. Of course the energy may be supplied to the lamps directly without the use of a transformer. C C represent the main-current coils of the wattmeter, and S S represent the potential coils of the wattmeter, connected across the mains A B. These coils conjoinly act upon an armature A, here shown as a cylinder of conducting metal. R is an inductive resistance connected, as usual, in the circuit with the potential coils to produce a lag of current in the potential coils as near ninety degrees as possible; but the current in the potential coils with the arrangement thus far described cannot, as will be described later, be expressed by the familiar expression $E_C \cos \varphi$ when $E$ is the electromotive force, C the current, and $\varphi$ the angle of lag. My invention requires, however, that the reading should correspond to $E_C \cos (\varphi - 20^\circ)$ or, say, $E_C \cos (\varphi - 20^\circ)$. It therefore becomes necessary to artificially retard the phase of the current flowing in the coils S S. I prefer to produce this result by shunting them with a device which acts to retard the phase of the current therein—such, for example, as a non-inductive resistance, (shown at R). This device will divide the current in the branch circuit already lagging by, say, eighty-five degrees into a leading component and a lagging component. The lagging component, which will obviously be behind the current in the coil R in phase, will pass through the coils S S. By properly adjusting the effect of this phase-retarding device, which is here shown as an adjustable resistance, the lag of the current in the potential coils may be made, for example, one hundred and ten degrees.

In addition to the resistance R, I may wind a coil or set of coils S S on the magnetic circuit of the coils S S. These coils, closed on themselves with or without an adjustable resistance R, will tend to beat back the flux due to the coils S S and to retard it in phase, as is well understood in the art, and produce an additional lag in the magnetism due to the potential coils.

Though I have shown two separate devices acting to retard this flux working conjointly, it is obvious that either one alone may be used.

By varying the amount of resistance in these respective sets of coils, since the amount of current flowing through them is thus varied, we can vary their relative magnetizing effect, and thus in turn effect the displacement in phase of their resultant magnetic flux.

Of course any well-known arrangement of varying the number of turns in either or both of these sets of coils may be used with the same effect in substance as the variable non-inductive resistances produce in either or both.

I do not limit myself to any particular form of alternating-current electrical measuring instrument, since I consider that I am the inventor of the broad apparatus for so shifting the relationship of the reactant and electromotive forces which set in motion the armature of an alternating-current indicating or registering instrument, such as a meter or galvanometer, to establish such lag, either in current or magnetomotive forces, as will when the registering mechanism is properly adjusted record a predetermined amount of wattless current in an alternating-current circuit.

What I claim as new, and desire to secure by Letters Patent of the United States, is—

1. In an alternating-current wattmeter, or indicator, the combination of the actuating-coils, a reactance device included in one of said coils and registering or indicating mechanism actuated by the currents in said coils and so adjusted as to register or indicate a predetermined proportionate amount of wattless current.

2. In an alternating-current measuring instrument, the combination of the actuating-coils, an adjustable reactance device included in the circuit of one of said coils, and registering or indicating mechanism actuated by the currents in said coils, and so adjusted as to register or indicate a predetermined proportionate amount of wattless current.

3. In an alternating-current wattmeter, the combination of the actuating-coils, a reactance device included in circuit with one of the said coils, and registering mechanism adjusted so as to record the power delivered, and in addition thereto to record a portion of the wattless current.
4. In an alternating-current wattmeter, the combination of the main-current coils, the potential-current coils, the armature actuated by the current flowing in these respective coils, a reactance device included in the potential-current circuit, and registering mechanism adjusted to record accurately at non-inductive load the power delivered, whereby a proportionate amount of the wattless current is registered in addition to the power delivered.

5. In an alternating-current system of electrical distribution, the combination of the actuating-coils of a registering-wattmeter, an adjustable reactance device in circuit with one of the said coils, and registering mechanism adjusted relatively to the reactance to record wattless current in addition to energy current.

6. In an electric meter for alternating currents, the combination of a motive device, the speed of which with loads of unity-power factor is proportional to the real energy, a recording mechanism controlled thereby, and means for increasing the speed of the motive device by a predetermined proportional amount when the load becomes lagging.

7. In an electric meter for alternating currents, the combination of a motive device, the speed of which with loads of unity-power factor is proportional to the real energy, a recording mechanism controlled thereby, and means for increasing the speed of the motive device by a predetermined proportional amount when the load becomes lagging and for decreasing the speed of the motor when the load becomes leading.

8. In an alternating-current meter, the combination of a motive device and registering mechanism for recording on loads of unity-power factor the energy consumed in the circuit, with means for affecting the speed of the motor so as to record upon inductive load a desired part of the wattless current in addition to the energy-record.

9. In an alternating-current motor meter, the combination of a motor, recording mechanism driven thereby, and speed-regulating means for said motor so adjusted as to cause the motor to run on lagging currents at a rate intermediate between such rates of speed as would correspond respectively to measurements of the apparent and actual energy of the load in the work-circuit.

10. In an alternating-current motor meter, the combination of a motor, a recording mechanism driven thereby, and speed-regulating means for said motor so adjusted as to cause the motor to run on lagging currents at a rate intermediate between such rates of speed as would correspond respectively to measurements of the apparent and actual energy of the load in the work-circuit, and on leading currents to run at a rate less than that corresponding to the actual energy.

11. A motor-meter having an armature provided with a commutator, and a device possessing inductance in circuit with said armature.

12. An alternating-current electric meter constructed to measure wattless current in addition to energy current.

13. In an electric meter for alternating-current circuits, the combination of a motive device, a recording device controlled thereby, and means for causing the speed of the motive device to be dependent upon the power factor of the circuit.

14. In an electric meter for alternating currents, the combination of a motive device the speed of which with loads of unity-power factor represents the real energy, a recording mechanism controlled thereby, and means for causing the motive device to run faster when the load is lagging than when the same amount of real energy is flowing at unity-power factor.

In witness whereof I have hereunto set my hand this 14th day of April, 1902.

CHARLES P. STEINMETZ.

Witnesses:

BENJAMIN B. HULL,
HELEN ORFORD.