FACILITIES INSTRUCTIONS, STANDARDS, AND TECHNIQUES

Volume 3-10

WATT-HOUR METER MAINTENANCE AND TESTING

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UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

WATT-HOUR METER MAINTENANCE AND TESTING

Volume 3-10

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I. SCOPE

1.1. GENERAL. The intent of this volume is to provide general information on theory, checks, tests, adjustments, and records which will serve as a simple and convenient ready-reference guide for testing and servicing meters in the field. This volume is confined to the type of watt-hour meter most commonly used on Reclamation power systems - the 2-, 2-1/2-, and 3-element alternating-current, induction watt-hour meter rated at 115 volts and 2.5 or 5 amperes used with instrument transformers for metering relatively large blocks of power. However, the material herein will provide sufficient information for testing single-phase and polyphase meters of other current and voltage ratings by simple application of the principles discussed. For example, a 15-ampere meter such as might be used for residential service would have constants three times as large as a similar 5-ampere meter. In the same way, a meter rated 230 volts would have constants twice as large as a 115-volt meter. Meters used without instrument transformers on single-phase service are commonly rated at 15 or 50 amperes, 230 volts. To supplement the general information in this volume, an appendix devoted specifically to revenue metering has been included.

1.2. SELECTION OF METERS. Meters are selected for Reclamation installations (Figures 1 and 2) so that accuracy on reduced loads will be maintained. This is accomplished by using a 2-1/2-ampere meter with 5-ampere current transformers; and in the case of meters used without instrument transformers, by choosing a meter whose current rating is approximately one-fourth of the probable maximum sustained load. Modern meters maintain accuracy within close limits up to 667 percent load. Care should be exercised in the selection of current transformers; over-size can result in poor meter accuracy during light load conditions.

It is impractical to show by illustrations or to describe the construction, adjustment locations, constants, etc., of the multitude of meter types that will be found in Reclamation installations. Manufacturer's instructions for the particular meter should also be referred to, whenever available, for specific information on service procedures, constants, etc. The portable standard watt-hour meters which will be used in testing are normally provided with a card giving data on disk constants for various makes and models, which will be helpful in the absence of instructions. Methods for metering vars and volt- amperes are discussed in SECTION V. Demand meters are discussed briefly in SECTION XI.

II. TEST SCHEDULES

2.1 FREQUENCY OF TESTS AND SERVICING. To ensure reliability and accuracy, it is necessary that watt-hour meters be serviced and tested periodically. This is of paramount importance for meters measuring power to customers. Meters found registering incorrectly are almost invariably slow, which means a loss of revenue. It is standard utility practice to test customer's meters on circuits of over 100 - kVA capacity at

Figure 1

SELF-CONTAINED METERS

METER SERVICE	MFG'R.	VOLTAGE	PHASE	ELEMENTS	TYPE S METERS (SOCKET): MFG'RS. TYPE	SOCKET REQ'D.	CATALOG NUMBER: 5 AMP.	15 AMP.	50 AMP.	TYPE A METERS (TERMINAL BOX): MFG'RS. TYPE	CATALOG NUMBER: 5 AMP.	15 AMP.	50 AMP.
2-Wire single phase	Westinghouse	120	Single	1	CS	S	821541	821542	821543	CA	876648	876649	876650
	G.E.	120	Single	1	I-30-S	4-terminal	85X515	85X516	85X517	I-30-A	85X499	85X500	85X501
	Sangamo	120	Single	1	JS	S	Juros	Jobas	Jufis	JA	Jacot	Janal	Jader
	Westinghouse	240	Single	1	CS	S	821544	821545	821546	CA	876651	876652	876653
	G.E.	240	Single	1	I-30-S	4-terminal	85X518	85X519	85X520	I-30-A	85X502	85X503	85X504
	Sangamo	240	Single	1	JS	S	Jetes	Jatas	Jopes	JA	Javil	Jagor	Jafit.
3-Wire single phase	Westinghouse	240	Single	1	CS	S	821547	821548	821549	CA	876660	876661	876662
	G.E.	240	Single	1	I-30-S	4-terminal	85X521	85X522	85X523	I-30-A	85X505	85X506	85X507
	Sangamo	240	Single	1	JS	S	Jimas	Jelos	Jotis	JA	Jahop	Jaboy	Jated
4-Wire 3-phase-Wye	Westinghouse	120/208	Three	2½	CS-8	ST-8	1004030	1004032	1004034	CA-8	1055354	1055356	1055358
	G.E.	120/208	Three	2	V-5-S	7-terminal	86X4	86X6	86X8	V-5-A	85X928	85X930	85X932
	Sangamo	120/208	Three	2½	LC-2½-S	ST-8	Ciron	Cislo	Cisop	LC-2½-P	Cevat	Cevel	Cevia
4-Wire 3-phase-Delta	Westinghouse	120/240	Three	2	CS-7	ST-8	1004015	1004017	1004019	CA-7	1005331	1055333	1055335
	G.E.	120/240	Three	2	V-6-S	7-terminal	86X29	86X31	86X33	V-6-A	85X958	85X960	85X962
	Sangamo	120/240	Three	2	LC-2-SΔ	ST-8	Citto	Citur	Civel	LC-2-PΔ	Cicen	Cicam	Cifel
3-Wire 3-phase Delta or Wye	Westinghouse	120	Three	2	CS-5	S-5,ST-5	931419	931421	931423	CA-5	1004956	1004958	1004960
	G.E.	120	Three	2	V-2-S	5-terminal	85X743	85X745	85X747	V-2-A	85X723	85X725	85X727
	Sangamo	120	Three	2	LC-2-S	S-5,ST-5	Cafle	Cagaw	Cajah	LC-2-A	Cabba	Cacal	Cacem
	Westinghouse	240	Three	2	CS-5	S-5,ST-5	931424	931426	931428	CA-5	1004961	1004963	1004965
	G.E.	240	Three	2	V-2-S	5-terminal	85X748	85X750	85X752	V-2-A	85X728	85X730	85X732
	Sangamo	240	Three	2	LC-2-S	S-5,ST-5	Catan	Catus	Catto	LC-2-A	Cande	Capac	Capok
	Westinghouse	480	Three	2	CS-5	S-5,ST-5	1004005	1004007	1004009	CA-5	1004966	1004968	1004970
	G.E.	480	Three	2	V-2-S	5-terminal	85X753	85X755	85X757	V-2-A	85X733	85X735	85X737
	Sangamo	480	Three	2	LC-2-S	S-5,ST-5	Ceced	Cecko	Cecog	LC-2-A	Cazel	Ceach	Ceapa

TRANSFORMER TYPE METERS

METER SERVICE	MFG'R.	C.T. REQUIRED: QUANTITY	TYPE: ▲WIRE	INDOOR	OUTDOOR	VOLTAGE	PHASE	ELEMENTS	TYPE S METERS (SOCKET): MFG'RS. TYPE	SOCKET REQ'D.	CATALOG NUMBER: 2½ AMP.	5 AMP.	TYPE A METERS (TERMINAL BOX): MFG'RS. TYPE	CATALOG NUMBER: 2½ AMP.	5 AMP.
2-Wire single phase	Westinghouse	1	2	W-1	WO-5	120	Single	1	CS	S-5	—	1155140	CA	—	876687
	G.E.	1	2	JLF3	JW-6	120	Single	1	I-30-S	5-terminal	97X107	—	I-30-A	85X511	—
	Sangamo	1	2	K-50	—	120	Single	1	JS	S-5	Julis	Jubos	JA	Jarox	Jamer
	Westinghouse	1	2	W-1	WO-5	240	Single	1	CS	S-5	—	1155142	CA	—	876688
	G.E.	1	2	JLF3	JW-6	240	Single	1	I-30-S	5-terminal	97X108	—	I-30-A	85X513	—
	Sangamo	1	2	K-50	—	240	Single	1	JS	S-5	Jixes	Jeris	JA	Japax	Jalut
3-Wire single phase	Westinghouse	1	3	TW	—	240	Single	1	CS	S-5	—	1155144	CA	—	876636
	G.E.	1	3	JL-6	JL-2	240	Single	1	I-30-S	5-terminal	97X108	—	I-30-A	85X513	—
	Sangamo	1	3	M-3	—	240	Single	1	JS	S-5	Jixes	Jeris	JA	Japax	Jalut
	Westinghouse	2	2	W-1	WO-5	240	Single	1	CS	S-6	—	1158469	CA	—	876638
	G.E.	2	2	JLF3	JW-6	240	Single	1	—	—	—	—	I-30-A	85X514	—
	Sangamo	2	2	K-50	—	240	Single	1	JS	S-6	Jemab	Jemec	JA	Jelab	Jetob
4-Wire 3-phase-Wye	Westinghouse	3	2	W-1	WO-5	120/208	Three	2½	CS-8	ST-3	1063691	1063695	CA-8	1055373	1055377
	G.E.	3	2	JLF3	JW-6	120/208	Three	2	V-5-S	♦ Special	86X24	—	V-5-A	85X948	—
	Sangamo	3	2	K-50	—	120/208	Three	2½	LC-2½-ST	ST-3	Cited	Citha	LC-2½-PT	Ceydo	Ciata
4-Wire 3-phase-Delta	Westinghouse	3	2	W-1	WO-5	120/240	Three	2	CS-7	ST-3	1063680	1063682	CA-7	1055341	1055339
	G.E.	3	2	JLF3	JW-6	120 240	Three	2	—	—	—	—	V-6-A	97X134	—
	Sangamo	3	2	K-50	—	120/240	Three	2	LC-2-SΔT	ST-3	Civia	Cizar	LC-2-PΔT	Cigna	Cilux
	Westinghouse	2	1-3,1-2	TW,W1	—	120/240	Three	2	CS-2	ST-2	1004055	1004057	CA-2	929543	929545
	G.E.	2	1-3,1-2	JL-6,JLF3	JL-2,JW-6	120/240	Three	2	V-3-S	8-terminal	85X999	—	V-3-A	85X904	—
	Sangamo	2	1-3,1-2	M-3,K-50	—	120/240	Three	2	LC-2-ST	ST-2	Cinol	Cinse	LC-2-PT	Cesen	Cesno
3-Wire 3-phase Delta or Wye	Westinghouse	2	2	W-1	WO-5	120	Three	2	CS-2	ST-2	1004052	1000000	CA-2	929539	929541
	G.E.	2	2	JLF3	JW-6	120	Three	2	V-3-S	8-terminal	85X998	—	V-3-A	85X903	—
	Sangamo	2	2	K-50	—	120	Three	2	LC-2-ST	ST-2	Cinim	Cinko	LC-2-PT	Cepek	Cepto
	Westinghouse	2	2	W-1	WO-5	240	Three	2	CS-2	ST-2	1004055	1004057	CA-2	929543	929545
	G.E.	2	2	JLF3	JW-6	240	Three	2	V-3-S	8-terminal	85X999	—	V-3-A	85X904	—
	Sangamo	2	2	K-50	—	240	Three	2	LC-2-ST	ST-2	Cinol	Cinse	LC-2-PT	Cesen	Cesno
	Westinghouse	2	2	W-1	WO-5	480	Three	2	CS-2	ST-2	1004059	1004061	CA-2	929547	929549
	G.E.	2	2	JLF3	JW-6	480	Three	2	V-3-S	8-terminal	86X1	—	V-3-A	85X905	—
	Sangamo	2	2	K-50	—	480	Three	2	LC-2-ST	ST-2	Cinto	Cione	LC-2-PT	Cesse	Cesta

▲ 2-Wire current transformers have one primary and one secondary winding, 3-wire current transformers have two primary and one secondary winding.

♦ Use socket catalog number 83X786 (1¼-inch hub), 83X787 (2-inch hub).

NOTE

For general notes see X-D-3572 (Selection chart — Sheet No. 2)

REFERENCE DRAWING

SELECTION CHART — SHEET NO. 2........X-D-3572

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DESIGN DATA

ELECTRICAL STANDARDS
WATTHOUR METERING EQUIPMENT
SELECTION CHART - SHEET 1 OF 2

DRAWN J.R.S. SUBMITTED D. Clark
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ASST. CHIEF ENGINEER

DENVER, COLORADO — AUG. 12, 1946 X-D-3571

Figure 2

INSTRUMENT CURRENT TRANSFORMERS

CONSTRUCTION	FOR USE	MANUFACTURER	TYPE	VOLTAGE	PRIMARY CURRENT RATING							
					100 AMP.	150 AMP.	200 AMP.	300 AMP.	400 AMP.	500 AMP.	600 AMP.	800 AMP.
2-Wire	Indoors	Westinghouse	W-1	1200	1026088	1026089	1026090	1026091	1026092	1026093	—	—
		General Electric	JLF-3	5000	70X196	70X199	70X200	70X202	70X203	—	70X205	70X206
		Sangamo	K-50	5000	●	●	●	●	●	●	●	●
3-Wire	Indoors	Westinghouse	TW	1200	1199464	1199466	1199467	1199469	1199470	1199471	—	—
		General Electric	JL-6	1200	408X95	408X96	408X97	408X98	408X99	—	3092042●	3092043●
		Sangamo	M-3	2500	●	●	●	●	●	●	●	●
2-Wire	Outdoors	Westinghouse	WO-5	5000	824621	824623	824624	824626	824627	824628	824629	824630
		General Electric	JW-6	5000	88X824	88X826	88X827	88X829	88X830	—	88X832	88X833
		Sangamo	—	—	—	—	—	—	—	—	—	—
3-Wire	Outdoors	Westinghouse	—	—	—	—	—	—	—	—	—	—
		General Electric	JL-2	2500	93X890	93X891	93X892	93X893	99X914	—	—	—
		Sangamo	—	—	—	—	—	—	—	—	—	—

● 600/600-, and 800/800-ampere ratings are type WCM-12.
● Sangamo current transformers are not listed by catalog number. Specify type number and primary rating.
Current transformers listed have an ASA accuracy classification of at least 0.3B-0.1, 0.3B-0.2, 0.6B-0.5 and are suitable for use with one or two watthour meters.

METER SOCKETS *

HUB SIZES	WESTINGHOUSE							GENERAL ELECTRIC						
	SOCKET TYPE	NON-CIRCUIT CLOSING TYPE TERMINALS			CIRCUIT CLOSING TYPE TERMINALS			SOCKET TYPE	NON-CIRCUIT CLOSING TYPE TERMINALS			CIRCUIT CLOSING TYPE TERMINALS		
		SET SCREW	SEMI-FLOATING	SUB+	SET SCREW	SEMI-FLOATING	SUB+		SET SCREW	SEMI-FLOATING	SUB+	SET SCREW	SEMI-FLOATING	SUB+
3/4-inch	‡ S	930577	—	—	930583	—	—	4-terminal	67X970	—	—	67X976	—	—
	‡ S-5	934321	—	—	934327	—	—	5-terminal	76X26	—	—	76X32	—	—
	‡ S-6	929474	—	—	929476	—	—	6-terminal	None	—	—	None	—	—
1-inch	‡ S	930578	—	—	930584	—	—	4-terminal	67X971	—	—	67X977	—	—
	‡ S-5	934322	—	—	934328	—	—	5-terminal	76X38	—	—	76X44	—	—
	‡ S-6	929475	—	—	929477	—	—	6-terminal	86X10	—	—	86X14	—	—
1 1/4-inch	‡ S	839461	—	—	839479	—	—	4-terminal	67X972	—	—	67X978	—	—
	‡ S-5	934323	—	—	934329	—	—	5-terminal	76X50	—	—	76X56	—	—
	‡ S-6	929478	—	—	929479	—	—	6-terminal	86X12	—	—	86X16	—	—
	ST-2	1205072	1205076	1205656	1205074	1205078	1205658	8-terminal	—	—	94X994	—	—	83X788
	ST-3	—	—	—	1205080	—	—	—	—	—	—	—	—	—
	ST-5	—	1205668	—	—	1205672	—	—	—	—	—	—	—	—
	ST-8	1205092	1205096	1205676	1205094	1205098	1205678	7-terminal	—	—	83X784	—	—	94X996‡
2-inch	ST-2	1205073	1205077	1205657	1205075	1205079	1205659	8-terminal	—	—	94X995	—	—	83X789
	ST-3	—	—	—	1205081	—	—	—	—	—	—	—	—	—
	ST-5	—	1205669	—	—	1205673	—	—	—	—	—	—	—	—
	ST-8	1205093	1205097	1205677	1205095	1205099	1205679	7-terminal	—	—	83X785	—	—	94X997‡

* 4-, 5-, and 6-terminal sockets (S, S-5, S-6) are of the round die cast type with 2 vertical hubs and breakout in back. 7-and 8-terminal sockets (St-2 to St-8) are the rectangular galvanized steel type with 1 vertical hub and knockouts in bottom and sides. Sangamo Electric Co. and Westinghouse Electric Corp. catalog numbers are identical.
‡ May be supplied with bus line or bus load terminals upon request.
‡ For use with self-contained meters only.

Capacity of terminals in A.W.G. Wire size (stranded)	Set screw	Bus	Semi-floating	Sub+
	2	0		4/0

(The 4/0 printed under Semi-floating is in the wrong place: it is printed slightly to the left, and may belong to Semi-floating rather than Sub+. As printed: Set screw 2, Bus 0, Semi-floating 4/0, Sub+ 4/0.)

+ With disconnect facilities. (Service may be disconnected and meter retained).

GENERAL NOTES

The meters listed are suitable for general purpose metering in conventional installations. Installations involving unusually high accuracy, switchboards, and other special metering problems will require metering equipment other than listed.

Requisitions for watthour meters should specify ball type bearing assemblies and that current transformer type meters be equipped with registers of the Kw capacity corresponding to the meter rating; i.e., total power consumption will be the product of the meter reading and the transformer ratio.

It is recommended that the meter selection be made in accordance with the following chart:

Probable maximum sustained load	Meter rating and type
0-20 amperes	5-ampere, self-contained
20-60 amperes	15-ampere, self-contained
60-125 amperes	50-ampere, self-contained
Over 125 amperes	2½-ampere, transformer type

REFERENCE DRAWING

SELECTION CHART — SHEET NO.1 .... X-D-3571

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DESIGN DATA

ELECTRICAL STANDARDS
WATTHOUR METERING EQUIPMENT
SELECTION CHART - SHEET 2 OF 2

DRAWN J.R.S. SUBMITTED D. Clark
TRACED M.E.K. RECOMMENDED H. H. Plumb
CHECKED JXC R.R.B. APPROVED L N McClellan
ASS'T. CHIEF ENGINEER
DENVER, COLORADO — AUG. 12, 1946 X-D-3572

least annually. The standard articles in Western (Western Area Power Administration) contracts for the sale of power specify a test annually, or more often if requested by either party (Reference, Reclamation Instructions, Part 224, Appendix I, also see Appendix A of this volume).

Most Reclamation watt-hour meters should be serviced, tested, and sealed at intervals of not more than 12 months. Exceptions might be meters measuring very small amounts of power (under 100 kVA) or when no sale of power is involved. The interval in such cases might be extended to 2 years; but for uniformity in scheduling work, it is believed that it will be found most convenient and best practice to test all watt-hour meters annually, or more often if circumstances warrant.

When testing billing meters, representatives of the customer and the power wheeling agency should be afforded opportunity to be present to witness and participate in the test. The meter seal should be broken in the presence of the witnesses and the meter re-sealed before their departure. Care and consideration should also be exercised in reading the register and an agreement reached in regard to resetting after test, or in estimating the energy registration lost during the meter outage for testing.

III. WATT-HOUR METER OPERATING PRINCIPLES AND CONSTRUCTION

3.1. GENERAL. For the sake of simplicity, the discussion in this section will be mainly based on a single-element (single-phase) meter. Two- and three-element meters are simply two or three single elements having a common shaft and register, which serve to totalize the energy measured by each element.

3.2. BASIC SINGLE-PHASE METER. A single-phase watt-hour meter is essentially an induction motor whose speed is directly proportional to the voltage applied and the amount of current flowing through it. The phase displacement of the current, as well as the magnitude of the current, is automatically taken into account by the meter. In other words, the power factor influences the speed, and the moving element (disk) rotates with a speed proportional to true power. The register is simply a means of registering revolutions, and by proper gearing is arranged to read directly in kilowatt-hours. (Note: In some cases, the meter reading must be multiplied by a factor called the "register constant" or "meter multiplier" to obtain total kilowatt-hours. See "Register constant (K), "Paragraph 3.9.4.

3.3. DISK DRIVING TORQUE. As stated above, the meter operates similarly to an induction motor. The aluminum disk acts as a squirrel-cage rotor, torque being produced as a result of eddy currents induced in it by the potential (voltage) and current coils on the electromagnet. In order that registration be correct, the torque (and speed) must be greatest at a power factor of 1.0. To have maximum speed at unity power factor, it is necessary that the current in the potential coil lag exactly 90° behind that in the current coil, or in other words 90° behind the voltage applied to the potential coil. This is also necessary if the meter is to register correctly at power factors less than unity. (See Figure 3.) To get this exact 90° displacement, a short- circuited (lag) coil is placed on the voltage coil pole. (See Figure 4.) The resistor in the circuit of this coil may constitute the "lag" or power-factor adjustment of the meter, but in many meters this adjustment is obtained by movement of a "lag plate," and the resistor should not be disturbed.

Do not confuse this 90° lag within the meter at unity power factor, which is necessary for proper functioning of the meter, with the current and voltage supplied to the meter by the instrument transformers. These are in phase (0° displacement) at unit (1.0) power factor.

3.4. FRICTION. To compensate for friction, additional torque must be introduced. This usually is accomplished by placing a movable short-circuited turn of large cross section in part of the field of the voltage (potential) coil. This also serves as a "light-load" adjustment.

3.5. BRAKING MAGNETS. Normally there is very little friction present in meters, and if no additional retarding force other than friction were placed in

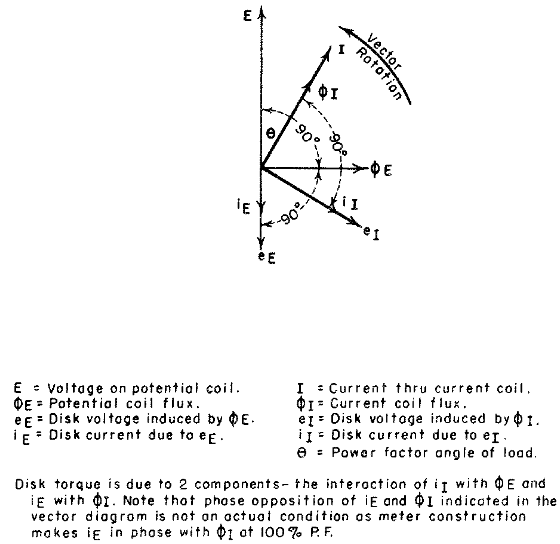


Figure 3. Vector diagram of watt-hour meter element.

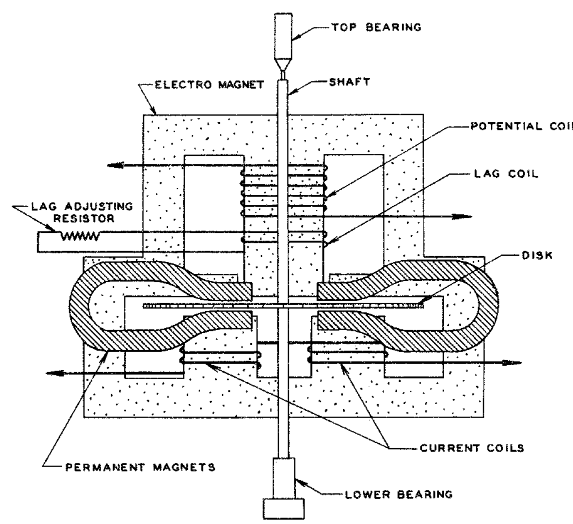


Figure 4. Fundamentals of a single-phase induction watt-hour meter.

the meter, the rotating element would travel at a relatively high speed. The necessary retarding action is provided by a magnetic brake consisting of a permanent magnet operating on the aluminum disk. This retarding action is adjustable and is known as the "full load" meter adjustment. Two methods of varying the braking effect of the magnet are in common use. The first is to adjust the position of the magnet; moving it outward radially toward the edge of the disk increases the braking effect and decreases speed and registration. In the second method, the magnet is fixed, and the braking effect is adjusted by a magnet shunt which bypasses part of the magnet flux of the permanent magnet, as shown in Figure 5.

3.6. BEARINGS. Figure 4 shows the basic mechanical arrangement and relationship of the moving element, bearings, permanent magnets, and electro-magnet. The register which is geared to the shaft

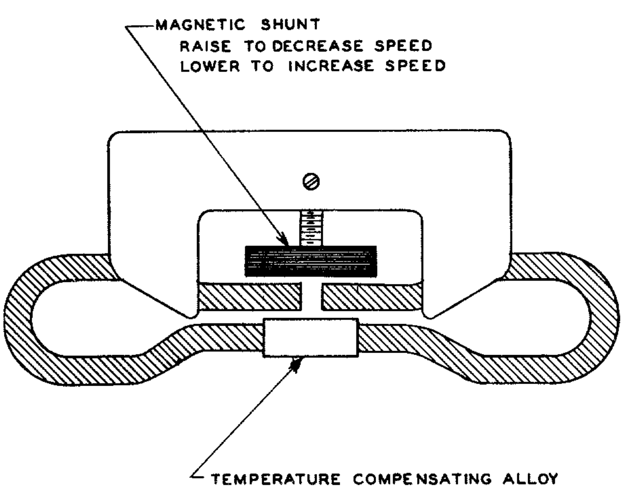


Figure 5. Magnetic shunt method of adjusting speed of disk.

is not shown. The moving element consists of an aluminum disk on a shaft. The bottom bearing may be either of two types two cupped jewels with a steel ball between or a cone- shaped pivot on the shaft which rotates in a cupped jewel bearing. The top bearing is usually a hardened steel needle-like pin fitting loosely inside the hollow shaft.

3.7. MULTIELEMENT METERS. Multielement meters usually consist of additional elements stacked vertically, with two or more disks on the same shaft, although meters may be ehcountered which have more than one electromagnet system acting on the same disk. Usually there is a set of permanent magnets per disk, but they may not all be capable of adjustment.

3.7.1. Balance adjustment. - In multielement meters, an adjustment must be provided to equalize the torque of the various elements. This is the "balance" adjustment and may be a magnetic shunt or a means of adjusting the position of the whole element radially with respect to the disk.

3.8. DETENTS. A detent or ratchet is sometimes attached to meters to prevent rotation in a reverse direction when it is desired not to register reverse power flow. This usually consists of a collar having notches or pins which is placed on the disk shaft and a pawl attached to some fixed part of the meter which engages the notches or pins upon reverse rotation but slides easily over them in the forward direction. The slight amount of friction introduced by the installation of a ratchet may affect the light-load registration and require that the meter be readjusted.

3.9. METER CONSTANTS. A knowledge of register and gear ratios and of watt-hour and register constants is required in order to check the correctness of kilowatt-hours as read from the register. (See also Paragraph 3.11 .)

3.9.1. Watt-hour constant (Kh). The watt-hour constant is the registration of one revolution of the rotating disk element expressed in watt-hours. The watt-hour constant is also sometimes called the *disk constant.* The Kh will usually be found marked on the meter nameplate or on the rim of the disk. Values of secondary Kh (see Paragraph 3.10) (per 5-ampere, 115-volt element) commonly used by various manufacturers for transformer-rated meters are listed below. Some other values that may be encountered are listed in parentheses.

Values of Secondary K_h

General Electric	0.7, 0.9, 1.2, 1,8 (0.3, 1/4)
Westinghouse	1/3, 0.9, 1.8(1/4)
Sangamo	0.6, 0.9, 1.2, 1.8(1/3,5/24)
Duncan	0.9, 1.2, 1.8

3.9.2. Gear ratio (Rg). - The gear ratio of a meter is the number of revolutions of the rotating disk element for one revolution of the first dial pointer.

3.9.3. Register ratio (Rr). - The register ratio of a meter is the number of revolutions of the wheel meshing with the worm or pinion on the rotating disk element, for one revolution of the first dial pointer.

The gear or register ratio is often found marked on the rear plate of the register or on the gear train frame. In checking the register and gear ratios, it will probably be found most practical to determine the register ratio by counting the number of revolutions that the wheel meshing with the shaft must make for, say, one-tenth revolution of the first dial pointer. By counting the teeth on this wheel and the number of teeth on the shaft pinion, the "first reduction" is determine. Register ratio times "first reduction" equals gear ratio. In the case of worm on the shaft, the lead or number of threads on the worm should be observed to determine how many teeth the meshing wheel is advanced by one revolution of the shaft.

3.9.4. Register constant (Kr). - The register constant is a factor by which the register reading is multiplied to ascertain the number of kilowatt-hours recorded by the meter. The register constant is also sometimes called the *dial constant or multiplier.* The register constant may be 1, 10, 100, or some integral of 10, except that for meters used with instrument transformers, it may be the register constant of the meter alone, multiplied by the product of the ratios of the instrument transformers. The register constant is usually marked on the dial face and may or may not take into account the instrument transformer ratios. Registers should be standardized as much as possible to eliminate the stocking of spares.

3.10 PRIMARY VERSUS SECONDARY CONSTANTS. At this point, a word of caution is in order. If the meter were rated for use with instrument transformers, as indicated by data on the nameplate, the watt-hour constant (Kh) and register constant (Kr) as marked on the meter or nameplate may be "primary constants" and include the product of the instrument transformer ratios. If this is the case, it will be obvious, because the Kh will be much greater than the 1/3, 1/2, 2/3, 0.6, etc., which is the basic or "secondary" Kh of the meter itself. As stated in the first part of this bulletin, discussion is based on 5-ampere meters. In the case of 15- or 50-ampere meters, such as might be found in Government camp service, the "secondary" Kh would be large. It is also possible that installations will be found where meters are operating with instrument transformers of different ratios than originally intended. For this reason, when checking it is recommended that the meter be considered separately (as if it were not used with instrument transformers), and its constants be determined. Then in the last step - checking the register constant - bring in the factor of instrument transformer ratios.

3.11. FORMULAS FOR CONSTANTS. To recapitulate the foregoing in a different manner, and in a sequencewhich can be used in a checking procedure, and also to present a useful equation, the following procedure is suggested.

One revolution of the rotating disk element of the meter is equal to Kh watt-hours. The number of revolutions of the rotating disk element for one revolution of the first dial pointer is equal to the gear ratio, Rg, and therefore one revolution of the first dial pointer will represent:

$K_h \times R_g$ watt-hours, or

$$\frac{K_h \times R_g}{1{,}000} \text{ kilowatt-hours.}$$

The numerical value of one revolution of the first dial pointer of a standard register is 10; therefore the register constant for kilowatt-hours is:

$$Kr = \frac{K_h \times R_g}{10 \times 1{,}000}$$

and

$$Rg = \frac{K_r \times 10{,}000}{K_h}$$

First determine the *ratio of reduction* between the shaft of the rotating disk element and the shaft of the gear engaging with it. This is called the "first reduction." Next determine the register ratio, Rr, (Paragraph 3.9.3). The gear ratio, Rg, is equal to the register ratio multiplied by the first reduction, and its value may be substituted in the equation. In this checking process, it is recommended that the secondary Kh of the meter be used, and the Kr of the meter alone be determined first, and then multiply it by the transformer ratios to find the factor (multiplier) by which the dial reading must be multiplied for correct measurement of kilowatt-hours.

3.12. BASE-LOAD SPEED. Another useful characteristic of the meter, if known, is the base-load speed. Base-icad speed is rpm at 115 volts and 5 (or 2-1/2) amperes, unity power factor. On a steady load, by timing the meter speed with a stopwatch, a very accurate value of kilowatt Icad may be obtained in the absence of a wattmeter; or the same method may be used to check the accuracy of an indicating wattmeter. (See Paragraph 4.1.4.) Base-load speeds commonly used by various manufacturers follow, but should not be construed as applying in all cases. For example, Westinghouse also uses a speed of 33-1/3 rpm in their Type CA-8 meter.

Base-load speeds - 500 ('or 250) watts/element

General Electric . . . . 16-2/3 rpm
Westinghouse . . . . 25 rpm
Sangamo . . . . 16-2/3 rpm
Duncan . . . . 25 rpm

Kh and base-load speed are related as follows for single phase:

$$Kh = \frac{\text{Nominal volts (115) x nominal amps (5 or } 2-1/2)}{\text{Base}-\text{load speed (rpm) x 60}}$$

3.13. METER CONNECTION DIAGRAMS. Figures 6 through 14 illustrate typical meter connections. Not all possible meter types are included, but it is believed that in Reclamation powerplants, substations, and pumping plants, instances where other types of meters are en countered will be extremely rare. The meter terminal arrangements shown in the figures were chosen solely for simplicity and clarity. Actual arrangement of terminal studs varies widely with make and model. One thing they all have in common, however, is symmetry, and it is usually quite easy to trace the internal meter connections to determine the identify of studs. For example, in the case of a 2-element meter with horizontal stud arrangements, the two phases are separated by an imaginary horizontal line through the center of the meter, and for the sake of symmetry the voltage studs may be at extreme top and bottom. In some installations the instrument transformers may supply other instruments besides the watt-hour meters.

IV. METERING POWER IN 3-PHASE CIRCUITS

4.1. METHODS FOR METERING 3-PHASE POWER. Four methods are in general use for metering the power or energy in 3-phase circuits. Each has its particular application, depending on whether the circuit is 3- or 4-wire, and whether inaccuracy due to unbalanced currents or voltages can be tolerated. Each of the four methods is described in more detail in the following paragraphs. Although each description refers particularly to watt indication, it is also applicable watt-hour metering.

It is always possible to measure the power in any circuit by using one instrument or element less than there are lines or paths in the circuit. This is known as Blondel's Theorem, or the

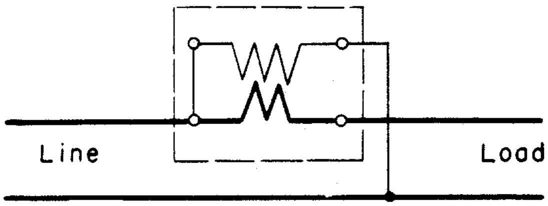


Figure 6. Single-phase, 2-wire meter.

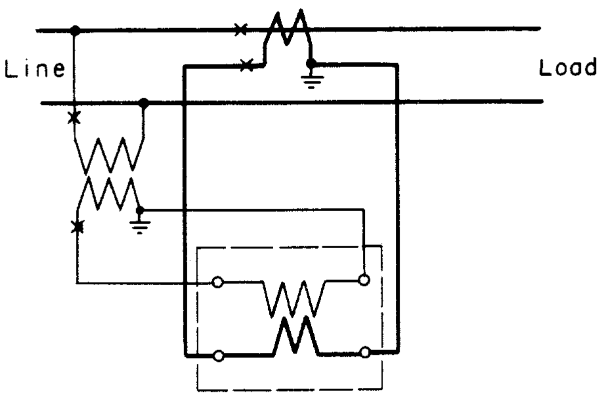


Figure 7. Single-phase, 2-wire meter using instrument transformers.

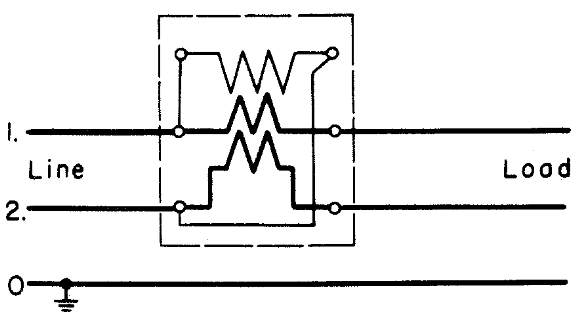


Figure 8. Single-phase, 3-wire meter.

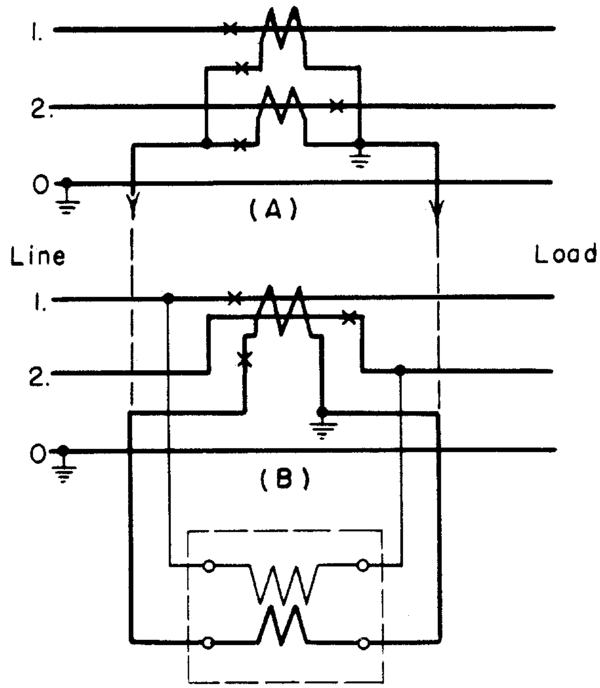


Figure 9. Single-phase, 3-wire circuit using 2-wire meter and current transformers. (A) Two current transformers. (B) One 3-wire current transformer.

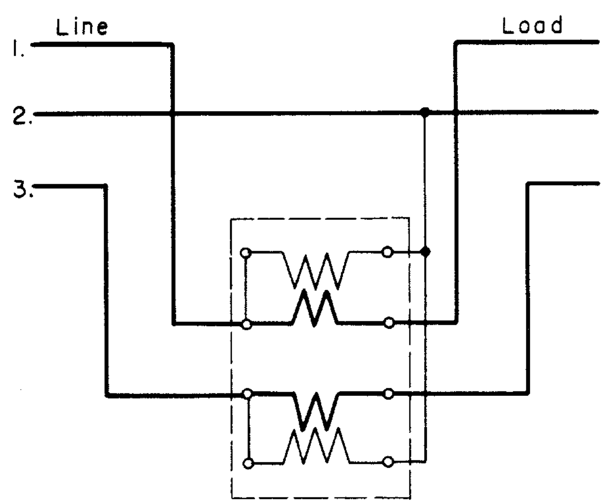


Figure 10. Three-phase, 3-wire, 2-element meter, self-contained.

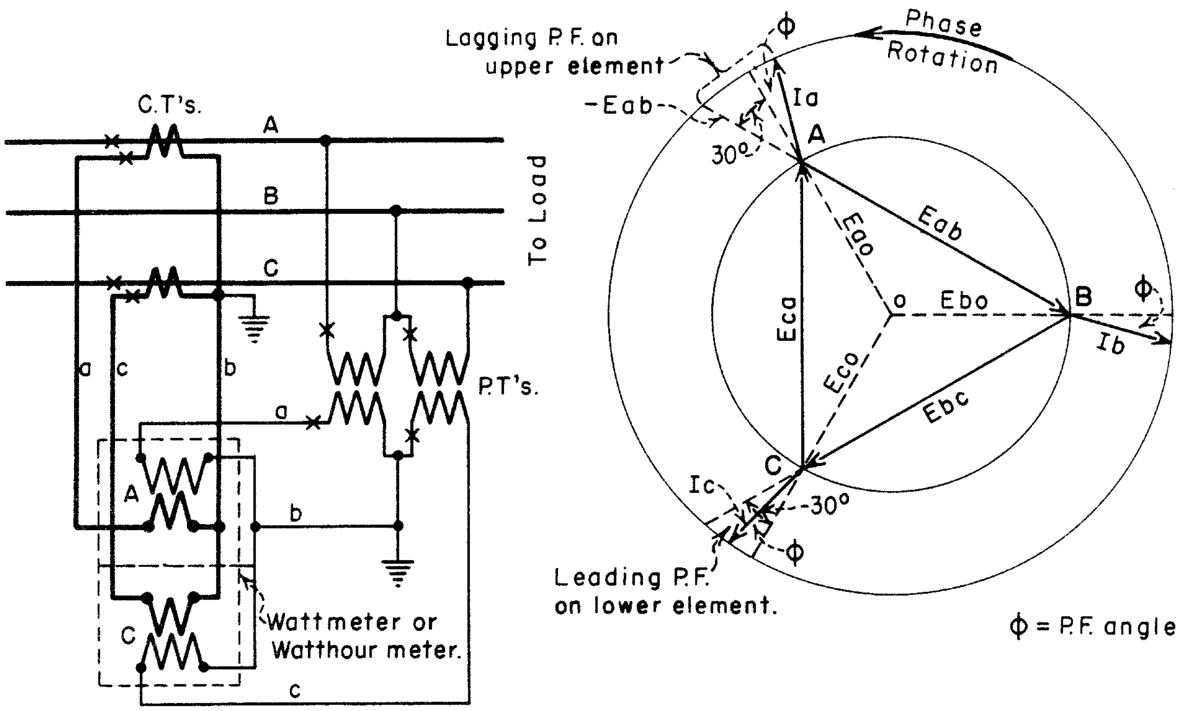


Figure 11. Three-phase, 3-wire, 2-element meter, two current transformers and two potential transformers.

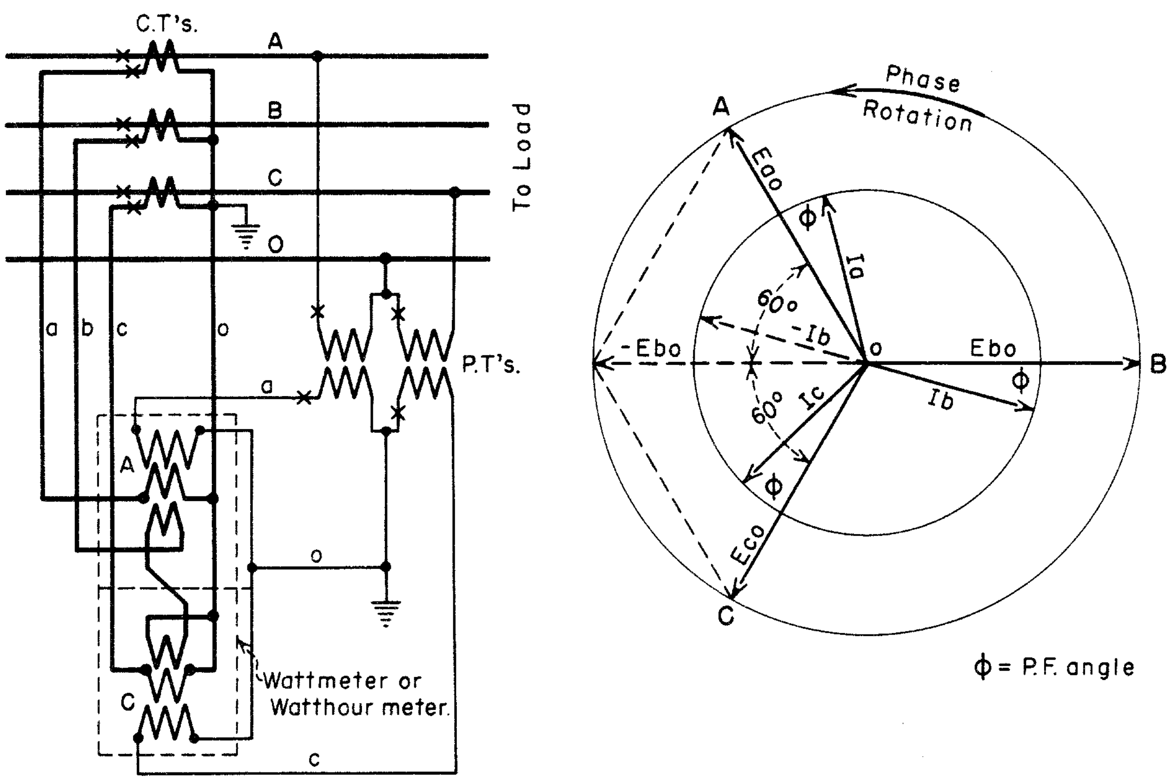


Figure 12. Three-phase, 4-wire, 2-1/1-element meter, three current transformers and two potential transformers.

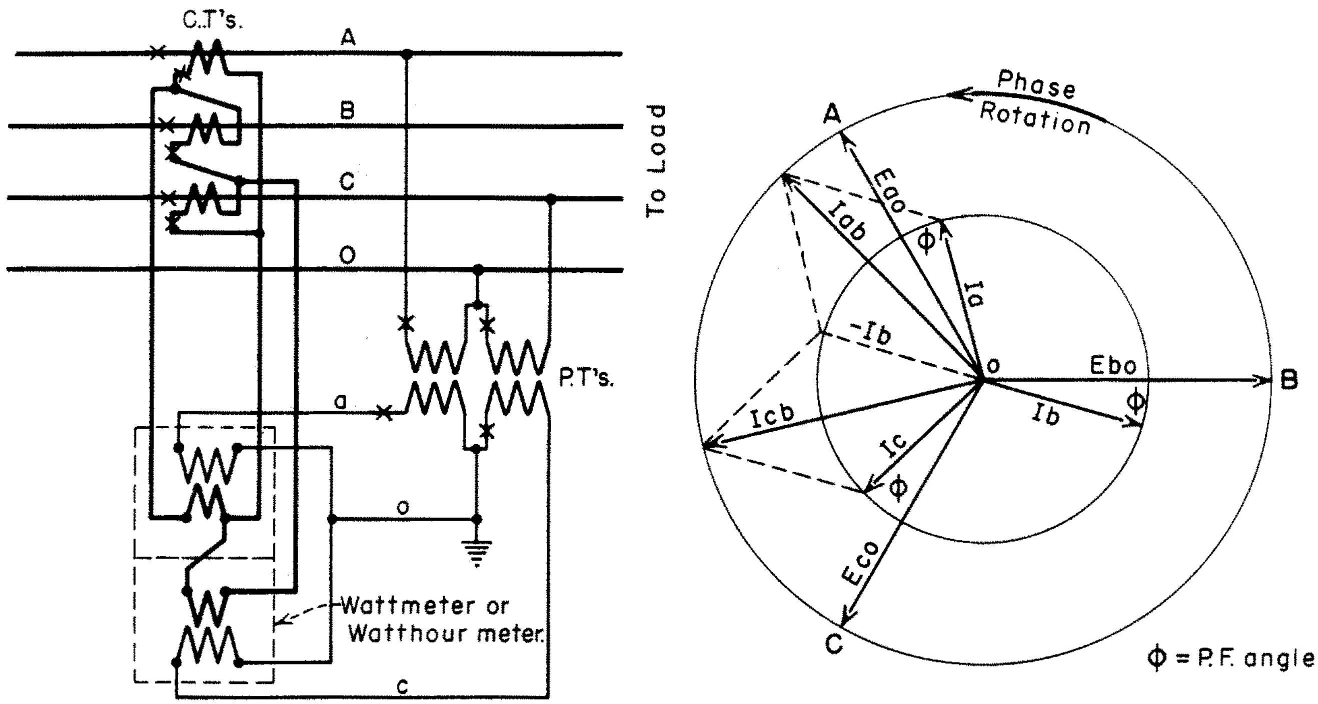


Figure 13. Three-phase, 4-wire, 2-element meter with delta-connected current transformers.

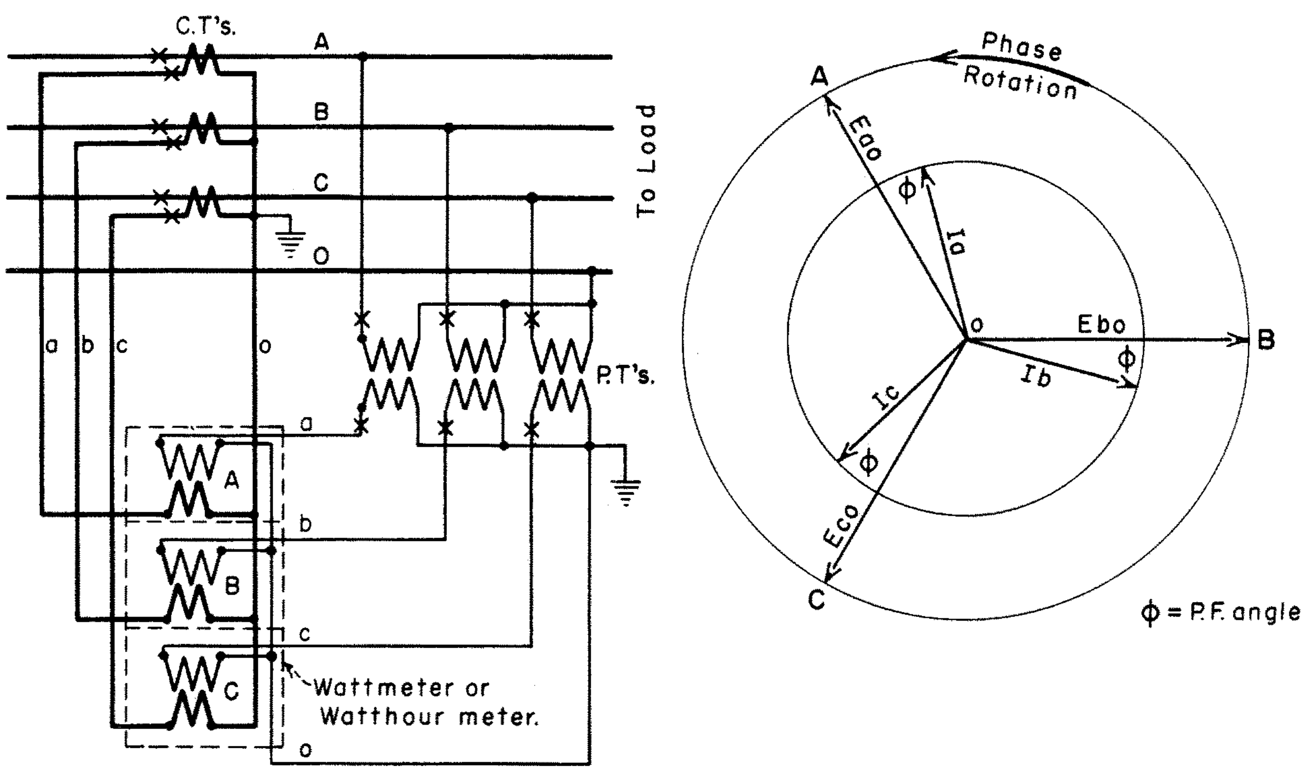


Figure 14. Three-phase, 4-wire, 2-1/1-element meter, three element meter.

(n -1) wattmeter rule. This is shown in the following tabulation:

Type of circuit	Number of lines	Meter elements required
Single phase	2	1
3-phase, 3-wire, (delta)	3	2
3-phase, 4-wire (wye)	4	3

4.1.1. 2-element meters. - The 2-element-type meter is designed to operate from current in two of the three phases and the potential between the two phases, as shown in Figures 10 and 11. It is the most universally used 3-phase meter connection, and it is recommended for ungrounded delta-connected circuits only, although applicable to all 3-phase, 3-wire ungrounded circuits and to 4-wire or grounded circuits if no load is connected between a phase wire and the neutral or ground. The connection is the same as used on the 2- wattmeter method of power measurement, and is theoretically as accurate as the 3-wattmeter or 3-element method when used on 3-phase, 3-wire systems. However, the power factor and resulting torque on the two elements is always different, and therefore the two elements must be accurately compensated for power-factor errors over the full range of leading and lagging power factors over which the meter will be operated. For example, at a load power factor of 96-percent lagging (15E), the power factor on one element of the meter will be 96-percent (15E) lead while the other is 70-percent (45E) lag, as shown in Figure 11. At a load power factor of 50-percent lagging, the torque on one element becomes zero, and below 50-per-cent power factor it reverses.

4.1.1.1. *2-element Meter, Basic Formulas.* Referring to Figure 11, the upper element measures:

$P1 = E_{ab} I_a \cos (30 + i)$
(E_{ab} is reversed from its symmetrical order.);

the lower element measures:

$P_2 = E_{bc} \; I_c \cos (30 - i);$

and the total power measured is:

$P = P_1 + P_2 =$
$[E_{ab} I_a \text{COS} (30 + i)] +$
$[E_{bc} \; I_c \text{COS} (30 - i)].$

The above formula is applicable to any condition of unbalanced voltage and current. For normal balanced conditions, the formula can be simplified by assuming:

$E_{ab} = E_{bc} = E$

and

$I_a = I_c = I.$

And since

$\text{Cos} (30 + i) = \cos 30 \cos i$
$- \sin 30 \sin i$

and

$\text{Cos} (30 - i) = \cos 30 \cos i$
$+ \sin 30 \sin i,$

in adding the two quantities, the term "sin 30 sin i" cancels out.

Therefore,

$$P = P_1 + P_2 = 2\ EI \cos 30 \cos i$$

$$\cos 30 = .866$$

$$P = 2 \times .866\ EI \cos i = 1.73\ EI \cos i$$

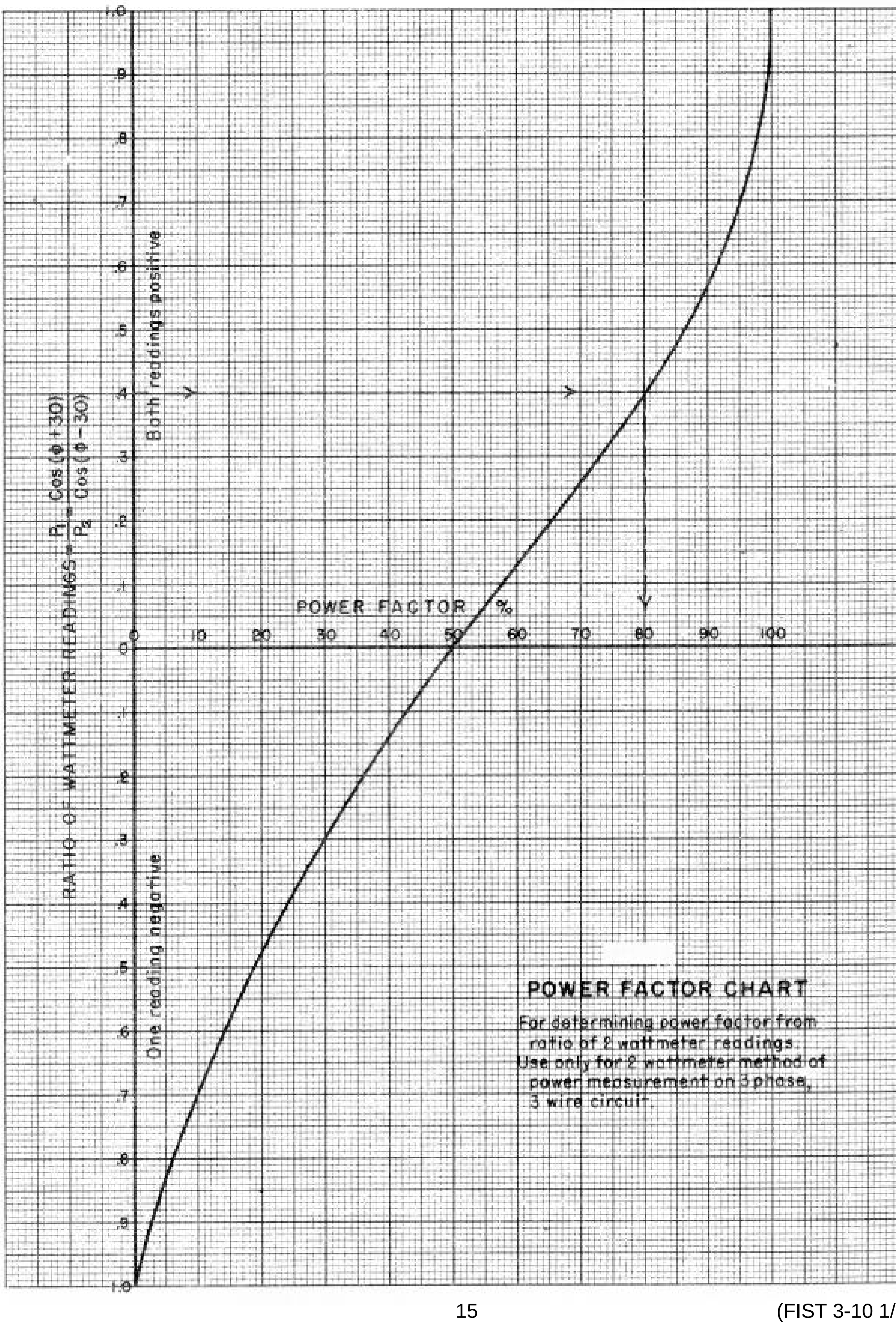
$$= \sqrt{3}\ EI \cos i$$

which is the basic formula for total power in a 3-phase circuit.

4.1.1.2. *Checking Power Factor with 2-element Meter.* The power factor of the load being measured can be determined by the ratio of the readings of the two wattmeter elements, when using the 2-element wattmeter method. When using two separate single-phase wattmeters, the power factor is obtained by the ratio of the two wattmeter readings P_1 and P_2 from the curve in Figure 15. When using a 2-element watt-hour meter, the potential circuit to one element at a time should be opened and the revolutions of the disk counted for a definite time period. The power factor is then obtained from the ratio of the disk revolutions for the two readings. The load must of course be constant while the readings are taken. Referring to Figure 15, the upper half of the graph is used when both readings are in the same direction (positive), and the lower half when one of the readings is reversed (negative).

4.1.1.3. 2-element Meter with Delta-connected Current Transformers. The 2-element meter with delta-connected current transformers is designed to use the standard 2-element meter operated from current transformers in each of the three phases, which are connected in delta, and potential transformers connected between two of the phases and neutral or the third phase wire in which no current transformer is installed as shown in Figure 13. It is applicable to metering 3-phase, 4-wire or grounded neutral circuits. It is equivalent in the source and amount of errors to the 2-1/2-element metering method described in Paragraphs 4.1.2. and 4.1.2.1. Whereas the 2-1/2 element meter obtains the vector sum of the flux of two current coils within the meter, the 2-element meter with delta-connected current transformers obtains the vector sum of two currents by means of the delta connection and passes this current through the meter coils, the resultant effect of the two methods being identical. The B-phase voltage is not measured, as shown in Figure 13, and is therefore subject to the same errors due to unbalanced voltages as those encountered in the 2-1/2-element meter. This method is also objectionable because of the delta connection of current transformers, which makes the current circuits unsuitable for some relays and instruments which may be used in the same circuit, and the secondary circuit current is 8.66 amperes at full-current

Figure 15


RATIO OF WATTMETER READINGS = P1/P2 = Cos (φ + 30) / Cos (φ − 30)
Both readings positive
One reading negative
POWER FACTOR %
0
10
20
30
40
50
60
70
80
90
100
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
POWER FACTOR CHART
For determining power factor from ratio of 2 wattmeter readings.
Use only for 2 wattmeter method of power measurement on 3 phase, 3 wire circuit.

transformer rating instead of the usual 5 amperes. The formulas given for the 2-1/2-element meter also apply to this meter and the vector diagram, Figure 13. Relays and other instruments are not normally permitted to be connected to single secondary current transformers or potential transformers installed for metering purposes. The burden on metering transformers should be kept as low as possible to accomplish satisfactory metering accuracy.

4.1.2. 2-1/2-element meters. - The 2-1/2-element watt-hour meter is designed to operate from current transformers in each of the three phases and potential transformers connected between two of the phases and neutral, as shown in Figure 12. It is a substitute for the 3-element meters used for metering 3-phase, 4-wire or grounded neutral circuits where it is desired to save the expense of the extra potential transformer, which may be a considerable item on high-voltage circuits. However, it is not equivalent in accuracy to the 3-element meter, particularly when the voltage is unbalanced, because the voltage of one of the phases is not measured. Its use on permanent Reclamation power circuits is not recommended because of its possible inaccuracy and because it is more difficult to test and adjust than a 3-element meter.

4.1.2.1. *2-1/2-element Meter, Basic Formulas.* Referring to Figure 12, since the B-phase potential is missing, the B-phase energy is measured by using the B-phase current reversed with the A-phase voltage on one element and with the C-phase voltage on the other. This is equivalent to using the B-phase current with the B-phase voltage, since the B-phase voltage under balanced voltage conditions is equal to the vector sum of the A- and C-phase voltages reversed. It is therefore obvious that the meter will not indicate accurately when the voltages are unbalanced so that the B-phase voltage reversed is not equal to the vector sum of the A- and C-phase voltages. The accuracy is not affected by unbalanced currents, since all three currents are measured. The upper element measures:

$$P_1 = E_{ao} Ia \cos i + E_{ao} [Ib \cos (60 - i)].$$

(Ib is reversed from its symmetrical order.)

The lower element measures:

$$P_2 = E_{co} I_c \cos i + Eco [I_b \cos (60 + i)].$$

$$P = P_1 + P_2 = E_{ao} I_a \cos O + E_{ao} [I_b \cos (60 - i)] + E_{co} I_c \cos i + Eco [I_b \cos (60 + i)].$$

Reversing the leads in the meter causes Ib to be read positively and all units of power can be added as positive numbers. Assuming balanced currents and voltages,

$$E_{ao} = E_{bo} = E_{co} = E$$

and

$I_a = I_b = I_c = I$.

And since

$\text{Cos}\ (60 + i) = \cos 60 \cos i - \sin 60 \sin i$,

$\text{Cos}\ (60 - i) = \cos 60 \cos i + \sin 60 \sin i$, and

$\text{Cos}\ 60 = 0.5$,

$P = 3\ EI \cos i$ in terms of line-to-neutral voltages,

or

$$P = \frac{3\ EI \cos \varnothing}{1.73} = 1.73\ EI \cos i$$

in terms of line-to-line voltages, which is the basic formula for power in a 3-phase circuit.

The meter torque due to

$$E_{ao}\ [I_b \cos (60 - i)] + E_{co}\ [I_b \cos (60 + i)],$$

which is the portion affected by unbalanced voltage, is always one-third of the total torque for balanced conditions. The error in metering due to unbalanced voltages is therefore:

$$\text{Percent error} = \frac{\text{Percent unbalanced in voltage}}{3}$$

The unbalance in voltage equals the difference between the voltage of the unmeasured phase and the vector sum of the other two voltages.

It is assumed that the three voltages remain 120^{O} apart in phase relation.
Thus for an unbalance in voltage of
10 percent, the metering error will be

$$\frac{10}{3} = \text{3-1/3 percent.}$$

4.1.3. 3-element meters. - The 3-element type meter is designed to operate from a current transformer in each of the three phases and a potential transformer connected between each phase and the neutral or ground, as shown in Figure 14. It is applicable to 3-phase, 4-wire or grounded neutral circuits. Its accuracy is independent of all conditions of unbalanced currents and voltages and varying power factor. It is essentially three single-phase elements mounted on one shaft so that their torques can be totalized. Each element operates at the same power factor as the metered load for all conditions. Special transformers may be required when used with delta-connected loads.

4.1.3.1. 3-element Meter, Basic Formulas. Referring to Figure 14, the energy measured by each element is as follows:

$Pa = E_{ao}\ I_a \cos i$,

$Pb = Ebo\ Ib \cos i$,

$P_c = E_{co}\ I_c \cos i$, and

$P = Pa + Pb + Pc = E_{ao} I_a \cos i + E_{bo} Ic \cos i + E_{co} I_c \cos i$, which is applicable to all conditions of unbalance. Assume the usual condition where the voltages and currents are balanced,

$$E_{ao} = E_{bo} = E_{co} = E,$$

and

$$I_a = I_b = I_c - I.$$

$$P = 3\ EI \cos i,$$

in terms of line current and line-to-neutral voltage, or

$$P = \frac{3\ EI \cos \varnothing}{1.73} = 1.73\ EI \cos i,$$

In terms of line current and line-to-line voltage, which is the basic formula for total power in a 3-phase circuit.

4.1.4. Measuring watts with a watt-hour meter. - The load on a circuit, in watts, can be found from any watt-hour meter by taking a reading of the time in seconds, required for the disk to make a given number of revolutions, from which

$$P = \frac{3{,}600\ K_h\ R}{S}$$

where

P = Power in watts,

K_h = Watt-hour constant marked on rim of disk or on nameplate (see Paragraphs 3.9.1, 3.10, and 3.12)

S = Seconds duration of test,

R = Revolutions of disk in Time S. Obviously, for such measurements the load must remain constant over the test period. Otherwise the reading obtained will be the average watts over the time period used.

V. METERING VARS AND VOLT-AMPERES

5.1. GENERAL. In the following paragraphs reference to measurement of vars and volt-amperes by indicating or recording instruments also applies equally well to registration of varhours and volt-ampere-hours, respectively, by integrating meters.

5.2. VAR METERING. Vars (reactive volt-amperes) can be measured on standard indicating or recording wattmeters, provided the potentials applied to the instrument coils are shifted 90^{O} from the position used for measuring watts. This is due to the fact that watts and vars are at right angles to each other in vector relation. For single-phase circuits, the 90^{O} phase shift is usually accomplished by connecting a capacitor-resistor combination in the meter coil potential circuit, as shown in Figure 16.

For balanced 3-phase circuits, the vars can be measured by one instrument using the current in one phase and the

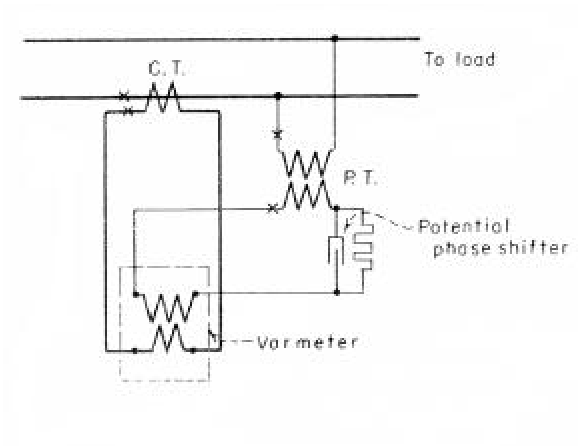


Figure 16. Single-phase varmeter.

potential between opposite phases; that is, Phase C current with Phase AB voltage, as shown in Figure 17. The total vars in the 3-phase circuit is three times the single-phase value, keeping in mind that the single-phase value implies using phase current and phase-to- neutral voltage. Since the phase-to-phase voltage used above is 1.73 times the phase-to-neutral value, the total 3-phase vars for the above condition will be single-element reading times $\frac{3}{1.73}$ or 1.73.

The usual varmeters for 3-phase circuits have two or three elements, the same as wattmeters. The quadrature (90^{o}) potential required can be obtained either by using a cross-phase connection as described above for the single-element method, or with a phase-shifting autotransformer. Referring to Figure 11, the cross-phase method would use Currant Ia with Potential E_{bc} on one element, the Current I_c with Potential E_{ab} on the other element. A third element could be connected in a similar manner. This method is merely two or three

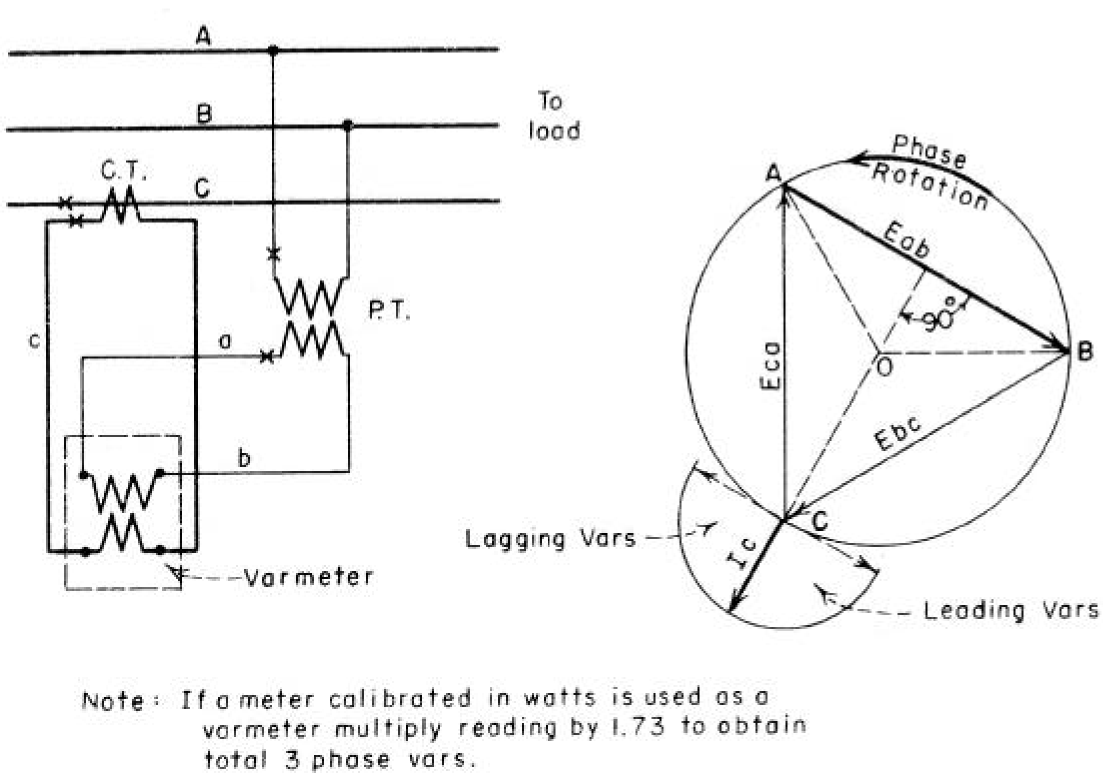


Figure 17. Varmeter for balanced three-phase circuit.

of the Figure 17 elements combined. At l00-percent power-factor load, the current and voltage on both elements will be 90^{O} out of phase. The sum of the readings of two elements must be multiplied by $\frac{1.73}{2}$ or .866, or the sum of the readings of three elements by $\frac{173}{3}$ or .576, to obtain total 3-phase 3 vars. The 2-element method is accurate only on balanced 3-phase circuits, but the 3-element method is accurate for all conditions of unbalanced currents and voltages.

Connections for a 2-element meter having a phase-shifting autotransformer are shown in Figure 18. Autotransformers of various types and connections are available for use with other types of circuits and meters. It should be noted that the autotransformer method shifts the potential that would normally be used for watt indication by 90^{O}, and maintains the same magnitude of voltage on the meter coil. Therefore, no different multiplier is needed than that which would be used for reading watts in the same circuit, and the varmeter calibration will be the same as for reading watts, whereas with the cross-phase method a multiplier of .866 must be used. At 100-percent power-factor load, the current and voltage are 60^{O} out of phase on one element and 120^{O} out of phase on the other element. The 2-element meter is accurate for all conditions of unbalanced currents and voltages for a 3-phase, 3-wire circuit, for the same reason that applies to the 2-element wattmeter method.

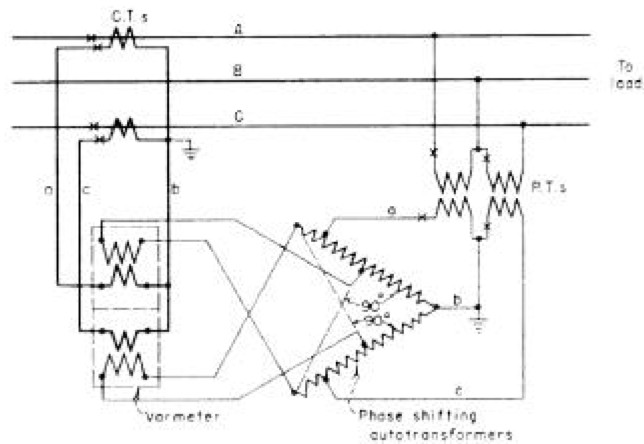


Figure 18. Three-phase varmeter using autotransformers

At 100-percent power-factor load on the circuit the varmeter will read zero, and the reading will be on the opposite side of zero for leading and lagging power-factor loads. It is customary to make indicating and recording var-meters with zero center scales so that indication can be obtained for loads of either leading or lagging power factors. In the case of integrating varmeters, two meters, each with ratchets, would be necessary if registration for both leading and lagging power-factor conditions is required. Furthermore, if power can flow in either direction through the circuit, four var-hour meters with special provisions to prevent reverse rotation would be required to properly register for the four conditions; that is: lagging power flowing in, lagging power flowing out, leading power flowing in, and leading power flowing out.

5.3. VOLT-AMPERE METERING. Instruments and meters with certain accuracy limitations are available for indicating, recording, or registering volt-amperes and volt-ampere hours.

As an alternate to metering volt-amperes on a direct reading instrument, watts and vars may be measured separately and the volt-amperes determined by calculation from the formula:

$$va = \sqrt{watts^2 + vars^2}$$

The self-contained volt-ampere meter utilizes a wattmeter in which the voltage is displaced by an angle corresponding to the average power factor of the load. The phase shift in the voltage is ordinarily obtained by the use of an autotransformer. Such a meter will register accurately only when the load power factor corresponds to the average power factor for which the meter is designed, but the accuracy will decrease for power factors on either side of the design value. However, the power factor can vary over an appreciable range without causing an intolerable error, since the cosine of the phase angle changes only about 1 percent for angles up to 8° as shown in the following table:

Angle, in degrees	Cosine
0	1.0000
1	.9998
2	.9994
3	.9986
4	.9976
5	.9962
6	.9945
7	.9925
8	.9903
9	.9877
10	.9848
11	.9816
11.5	.9799

For example, if the meter were designed for a 90-percent power-factor load, the registration would be within 1-percent accuracy between 83.1- and 95.6- percent power factor and exact at 90-percent power factor.

The permissible range of load power factor can be further extended by setting the meter 1 percent fast at 90-percent power factor in which case the registration will be within plus-or-minus 1 percent over a range of about +11.5° or from 79.5- to 96.9-percent power factor. The satisfactory application of this metering method will depend on the accuracy required and the range of average power factor for the particular load involved. When using this metering method, a periodic check of the load power factor should be made at reasonable intervals to see that the power factor is still within the range for which the meter is connected.

The above is known as the displaced voltage method of measuring volt-ampere hours and consists of using a watt-hour meter in which the voltage has been shifted to an angle corresponding to the load power factor so as to be in phase with the line current yet equal in magnitude to the original circuit voltage. Thus, the power factor in the meter is unity and the registration of the meter will be proportional to volt-ampere hours over a limited range of power factor.

This metering method and the accuracy considerations involved are discussed in Chapter 9 of the Electrical Metermen's Handbook.

Although ANSI Standards C12-1965 Paragraph 8.1.3.4 restricts the allowable registration error to 1 percent at unit power factor for light and heavy load and 2 percent at 0.5 power factor lag, much closer tolerances can and should be maintained.

VI. ERRORS IN WATT-HOUR METERING

6.1 METER ACCURACY. The watt-hour meter is a precise instrument capable of adjustment within very close limits and with periodic servicing will maintain such accuracy indefinitely. As a Reclamation standard, meters should be adjusted within the following limits:

At rated voltage and frequency	Percent registration
Unity power factor, 100% current	99.7 to 100.3
Unity power factor, 10% current	99.7 to 100.3
Unity power factor, 50% current	99.7 to 100.3
50% lagging power factor, 100% current	99.3 to 100.7

n the recording of meter accuracy, the term "percent registration" is used rather than "percent error."

$$\% \text{ registration} = \frac{\text{actual registration kWh x 100}}{\text{true kWh}}$$

The above accuracy limits apply to each element of a polyphase meter and to the combination of all elements when tested on a single phase with the current coils in series.

6.2. INSTRUMENT TRANSFORMER ERRORS. Meters used with instrument transformers can be calibrated to compensate for the errors of the transformers, but with high-accuracy instrument transformers operated within their ratings (burden), the error is small and usually neglected. If necessary, the correction factor (K_f) for ratio and phase-angle errors may be determined from the following if the required data are available on the instrument transformers:

$$K_f = CV\ K_p$$

where:

$$C = \frac{\text{Actual transformer ratio}}{\text{Marked transformer ratio}}$$

(current transformer):

$$V = \frac{\text{Actual transformer ratio}}{\text{Marked transformer ratio}}$$

(potential transformer):

K_p = Phase-angle correction factor for combined potential and current transformers

$$= \frac{\text{Cos } (\varnothing + B - Y}{\text{Cos } \varnothing\ 2}$$

in which

Cos i 2 = Apparent power factor of load as measured on the secondary of the transformers;

B = Angle by which the reversed secondary current leads the primary current;

Y = Angle by which the reversed secondary voltage leads the primary voltage.

In using this formula, care must be taken to use the proper sign with B and Y. Information is available in the *Code for Electricity Metering* from which K_p may be readily obtained, without carrying out the detailed calculations of the formula.

6.3 SOURCES OF METER ERRORS. Aside from the inherent errors due to variations in temperature, frequency, etc., which are factors of design, the most common causes of error within a meter are listed below and may be detected by inspection and corrected.

6.3.1. Common causes. -

(1) Dirt (on the disk; in the air gaps).

(2) Magnetic particles (in the permanent-magnet air gaps).

(3) Gummy oil and/or dirt in bearings.

(4) Broken jewels.

(5) Disk rubbing in air gap.

(6) Improper mesh of gears or dirty gearing.

(7) Improperly adjusted bearings.

(8) Vibration of the meter mounting.

(9) Creeping.

With the exception of (8) and (9) above, it will be noted that all defects listed introduce friction and will cause the meter to register "slow."

6.3.2. Other causes. -

(1) External magnetic fields which may add to, or subtract from, the normal meter magnetic flux.

(2) Overloads and short circuits. The effect of overloads and short circuits may be to alter the magnetization of the brake magnets,

to magnetize adjacent masses of iron, and in general to disarrange the parts.

(3) Short-circuited turns in meter coils.

6.3.3. External causes. - Some of the sources of error which may occur outside the meter itself are:

(1) Instrument transformer phase-angle and ratio errors.

(2) Improper connections such as cross-phasing and reversed polarity.

(3) Broken or high-resistance connections and short circuits in meter wiring and test blocks, blown potential fuses, short-circuiting switches inadvertently closed or left closed, etc.

(4) Improperly calibrated or poorly maintained rotating standards.

VII. METER TEST EQUIPMENT AND CONNECTIONS

7.1 TEST LEADS AND CONNECTIONS. Since routine tests are required at least annually, and in the interests of safety and saving time, it is recommended that suitable and convenient test leads and jumpers be made up and kept on hand solely for meter testing. In case it is advantageous or necessary to use test clips instead of spade lugs on the wires, the clips should be insulated and capable of gripping the meter studs, terminals, or other test-connection points securely without damage to them. Short-circuiting loaded current transformer secondaries with jumpers having *test clips on the ends* should be avoided whenever possible. If such connections are insecure, the test man and current transformer may be exposed to the high voltages that will result if the jumper becomes dislodged or is inadvertently disconnected while changing test connections.

Before connecting to a meter to be tested, check to insure that all wiring from the instrument transformers has been disconnected at the meter, or that the meter has been isolated by other means such as test jacks or test terminals. Make certain in particular that no ground connection remains connected to any of the meter circuits, since undoubtedly one or both sides if the circuit used to supply test power will be "hot" with respect to ground. As mentioned in Paragraph 7.2 below, a hand potential switch and leads should be available for the standard watt-hour meter (rotating standard), as well as a fused switch for the supply.

All test connections should be made in a safe manner, taking care to avoid accidental contact with any other connections or equipment on the switchboard. Leads and test equipment should be arranged and located so as to avoid the possibility of anyone tripping over them, and so as to avoid interference with normal or emergency duties of the operators.

7.2. PORTABLE STANDARD WATT-HOUR METER. The portable standard watt-hour meter, sometimes called a "rotating standard," is merely a precision-built and calibrated portable single-phase watt-hour meter. A pointer attached to the disk shaft enables accurate reading on a 100-division scale. A smaller pointer totals the revolutions of the larger pointer. A reset knob or button is provided to set all pointers to zero. For flexibility, various current and potential ranges are usually incorporated. Polyphase standards are commercially available, but a single-phase standard is sufficient for all ordinary purposes. A special hand switch, which operates in the potential circuit of the standard, enhances the accuracy of starting and stopping the standard and is considered an essential accessory.

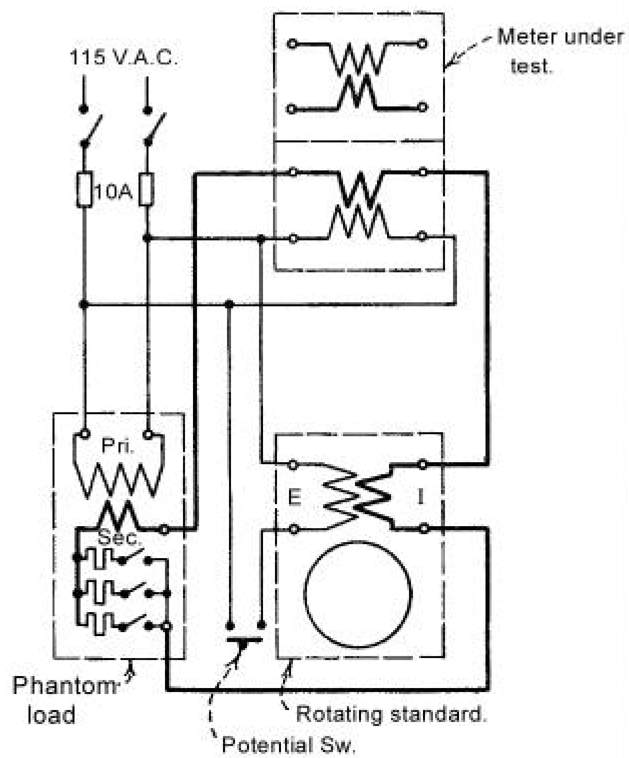


Figure 19. Testing both elements of a meter using resistance load.

7.3. LOADING DEVICES. The circuit load may be used if it can be controlled to obtain the various test conditions required. However, this is not usually the case, and artificial current loading devices are generally used. Two are in common use.

7.3.1. Resistance load. - A resistance box with taps controlled by switches to vary the current is used in series with the current coils of the meter to adjust the current drawn from a 115-volt or 230-volt source. See Figure 19.

7.3.2. Transformer load. - The transformer load is sometimes called a "phantom" load. This device is a stepdown transformer supplying a low voltage from a 115- or 230-volt source to operate the meter current coils. The current is controlled by a built-in rheostat. A very convenient feature incorporated in some phantom loads is a provision for 50-percent lagging power factor. See Figure 20.

A real difficulty with resistance loading lies in the problem of dissipating the energy consumed by the high 12R loss at high currents. For more details of this problem, see Chapter 15 of the Electrical Metermen's Handbook.

The resistance load is preferred when test currents are light, since the current in the current coil is assured of being in phase with the potential coil, and no waveform distortion is introduced. Furthermore, in the case of meters

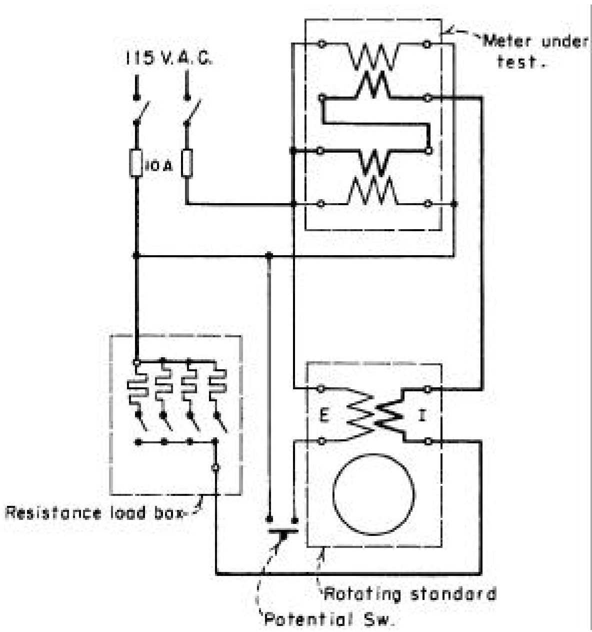


Figure 20. Testing one element of a meter using phantom load device.

used with instrument transformers and having 2.5- or 5-ampere current coils, there is not much advantage in using a phantom load; the main advantage of phantom loads is realized when they are used with meters requiring heavy test currents. Another reason for the choice of resistance loading is that resistance load boxes are generally used in relay testing to assure freedom from wave distortion, and thus can serve double duty. A well-designed phantom load, as sold by leading manufacturers of meter-testing equipment is, however, an acceptable load for *watt-hour meter* testing.

7.4. METER TEST BLOCKS. Modern Reclamation installations provide a test jack or terminal block for convenience and safety in making connections to watt-hour meters under test. The most convenient style is a jack into which a plug carrying test connections may be inserted. The insertion of this plug opens the potential transformer circuits and shorts the current transformer circuits, leaving the meter isolated from the instrument transformers and connected to the test equipment. The terminal block style is provided with switches or links to accomplish the same, and the terminals afford a convenient means of making test connections. At older installations, bridging jumpers and test connections will have to be applied wherever most convenient.

Some switchboard-type watt-hour meters are equipped with internal links and screws for test connections. The following equipment should be provided for testing watt-hour meters in the field.

7.4.1. Test equipment required. -

(1) Rotating standard with potential switch and leads

(2) Load device - Resistance box, adjustable resistors, or phantom load

(3) Ammeter(s) of suitable ranges (not absolutely necessary when using resistance box or phantom load calibrated in amperes)

(4) Power-factor meter (not necessary, but very convenient not only for reading power factor but

also for checking phase relationships)

(5) Voltmeter (not necessary, but useful in checking connections)

(6) Phase-sequence indicator (see Figure 21)

(7) Power supply switch, fused

(8) Test leads and jumpers

(9) Tools for cleaning, jewel and pivot wrenches, etc.

(10) Jewel oil

7.5. ERRORS DUE TO IMPROPER TEST CONNECTIONS. In connecting up for test, each hookup should be checked to see that no connection has been made that will result in erroneous measurements. The current drawn by potential coils or the phantom-load device primary should not pass through any current coil; the same load current should pass through all current coils; and the same voltage should be applied to all potential coils. The above conditions are easily satisfied by making sure that all potential connections (and phantom- load primary if used) are connected to the supply ahead of the resistance box and meter current coils; and that all current coils are connected in series. Refer to Figure 19, 20, and 22 for examples.

If symmetrical test connections to the meter should result in one element running reversed, do not simply reverse connections to a coil of that element and proceed. Stop, recheck the test connections, and determine whether the test connections are in error or whether an internal connection of the meter has been changed. If such a condition is found, it will, of course, affect the sketch made in verifying the physical connections (Paragraph 8.1), and may explain an apparent discrepancy found at that time.

7.6. TEST SUPPLY SOURCES. In using a resistance box for loading, observe the voltage for which the box was designed. A 115-volt box cannot be used on 230 volts without adding resistance externally. A 230-volt box can be used on 115 volts, but the current range and steps will be halved. The same precaution also applies to phantom-load devices, although many are designed for dual voltage. Obviously, also, the voltage of the supply for the potential coils of the standard and meter under test must be appropriate. It is not necessary, however, that the supply used for the current circuit be the same as that for the potential coils; 230 volts may be used for the current-circuit if the loading device is designed for that voltage. In the case of dual supply sources, care must be taken to choose the same phase of each source. For this reason, it is usually better to use a common supply to avoid errors and simplify checking connections.

7.7. TEST CONNECTION DIAGRAMS. Test connection diagrams, Figures 19, 20, and 22, show methods of connecting the rotating standard and different types of load devices to various types of meters.

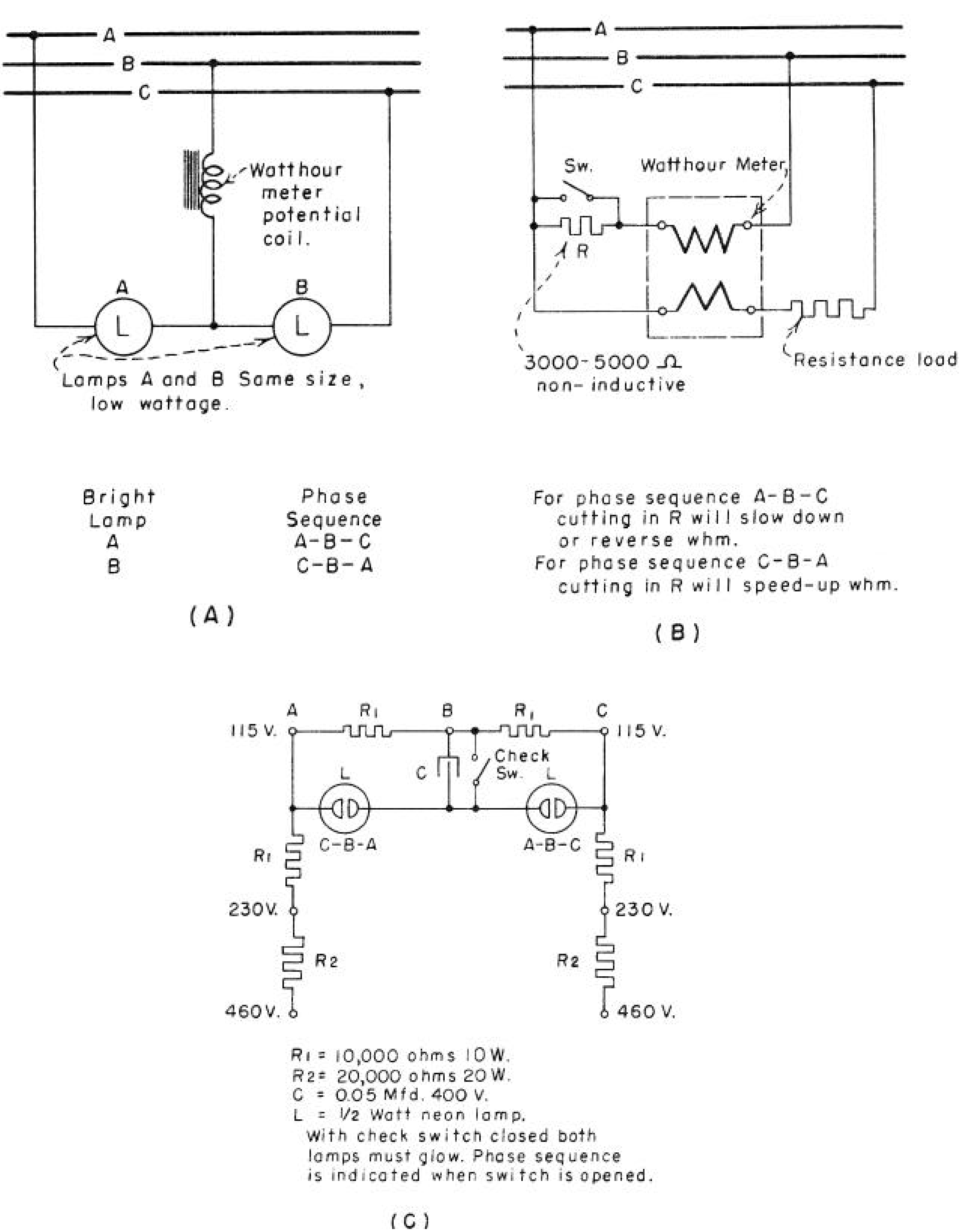


Figure 21. Phase sequence indicators.

7.8. TESTS AT 50-PERCENT POWER FACTOR. The test at 50-percent lagging power factor is most conveniently performed when a phantom load with this feature is available. However, if a 115-volt, 3-phase supply is available and the phase sequence is known, the 50-percent power factor test may be made as follows:

When sequence is 1-2-3: Use potential from 1-2, current from 1-3, or potential from 2-3, current from 2-1, or potential from 3-1, current from 3-2.

When sequence is 3-2-1: Use potential from 2-1, current from 2-3, or potential from 1-3, current from 1-2, or potential from 3-2, current from 3-1.

Figure 21 shows three methods of determining phase sequence with apparatus that can be assembled on the project. Inexpensive indicators are also available commercially.

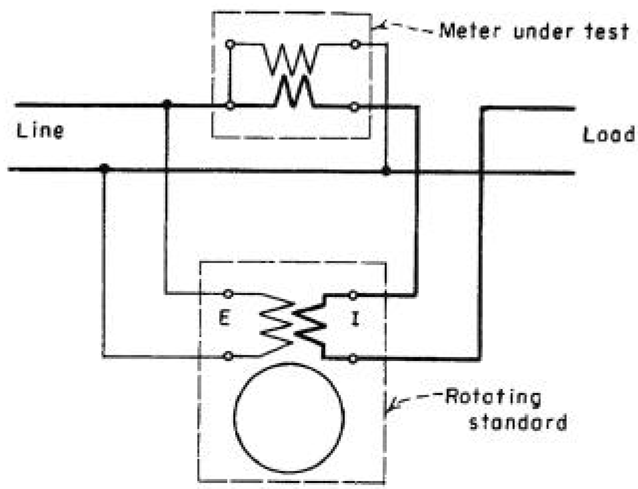


Figure 22. Testing single-phase meter using customer's load.

VIII. PRETEST CHECKING

8.1. VERIFICATION OF METER CONNECTIONS. In 3-phase metering with instrument transformers, the possibilities of wrong connections are many; obviously the meter registration will be false unless all connections are correct. It is, therefore, of utmost importance that the wiring be checked against the Denver drawing for the installation, the manufacturer's instruction book, or other appropriate diagram. When instrument transformers are used, the best check method is a physical tracing of wiring and making a sketch of the connections. Before taking a meter out of service, be sure to make a record of the time, meter reading, and the disk speed of the meter.

CAUTION: Observe all safety precautions in working around live circuits. It is preferable to obtain a clearance if the instrument transformers must be worked on. The potential transformer secondary circuit should be opened at test blocks or fuses, where provided. *Never* open any part of the secondary circuit of current transformers which are carrying load current until a secure short circuit has been placed across the secondary terminals. Some of the older current transformers are not provided with a terminal strip having an automatic shorting device which operates when the terminal-strip cover is removed, and a jumper must be placed across the terminals before disconnecting the wiring. Too great an emphasis cannot be placed on the importance of being extremely careful not to open the secondary of a current transformer which is in service. Very high voltages are developed which are not only a hazard to life, but may damage the transformer and/or affect its accuracy.

8.1.1. Checking wiring. - Wires in conduit, after being tagged and disconnected at both ends, can be traced or "rung" using a battery and buzzer, ohmmeter, magneto, test lamp, etc., if the wires are not color-coded for identification. Do not use a 1,000- or 2,500- volt insulation resistance meter as insulation may be damaged.

Connections of the instrument transformers in the power circuit should be checked, noting the polarity. Polarity markings are conventionally white and may be paint or white porcelain buttons. The terminals may also be marked H1 and X1 to denote polarity; e.g., at any instant, if current is entering at H1, it will be leaving at X1. Although cases of incorrect polarity marking of instrument transformers have been found, the polarity can be assumed correct.

After the sketch of the wiring as found has been made, it should be compared with the Denver drawing or the appropriate diagram in this bulletin, noting carefully every connection and the polarities of transformers. With regard to polarities, if *all* polarities are reversed, the connection is still correct. Similarly, a proper connection results if *all* connections at the meter are reversed. With regard to polarity, or proper direction of connections to meter terminals, it should be found that connections to the terminals or studs will be symmetrical unless someone has changed internal meter connections. It is not impossible that this condition may be found, since an error in wiring may have been corrected by shifting connections *within* the meter.

direction under all load conditions. This check will be of most value if a load condition of less than 50-percent power factor can be observed. Only a physical check will verify that the meter is connected to the proper transformers, and has not been cross-phased or connected to the wrong transformers such as those of another phase or circuit.

8.1.2. Other means of verifying connections. - In the case of poly-phase watt-hour meters supplied from instrument transformers, any method of complete checking by changing connections at the meter and noting results is complicated, and except when done by an experienced man, is of doubtful certainty. The physical checking of connections outlined above is usually no less laborious, but results are certain. Therefore, the method of tracing the wiring, sketching connections, and comparing with a correct diagram is strongly recommended in all cases. However, there may be occasions where safety considerations will prevent access to the instrument transformers, or for other reasons the wiring cannot be physically verified. For these reasons, some expedient checks are given that will give fair assurance of correct connections. Only simple checks which can be performed readily are outlined.

8.1.2.1. Single-phase Meters. No check is possible except to verify that the meter runs in the forward

8.1.2.2. 3-phase, 4-wire, 3-element Meters. (Figure 14). As in the case of single-phase meters, checking by simple means is limited to observing for proper rotation direction at all load conditions (under low power-factor condition if possible), taking each element individually.

8.1.2.3. 3-phase, 3-wire, 2-element Meters. (Figure 11). An inherent characteristic of this metering circuit lends itself to checking by means of shifting connections. On loads having a lagging power factor greater than 50-percent, both elements rotate forward, whereas on less than 50-percent power factor, one element tends to rotate backward, and will do so if the potential circuit of the other element is disconnected.

A power factor of 50-percent or less is not normally encountered in loaded power circuits. Loads such as an induction motor running with no load or a very light load, or a synchronous motor partly loaded and underexcited, will draw current at less than 50-percent power factor. Also, a generator operated at part load with strong excitation (field) can be made to supply power at less than 50- percent power factor. The following check procedures are fairly reliable if the load is reasonably well balanced and the meter is connected to the proper set of instrument transformers:

(1) On a load whose power factor is known to be greater than 50-percent, observe the rotation of each element while the potential circuit of the other element is disconnected. If connections are correct, the rotation will be forward on both, but one will be slower than the other, depending on the power factor. Next, arrange for a power factor of less than 50-percent in the power circuit being metered. The element of the meter that was the slower on the test above 50-percent power factor should now rotate in the reverse direction, while the faster element will still rotate forward.

(2) Another check that has been used, but which is not very conclusive when instrument transformers are involved, is to reverse potential connections a and c (Figure 11) at the meter. If the meter previously rotated forward, and rotation ceases after changing connections, the original connection is presumed correct.

8.2. CHECKING INSTRUMENT TRANSFORMER BURDEN. In order that the meter constants may be verified, the ratios of instrument transformers should be checked against their nameplates at the time the wiring is being traced. Also, at the same time note the capacity and other data on the nameplate. If the rated burden (load capacity, which is usually given in volt-amperes) is exceeded by the meters, instruments, relays, etc., connected to an instrument transformer, the ratio and phase-angle errors may be too great for accurate metering purposes. In some cases separate instrument transformers are used for metering purposes, and others installed for instruments and relays. Cases may be found, however, where equipment has been added since the original installation, and whenever it is suspected that the transformer capacity has been exceeded, the burdens of the connected instruments should be determined from the manufacturers' instruction booklets or measured by connecting a voltmeter, an ammeter, and a wattmeter ahead of the normal burden.

Ordinarily relays or other instruments are not permitted to be connected to single secondary current transformers or potential transformers installed for metering purposes. The burden on metering transformers should be kept as low as possible to accomplish satisfactory metering accuracy.

8.3. CREEP. The disk of a meter may move, either forward or backward, when all load is disconnected. A meter in service is considered to creep when, with all load wires disconnected, and test voltage applied, the moving element makes one revolution in 10 minutes or less. (ANSI Standards, C12-1965.) Meter disks usually have holes or slots punched in them to stop creep when the holes or slots reach a position directly under the potential coil pole. Observation of creep should, therefore, be based upon at least one complete revolution. Creeping may be caused by:

(1) Light-load adjustment used to compensate for instead of removing friction. Examine for friction. If the friction has since disappeared, or is found and eliminated, the meter will be found fast on light load under test, and the creep will disappear when the meter is adjusted at light load.

(2) Short-circuited turns in potential coil. In this case the meter will be found inaccurate at low power factor. Replace coil or entire electromagnet.

(3) Vibration. Remove cause of vibration. Move meter.

(4) Stray fields either internal or external.

(5) Too high voltage which has the same effect as overcompensation of light-load adjustment.

(6) The potential circuit being connected on the load side of the meter.

(7) Short-circuited turns in current coils. Replace coil or entire electromagnet.

(8) Mechanical disarrangement of the electromagnetic circuit.

A high-resistance short or ground in the customer's circuit can cause a turning of the rotating element which may be mistaken for creeping; therefore, residence wiring should be isolated from the meter when checking for creep.

Although the definition of creep permits one revolution in 10 minutes or less, the serviceman should persevere in eliminating any tendency of a meter to creep.

IX. METER SERVICING.

9.1. "AS FOUND" TEST. Before servicing a meter, the "as found" test (Paragraph 10.4) should have been made with the least disturbance possible. The cover should be left in place until this test has been made and recorded, if it is possible to make the necessary connections without removing the cover.

Servicing as discussed herein is defined as cleaning, along with a mechanical and electrical inspection.

9.2. CLEANING. After the cover has been removed, it should be cleaned and a new gasket fitted if needed. In localities where spiders and other small insects are present in large quantities, or there is much fine dust, it is particularly important that all cracks and openings be tightly sealed. The interior of the meter should be thoroughly cleaned of all dust and foreign material. A small hand bellows and camel's hair brush will be useful in removing dust. The air gaps may be inspected while directing a flashlight beam toward the rear of the meter or onto a piece of white paper placed behind the element. Dirt may be removed from the air gaps by using a folded piece of paper. Foreign magnetic particles adhering to the permanent magnets may be removed with a thin brass or phosphor bronze magnet cleaner having a steel edge or button insert.

CAUTION: Do not use a magnet cleaner such as the above, which has a magnetic section, in the gaps of Alnico magnets. Other precautions to observe in connection with Alnico magnets are to avoid striking them, to never disassemble or remove the magnets, and to never bridge the gaps with any magnetic material.

9.3. BEARINGS. Bearings should be disassembled so that all parts can be cleaned and inspected. Special wrenches are usually required for removing pivots. Corn pith is an aid in cleaning pivots. A solvent such as Chlorothene may be required to dissolve gummed oil deposits. An orangewood stick or even a toothpick may be used to clean out the top bearing guide sleeve in the shaft.

Jewels, balls, and pivots are best inspected with a microscope or high-power jeweler's glass, if available. Jewels crack, balls wear flat, and pivot points become rounded excessively these are defects to examine for when inspecting bearings. A cracked or rough jewel may often be detected by feeling the surface of the depression in the jewel with a *sharp* sewing needle. This method is not recommended because of danger of scratching the jewel, and should be avoided if a glass of high magnification is available. If a reddish powder has formed in a bearing, it is certain evidence of trouble.

Meter	Standard
5	9
10	18
15	27
20	36
or	or
5(n)	9(n)

where n = any reasonable number.

Whenever it is necessary to replace a jewel, the companion pivot (or ball) should also be replaced because it is sure to have been damaged. Pivots are screwed into the shaft and require a special wrench to remove. Jewels on the shaft are usually a slip fit and a special tool is very useful in removing and replacing them, though not absolutely necessary.

Care should be exercised in handling balls and pivots to protect them from rusting. If balls or pivots are covered with a protective grease film, it should not be removed until just before installation. Use tweezers to handle and do *not* touch with the *fingers.* One small drop of jewel (or high-quality clock) oil should be placed in the jewel of the pivot-jewel type of lower bearing. *Do not* use oil in the jewel-ball-jewel type. *Do not* oil top bearings. When reassembling bottom bearings, check the centering of the disk in the air gap and adjust if needed. The top bearing plug should not be lowered so much that its shoulder touches the end of the shaft.

9.4. REGISTERS AND GEARS. Register faces may be cleaned with a damp cloth. Alignment of pointers should be adjusted if required. The gears may be washed with a solvent or merely blown out and thoroughly inspected for foreign particles in the teeth as the case may require. Gear teeth may be cleaned with a small stiff brush (toothbrush) or a sharpened piece of softwood. Do not oil registers. Free motion of the gearing can be checked by spinning with the fingers.

When replacing the register in a meter, the mesh of the first wheel with the worm (or pinion) must be carefully observed and adjusted. It should be at the proper height to center on the shaft worm (or pinion), and must have a loose mesh or "backlash." One-third to one-half the depth of the worm (or pinion) teeth is a proper mesh - just enough so that the first wheel cannot be forced to slip when moved by the fingers.

X. TEST PROCEDURES AND ADJUSTMENTS.

10.1. TEST RUNS. The test period should be long enough, and sufficient runs made to insure that the determined accuracy is substantially free of human errors. The test period on any run should not be less than 30 seconds and the number of runs not less than three. More than three runs should be taken if necessary to determine a true average for recording. The length of run should be longer on light-load tests to enable accurate reading of the standard, and the meter under test should make more than one revolution to minimize starting and stopping errors. In choosing the length of run, it is often possible to select a number of revolutions of the standard that will be convenient in that the accuracy may be read directly from the standard and not require computation. For instance, 10 revolutions of the standard enables reading directly (on a 100-division dial) to 0.1 percent and estimating to 0.01 percent, 20 revolutions to 0.005 percent, etc. Choosing the number of revolutions of the standard in testing any meter will also be governed by the watt-hour constants of the standard and the meter under test. If the constants are the same or multiples, there is no problem; but when they are not, the choice is limited. For example: Assume you are using a standard with K_h = 1/3 and the meter under test has a K_h of 0.6; possible test runs that will result in integral (whole) revolutions of each meter are limited to the following:

It is, of course, possible to choose any number of revolutions of the meter under test and compute the corresponding standard revolutions (to a sufficient number of decimal places to insure accuracy), but the better plan is to make a choice that will result in an integral number of revolutions on the standard, and when possible, choose a number which will result in a direct accuracy reading, or one involving a minimum of calculations. Not only will the work be speeded up, but the chances of arithmetical errors are minimized.

The test cards, commonly furnished with standards, which tabulate revolutions and percent registration for testing various manufacturers' meters are very convenient. The factory calibration data furnished with the standard should be examined, and if the accuracy of the test requires, allowance for standard errors can be made. Before making the actual runs, load should be applied and the meter under test allowed to run a few minutes if it has been out of service long enough to cool appreciably. The standard also should be given a warmup run, preferably 30 minutes or longer.

From observation of the marking on the disk and construction of the meter, a definite and precise point in the rotation of the meter disk should be decided upon at which the standard will be started and stopped by the hand switch. The point where the forward edge of the black mark on the disk enters the magnet after passing through the gap, or passes a mark on the magnet frame, is a common choice. The stationary reference point or mark should be as close to the disk as possible, and the operator should try to maintain his eye in the same position during the run so that parallax error will be a minimum. Very little practice in the use of the hand switch is required to obtain consistent and close results. Any undue inconsistency in readings obtained should be interpreted as an indication of trouble in the meter, perhaps of an intermittent nature.

Test	Current coil connections	Percent current	Percent power factor lagging)
1	Series	100	100
2	Series	100	50
3	Series	10	100
4	Separately	100	100
5	Separately	100	50
6	Separately	*	100
7	Series	50	100

*10 percent for single-element meters, 20 percent for 2-element meters, 30 percent for 3-element meters.

10.2. TEST LOADING. No special precautions are necessary when the load is a resistance box. In the case of other resistors, they must, if course, have sufficient current-carrying and adequate ventilation for cooling. In the case of "phantom" or transformer load devices, the secondary circuit should always include resistance that is large compared to the reactance of the meter current coils to avoid waveform and phase-angle errors. Phantom-load devices as marketed by the better-known meter-test-equipment manufactures are generally satisfactory in this respect.

10.3. ADJUSTMENTS, GENERAL. If the "as found" test shows inaccuracy, and if the subsequent cleaning and mechanical servicing does not remove the errors, it will be necessary to make adjustments. It may also be found that a meter will be inaccurate after servicing although the "as found" test did not disclose errors - the meter may have been adjusted to compensate for friction which has been removed in servicing. At this point, it will be helpful to the tester in diagnosing the adjustments required, and planning the sequence of making adjustments, to discuss the interrelationship of adjustments.

The light-load adjustment alters the driving torque of the meter which must overcome friction and rotate the disk. The permanent magnets acting as a brake to regulate the speed is the full-load adjustment. The adjustment of either affects the speed at both loads. The effect of the light-load adjustment is inversely proportional to the load; i.e., one-tenth as much at full load as at light load. The effect of the full-load adjustment on the percent registration of a meter is the same at all loads; i.e., if the meter is 3 percent fast at both full and light loads, adjusting the magnets will correct the registration at both points.

Although fairly obvious, it should be mentioned here that adjusting any magnet in a multielement meter affects the speed of all elements of the meter, since the disks are on a common shaft. In other words, the light-load adjustment on any element affects only that element, whereas the full-load adjustment on any element affects all elements. In fact, in some meters not all of the magnets are adjustable. Thus, it will be seen that unless the same percent error exists at both loads, it is usually better to make the light-load adjustment first.

For the purposes of this discussion, it is assumed that the lag or power-factor adjustment of each element has been checked and found correct, or has been appropriately adjusted. The lag adjustment, if properly made at the factory, does not ordinarily change in service. Therefore, no lag adjustments should be made until the tester is absolutely certain of their need. After making a light-load adjustment on each element, the torque of all elements should be in fair balance, but at this point the balance should be checked by bucking elements as described in Paragraph 10.5.3.

It is now in order to make a full-load adjustment at 100-percent current with the current coils of all elements in series. Next, the overall 50-percent power-factor and light-load registration should be checked, followed by checks on individual elements. If lag readjustments are necessary, both light and full loads and balance must be rechecked. If only light-load adjustments are necessary, balance and full load must be rechecked. Step-by-step test procedure is outlined in the following paragraphs.

10.4. "AS FOUND" TEST. Since it is extremely important to know of any past inaccuracy of meters measuring large blocks of power or used for billing purposes, it is essential that an "as found" test be made, and that nothing be disturbed before making this test. Also, the information gathered in this test will be valuable in locating the source of any inaccuracy found. The following procedure is recommended:

(1) Examine all wiring, seals, and other external conditions without disturbing anything. Record any unusual conditions found and anything that might affect meter performance. Also, record the meter reading and time of removing from service.

(2) Make connections for testing without disturbing anything that can be avoided.

(3) With potential coils excited and no current in the current coils, note whether meter creeps. Record.

(4) With all potential coils excited, make following tests to obtain data on overall performance and performance of each element separately. Record results on Form 105 (Figure 23).

Three runs should be made at each of the above test points and the results averaged. The 50-percent lagging power factor and the separate element tests can be omitted if the "as found" condition shows no appreciable change from proceeding tests.

10.5. CALIBRATION TEST. Information obtained in the "as found" test should be analyzed and used as a guide to assist in locating any existing trouble during the cleaning and inspection of the meter which precedes a Calibration test. Refer to Paragraphs 9.2, 9.3, and 9.4, regarding cleaning and inspection. After cleaning and performing any other maintenance required, the following test runs should be made regardless of whether or not the "as found" test was satisfactory. If results of this test are within the limits specified in Paragraph 6.1, record in the "as left" section of Form 105. Otherwise, make adjustments and repeat runs as described below until specified accuracy is obtained. Note any repairs and adjustments made in the appropriate spaces on Form 105.

10.5.1. Overall test. - With all potential coils connected in parallel and current coils in series, make the following runs:

(1) 100-percent current, 100-percent power factor

(2) 50-percent current, 100-percent power factor

(3) 10-percent current, 100-percent power factor

If no appreciable changes from the last test are found, proceed to inspect, clean, and make "as left" check. Otherwise, do not make any adjustments at this point but proceed.

10.5.2. Individual element test. - Required for laboratory calibration of meters, or if meter proves faulty. Same as (1), (2), and (3) above with all potential coils excited, but taking one element at a time with no current in the other elements. This test should be made even if the overall test was satisfactory because the individual elements may have errors that compensate in an overall test. If errors are found in any element on individual test, adjustments should be made as discussed in previous paragraphs and runs repeated until each element has been adjusted within prescribed limits, then proceed.

10.5.3. Balance check. - Required for laboratory calibration of meters, or if meter proves faulty. (Not applicable to single-phase meters.) The individual element test should have established good quality of elements; however, this simple balance check is recommended to assure that the elements are closely matched. Take two elements at a time and oppose or "buck" them while varying the load current from 10 to 100 percent, and also at 100-percent current, 50-percent power factor. The "bucking" condition is obtained by reversing the current connections of either element. The disk should stand still; or rotate very slowly in one direction, stop, and reverse, as the load is varied from 10 to 100-percent. If the rotation is always in the same direction and exceeds 1 rpm, readjustment of individual elements is indicated. However, proceed with the bucking test at 50-percent power factor first to determine whether the inequality is due to light-load or power-factor (lag) adjustment. From an analysis of the behavior on this test and the percent registration records of the individual element test, it will not be difficult to decide which element and which adjustment should be changed to achieve proper balance at all loads and at 50-percent power factor. The accuracy of any individual element should, of course, be maintained within the prescribed limits.

10.5.4. Final overall test. - Following the individual element test and bucking check, an overall test run should be made as in Paragraph 10.5.1. if the results are satisfactory (within the limits prescribed in Paragraph 6.1), record the data for each element and overall on Power O&M Form 105 (Figure 23) in the "as left" section. If the overall test does not fall within prescribed accuracy limits, it will be necessary to go back, readjust the individual elements, and repeat the balance check and overall test. In readjusting the individual elements to adjust overall registration, all elements should be changed by equal amounts unless it is known from previous runs that some elements can stand a greater change in the required direction than others.

10.6. CONCLUDING THE TEST. After all adjustments have been made, the final calibration data recorded, and the meter is ready to be placed back in service, there are still several points to be covered:

10.6.1. Resetting register. - To compensate for the registration lost while the meter was out of service, it may be desirable to reset the meter dial to an appropriate reading cornputed from the length of time and average load shown by indicating meters during the meter outage. Or, the dial may be left as is and the station operator given the necessary data for making adjustments in station records. This would include the reading at the beginning of the outage, times of beginning and end of outage, and reading when placed back in service. The register is not to be removed after the final test to adjust for unmetered energy.

10.6.2. Removal of test equipment. - After reconnecting the meter and removing all jumpers, replacing fuses, etc., recheck all work carefully to see that all connections and equipment have been restored to proper conditions. Be especially careful not to leave any test jumpers connected, or test switches in wrong positions.

10.6.3. Check potential. - Check that potential is present on all elements by using a voltmeter, or by disconnecting potential leads at meter studs. If the meter is equipped with small potential indicating lamps, check that all are operating.

10.6.4. Meter seal. - Seal the meter in the presence of the customer's representative, if a billing meter.

10.6.5. Test records. - Make sure test records are complete and signed by both the Bureau and customer representatives and that a signed copy is furnished for the customer's files, if a billing meter.

10.6.6. Cleanup. Replace any equipment or furniture moved for the test, and clean up the area if necessary.

10.6.7. Customer relations. Every effort should be made to maintain and enhance good relations with the customer, not only by courtesy, but by a thorough and efficient test procedure in which the representative is offered an opportunity to participate.

10.7. METER TEST RECORDS. As mentioned in the paragraphs on testing, Bureau Power O&M Form 105, "Watt-hour and Demand Meter Test Report," Figure 23, or other revision thereof, is used to record "as found" and "as left" test results. In addition, there is provision for entering meter data, servicing performed, adjustments made, etc., as will be seen on the sample copy of the form (Figure 23). It is important that all pertinent information regarding the test be entered on the form. In the case of meters used for billing purposes, the original signed copy should be preserved in a permanent file for at least as long as the duration of the contract for sale of power. Meter maintenance and test records should be included in the maintenance card file so that tests will be scheduled at regular intervals not greater than 1 year.

Figure 23

PO&M-105 (2-73)
Bureau of Reclamation

WATT-HOUR AND DEMAND METER TEST REPORT

LOCATION	CIRCUIT	DATE
Rainbow #2	Montana Power Company	5-5-71

WATT-HOUR METER		DEMAND METER	
Manufacturer	General Elec.		
Serial No.	1269039		
Type	DG2	Recording	
Style/Model	8WDG2JAS190		
Class			
Multiplier	10,000	80,000	
Primary K_h		KW Full Scale	78,500
Secondary K_h	0.9	Dem. Interval	30
Amps	2.5	Chart No.	6724A
Volts	120	Contact Device	D13
Elements	2	Gear Ratio 10/9	
Reg. Ratio	13-8/9	1 rev (8 impulses) =	
1st Reduction	100	111-1/9 meter revs	
Detent	Yes		
C.T. Ratio	80/1	P.T. Ratio	1,000/1

METER READINGS			TIME
As found			
Dial	0325.6		8:30 a.m.
Demand			p.m.
Revolutions	1	Seconds	117
As left			
Dial	0326.6		11:30 a.m.
Demand			p.m.
Revolutions	1	Seconds	52

DEMAND METER TESTS	AS FOUND	AS LEFT
Revolutions	100	
Demand	0.18	
Revolutions		
Demand		
% Accuracy	100.0	

STANDARD DATA — Correction

Manufacturer	Model	Serial Number
GE	IB-10	6009523

VOLTAGE READINGS PHASE	VOLTS	PHASE ANGLE I_1	I_2	I_3
1-2		(Load too small)		
2-3				
3-1	111			
1-N	110			
2-N				
3-N	110			

CURRENT READINGS

PHASE	PRIMARY	SECONDARY	% BURDEN
A	55	0.7	56
B	60		
C	60	0.74	59

CONDITION OF METER

General OK	Register Cleaned
Demand Mechanism OK	Upper Bearing Replaced
Jewels & Ball Cleaned - replaced	Rotation of Individual Elements OK
Potential Creep No	

METER REGISTRATION

TEST	STANDARD K_h	STANDARD Amps.	METER Elements	METER Revs.	AS FOUND Standard	AS FOUND % Registration	AS LEFT Standard	AS LEFT % Registration
Full Load Series, 1.0 P.F.	.6	2.5	2	20	15.00	100.0	14.97	100.2
Light Load Series, 1.0 P.F.	.12	0.25		4	14.92	100.53	14.98	100.13
Power Factor Series, -.5 P.F.	.6	2.5		20	14.98	100.13	14.97	100.2
Full Load Individual Elements at 1.0 P.F.			Upper	5	7.47	100.4	7.46	100.53
			Lower	5	7.53	99.6	7.48	100.27
Light Load Individual Elements at 1.0 P.F.			Upper	1	7.50	100.0	7.47	100.4
			Lower	1	7.52	99.73	7.49	100.13
Power Factor Individual Elements at -.5 P.F.			Upper	5	7.50	100.0	7.47	100.4
			Lower	5	7.45	100.67	7.47	100.4

$$\text{Dial Adjustment} = \frac{0.9 \times 0.83 \times 60 \times 3 \times 8}{1{,}000} = 1.0$$

0325.6 Dial Reading As Found
1.0 +Dial Adjustment
0326.6 Dial Reading As Left

Remarks

Tested by Sam Rapos, USBR

Assisted by

XI. DEMAND AND TOTALIZING METERS

11.1. INDICATING DEMAND METER. The indicating type of demand meter is commonly used by utilities and consists of an attachment to the customer's watt-hour meter which indicates the maximum demand that has occurred since the last reading of the meter when the demand indicator was reset to zero. There is no indication of when the maximum demand occurred. The most common type consists of a pointer that is held by friction at the highest point to which it has been pushed by a mechanism geared to the watt-hour meter disk shaft during the demand interval. A small synchronous (Telechron) motor resets the actuating mechanism to zero at the end of each demand interval. Demand intervals are normally 30 or 15 minutes, and maximum demand may be defined as the maximum integrated (average) demand in kilowatts for the specified demand interval.

11.2. RECORDING DEMAND METERS. Demand meters as used in Bureau plants usually record the maximum demand on a chart or tape. Brief descriptions of some of the most common types follow:

11.2.1. Strip-chart recorders. - The General Electric Type DG and Westinghouse Type R recording demand meters are quite similar and are probably the most frequently encountered in Bureau installations. They consist of a 2- or 3-element watt-hour meter and a strip-chart on which a pen draws a line during each demand interval. The length of this line shows the maximum demand. Thus, there is a complete record of demand versus time. Briefly, the functioning of this type of meter is as follows: A pen-driving gear train mechanism geared to the watt-hour meter disk shaft moves the pen across the chart for 30 minutes, in the case of a 30-minute demand interval. At the end of this time, a Telechron motor or clock device returns the pen to zero and advances the chart approximately 1/16 inch for the next line to be drawn. A quirk or "pot hook" at the end of the inked line is produced just before the pen returns to zero to facilitate reading the maximum. A record of both 15- and 30-minute demand may be obtained in this meter by arranging to advance the chart at the end of 15 minutes, which produces a step in the inked line.

Maintenance and servicing of the demand part of the meter is purely mechanical and should only be attempted after familiarization with the manufacturer's instructions. The watt-hour element is identical to meters without the demand feature and is tested and serviced in the same manner, making sure that during calibration the demand device is operated so that the additional load imposed by it is taken into account.

The most common trouble with this type of meter is improper inking. The inking system must be kept clean, and only the proper type of ink used.

If the pen does not return to zero properly or pick up ink on the return; if the pen mechanism gets "out of time" or trips at the wrong time; if the chart does not advance correctly; or any other malfunction develops, the manufacturer's instructions should be consulted before making adjust-merits. Some early types of recording demand meters are now obsolete and are continuing sources of trouble. In such instances, it is recommended that they be replaced by a modern type of better design.

Recording and indicating demand watt-hour meters with pen drive systems sometimes have difficulties related to the drive system. When a malfunction occurs, the pen will fail to give readings or give excessive readings depending on the part that fails. Improper readings cause extra trips on the part of maintenance per-sonnel. A test which can be performed at the time the meter is tested can apparently predict failures. One of the principal parts of the pen drive system is the interval clock. To make the test, a variable voltage is applied to the motor; the voltage is raised from the zero point until the motor starts and then it is lowered until it stops. Motors in the best condition have the largest start-stop interval. Some experimentation may be required to determine the proper interval for a given watt-hour meter. Past results show that an interval of less than 35 volts indicates a faulty motor for General Electric VM3-A or VM4-A meters.

Equipment suggested for the test is a 120-volt variac, an analyzer or voltmeter, a fused test cord with jacks for the analyzer or voltmeter and plugs attached with solder for the G.E. Clock, M-30 demand clock, and Westinghouse Clock.

11.2.2. Impulse-type demand meter. - Another type of demand meter is a recorder operated by impulses received from a contact device installed in one or more watt-hour meters. This recorder totalizes the received impulses during the demand interval and makes a record on a chart or tape. The General Electric Type G records maximum demands as a series of inked lines on a continuously rotating circular chart, whereas the General Electric Type BR and Westinghouse WA use a strip chart and inking system like the Type DG and Type R, respectively. The General Electric Type PD prints numerals on a paper tape at the end of each demand interval. These types also have a counter or register that records the total number of impulses received. Thus, there is a record also of kilowatt-hours, which in the case of several connected meters serves to totalize kilowatt-hours.

Modern impulse-type demand recorders register the demand on magnetic tape or punched paper tape which eliminates the need for visual chart scanning by providing data in a form suitable for the utilization of automatic data-handling techniques. The tape is a recording medium for interval time pulses and kilowatt-hour or kilovar-hour pulses. The demand information is translated automatically into digital form on punched cards or paper tape for direct entry into billing computers. Examples of this equipment are the Westinghouse Types WR-2 and WR-4 demand recorders, the Duncan Types BTR-2W and 4W, the General Electric PDM recorder and PDT translator making up the Pulscript Demand Recording System, and the Sangamo Type DPR, punched paper tape recorder.

11.2.3. Totalizing demand meter. - As mentioned above, energy measurements from several watt-hour meters may be totalized on a registar that is actuated by impulses received from contact devices installed in the individual watt-hour meters. The meter constants, if different, must be taken into account by proper choice of contact device gear ratio and number of points on the cam which operates the contacts. Another method of totalizing energy in several circuits of the same voltage is to use a single watt-hour meter whose current coils are connected to paralleled secondaries of current transformers in the circuits to be totalized. The current transformers must all be the same ratio, or auxiliary current transformers must be introduced into the secondary circuits to achieve identical ratios.

Still another method of totalizing is to use a meter with 4, 6, 8, 9, 12, etc., elements, the addition being performed by adding the torques produced by elements in the various circuits by means of a common shaft or two coupled shafts. The contact device should be a break-before-make type providing a form "C" pulse and the contacts should be mercury-wetted (to eliminate contact bounce) in order to provide for maximum accuracy. A minimum time of 0.8 second is necessary between outgoing pulses from the totalizer to the recorder. This permits sufficient space between the pulses recorded on magnetic tape for translation purposes.

REFERENCES

1. Instruction sheets issued by the manufacturer for a specific meter should have been furnished with the equipment and are the best guide to use in servicing.

2. The Edison Electric Institute, 750 Third Avenue, New York, New York 10017, has published the Electrical Metermen's Handbook, which is a compilation of data on different manufacturers' meters, and also contains general information on testing and test equipment.

3. Electric Power Metering, by A. E. Knowlton, is an excellent book on all phases of metering theory and practice.

4. The Code for Electricity Metering, ANSI Standards, C12-1965, is the accepted standard prescribing construction details, acceptance test procedures, accuracy requirements, and service tests of meters and associated auxiliary equipment.

APPENDIX A

SUGGESTED GUIDELINES FOR MAINTAINING REVENUE METERING EQUIPMENT

A-1. TYPES OF METER TESTS.

a. Routine Field. - Meters are tested and adjusted by the series- parallel method using the procedure outlined herein. The only correction factor used is that of the rotating standard. Test points are 10, 20, 50, and 100-percent amps, 1.0 power factor and 100-percent test amps, 50-percent lagging power factor.

b. Precise Field. - Meters are tested as in routine field tests except their adjustment includes correction for instrument transformer and test equipment errors.

c. Laboratory. - The meter is tested in the laboratory. Tests include individual element as well as all elements combined. Tests are at 10, 20, 50, and 100-percent test amps, 1.0 power factor and 100 percent test amps, 50-percent power factor. After the tests and adjustments are completed, the meter is operated for 7 days if possible before returning to regular service.

Instructions for reading meters should be issued by the appropriate regional or project office.

A-2. FREQUENCY OF METER TESTS. - The intent of this paragraph is to insure proper testing and maintenance on the more important metering installations. Therefore, in line with utility practices, meter tests should be on the following schedule:

Type of load	Time between tests
Preference customers	
100,000 kW and above	6 months
Below 100,00 kW	12 months
Project loads	
100,000 kW and above	6 months
100 kW to 100,000 kW	12 months
Below 100 kW, 3 phase	24 months
Single phase, residential	60 months

In addition, all new equipment scheduled for installation should be laboratory tested and operated for 7 days on test, time permitting, prior to being placed in service.

A-3. ROTATING STANDARDS.

a. Minimum Required. - Each office engaged in the testing and maintenance of revenue metering equipment should maintain a minimum of three rotating standards; one reference and two (or more) field standards. The reference standard, chosen for stability and reliability, should be maintained in the meter shop and not used for routine field testing. Field standards should be used to calibrate revenue meters in the field and should be compared with the reference standard before, after, and at least once every 2 weeks during meter testing to assure that the field standard has not been damaged when transporting between locations. If this comparison shows a change of more than 0.15 percent from previous comparisons of the two standards, meter tests should be suspended until the difference is resolved. All rotating standards should be calibrated at least once every 12 months.

b. Calibration. - Detailed require-merits for improved accuracy in the calibration of rotating standards are provided in "Code for Electricity Metering." 5th Edition or later, ANSI Standards C12 published by the American National Standards Institute (formerly the United States of America Standards Institute formerly the American Standards Association). These calibration requirements should be adhered to. The following paragraphs modify them as necessary to meet the needs in the Bureau of Reclamation.

(1) *Laboratory Conditions.*

(a) *Laboratory restrictions.* - The laboratory should be restricted to personnel engaged in meter calibration work.

(b) *Contamination or other interferences.* - The laboratory shall be free of atmospheric contamination, mechanical disturbances or noises, and electrical or magnetic interferences in order that the results of the calibration work will not be adversely affected.

(c) *Temperature.* - The temperature should be maintained at approximately 23°C, the temperature at which the standard cells are calibrated by the National Bureau of Standards. Note: For each 4° C change in temperature, the voltage of the standard cell changes by approximately 10 microvolts.

(d) *Humidity.* - The ideal humidity range is 40 to 55 percent. Excessive humidity should be avoided.

(e) *Power supplies.* - Both the d-c and a-c power supplies should be closely regulated. The d-c supply shall be free from ripple. The a-c supply shall be substantially free from waveform distortion with the RMS waveform distortion not exceeding one percent of the magnitude of the fundamental. The phase relationship of the combined current and voltage supplies shall be adjustable.

(2) *Laboratory Equipment.*

(a) *Accuracy classification.* - All equipment used in the calibration of rotating standards shall be of the highest accuracy classification obtainable, preferably 0.1 or 0.25.

(b) *Maintenance.* - All equipment should be maintained in the laboratory, handled as little as possi-hie, and not used for routine measurements at locations outside the laboratory.

(c) *Reference standard.* - A rotating standard, chosen for stability, should be maintained in the laboratory as a reference standard. This should be used for the checking of rotating standards when regular calibration tests are not scheduled.

(d) *Standard cells.* - A minimum of three unsaturated cadmium cells should be maintained: one (chosen for stability) should be designated as the working cell; the others as reference cells. The working cell should be retained in the laboratory, maintained at $23^{\circ}C \pm 2^{\circ}C$, and disturbed as little as possible. It should not be shipped for NBS certification. The reference cells should be used to calibrate the working cell.

The voltages of the reference cells should be compared with that of the working cell immediately before shipping for certification purposes and upon return after first checking that their voltages have stabilized. The voltage of the working cell is to be determined by comparison to those of the certified reference cells. Each curve should show a uniform negative slope which represents a decrease in voltage with time. Any radical change in the curve will be cause for replacing the cell. Any cell whose voltage is found to be unstable should be replaced.

(e) *Standard resistors.* -Sufficient standard resistors should be maintained in order that the complete range of tests necessary for the calibration of rotating standards can be accurately performed.

(f) DC *ratio devices.* - DC ratio devices should meet or exceed the requirements of ANSI Standards C12, paragraph 4.5.6 "DC Ratio Devices."

(g) AC *ratio devices.* - AC ratio devices should meet or exceed the requirements of ANSI Standards C12, paragraph 4.5.7 "AC Ratio Devices."

(h) *AC-DC transfer standards.* -AC-DC transfer standards should meet or exceed the requirements of ANSI Standards C12, paragraph 4.5.8 "AC-DC Transfer Standards."

(i) *Time interval.* - The standard time interval used should be traceable to NBS.

(3) *Periodic Verification of Reference Standards.* Laboratory equipment should be checked by NBS (or other competent laboratory having NBS traceability) in accordance with the following schedule:

(a) *Standard cells.*

(aa) *Working cell.* - Only when purchased or used as reference cell prior to being assigned as working cell.

(bb) *Reference cells.* - At least once each year.

(b) *Standard resistors.* - Every 2 years.

(c) *Standards for ratio and for transfer (a-c or d-c).* These should be verified by NBS or an independent laboratory whenever their self-checking features fail to respond or whenever there is reason to question their performance.

(4) *Indicating Instruments.* - Alternating-current ammeters, voltmeters, wattmeters of appropriate ranges and of high quality are required as laboratory working standards.

(a) *Accuracy class.* - Indicating instruments should have an ANSI accuracy class of 0.1 or 0.25.

(b) *Stability.* The instrument should be capable of being read within 5 seconds after a step change is made.

(c) *Repeatability.* The instrument must demonstrate repeatability for several successive readings of identical measurements.

(d) *Intemal heating.* - Instruments should be energized only during testing in order to avoid changes in accuracy because of internal heating.

(5) *Calibration Procedures.* - Two different, independent procedures for the calibrating rotating standards are possible.

(a) *Direct comparison.* The standard wattmeter is accurately calibrated by using several combinations of precisely measured d-c volts and currents. The rotating standards are then compared to the wattmeter.

The procedure is slow, requires the skill of three or four technicians, and being replaced by the new electronic method (see paragraph (b)). However, since the direct comparison method will be used for some short period of time, it is described in detail.

(aa) *Calibration of standard wattmeter.* - The standard wattmeter is calibrated by using precisely measured values of d-c currents and voltages. The currents are 1.5, 2.5., and 5.0 amperes, while the voltage ranges selected vary between 100 and 125 to correspond with those experienced at the various revenue metering installations.

The test requires the services of four technicians: one to maintain precise voltage; one to maintain precise current; one to accurately read the standard wattmeter, and one to record data. The test circuit is shown in Figure A-1. Using an exact value of current and voltage, five readings (with changes between each) are made on the wattmeter. The polarity of the circuit is then reversed and five additional readings are taken for the same current and voltage values. The average of the ten readings divided

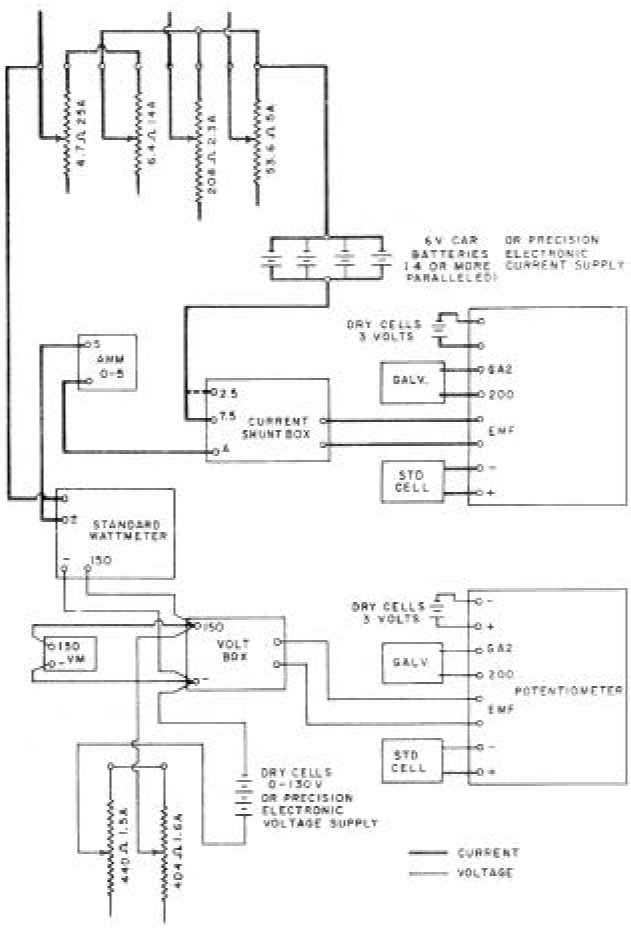


Figure A-1. Calibration of standard wattmeter circuit diagram, direct comparison method.

by the true watts (precise current times precise voltage) gives the correction factor for that combination of voltage and current. Similar tests and calculations are made for other current and voltage combinations, thus providing calibration curves for the standard wattmeter for several voltages. These are then used to calibrate the rotating standards.

(bb) *Calibration of rotating standard.* - The test circuit is shown in Figure A-2, and the rotating standard is to be calibrated for 0.5, 2.5, and 5 amperes at unity power factor and 5 amperes at 50-percent lagging power factor for the range of voltages encountered in revenue meter testing.

A series of five readings of the ammeter, voltmeter, standard wattmeter, rotating standard, and timer for each value of voltage, current, and power factor are required. Each measurement takes three minutes in order to secure better readings on the rotating standard. From these measurements, the following calculations are made in order to determine the correction factors for the rotating standard:

For 5 amp. range on rotating standard:

Calculated revs.

$$= \frac{\text{true watts x time in secs}}{2{,}160}$$

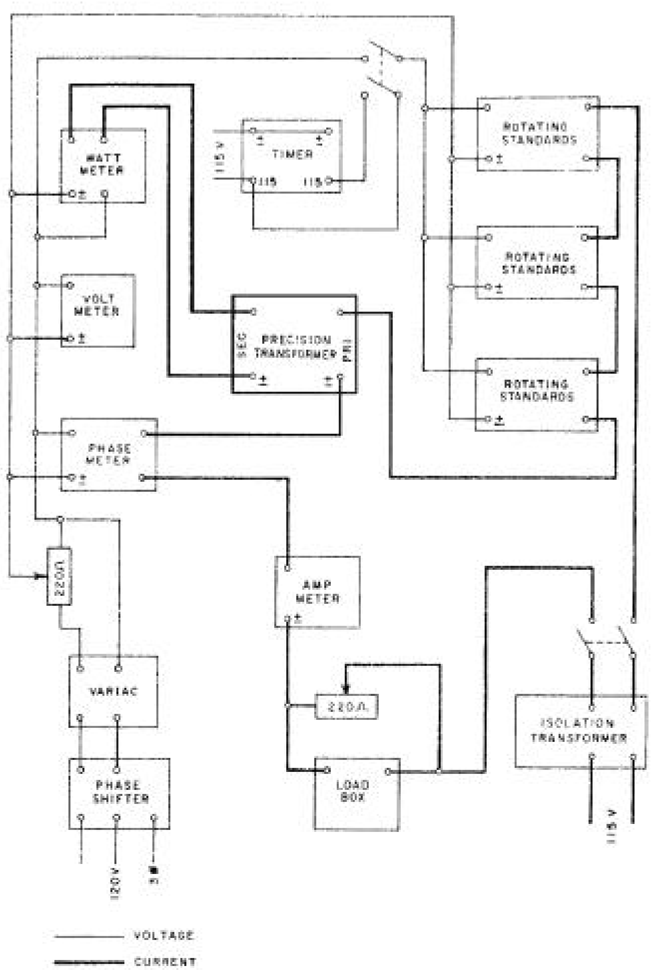


Figure A-2. Calibration of rotating standards.

or, for the I amp range,

Calculated revs.

$$= \frac{\text{true watts x time in secs}}{432}$$

From which the correction factor, C.F. is calculated.

$$\text{C. F.} = \frac{\text{calc. revs.}}{\text{actual revs.}}$$

Where,

true watts = true watts as determined from the calibrated wattmeter.
time in secs = reading of the timer.
actual revs. = reading of rotating standard.

When readings are taken at the 50-percent lag power factor, an additional correction must be made to the true watts. This correction is due to the difference between ac-dc reading of the wattmeter. The corrections for this wattmeter are minus watts, and this is determined by multiplying the reading on the wattmeter by the percent difference from the NBS certificate. The minus watts are then subtracted from the true watts to give actual true watts for the 50-percent lag power factor.

(b) *Electronic or digital method.*

(aa) *Procedure involved.* - The block diagram, Figure A-3, shows the basic schematic for this method. The electronic wattmeter produces a d-c voltage output which is proportional to the input power. Adjustment is such that 600 watts input equals 1 volt d-c output. This output voltage is fed into a high accuracy frequency converter which converts the 1 volt d-c to 10,000 hertz. Thus:

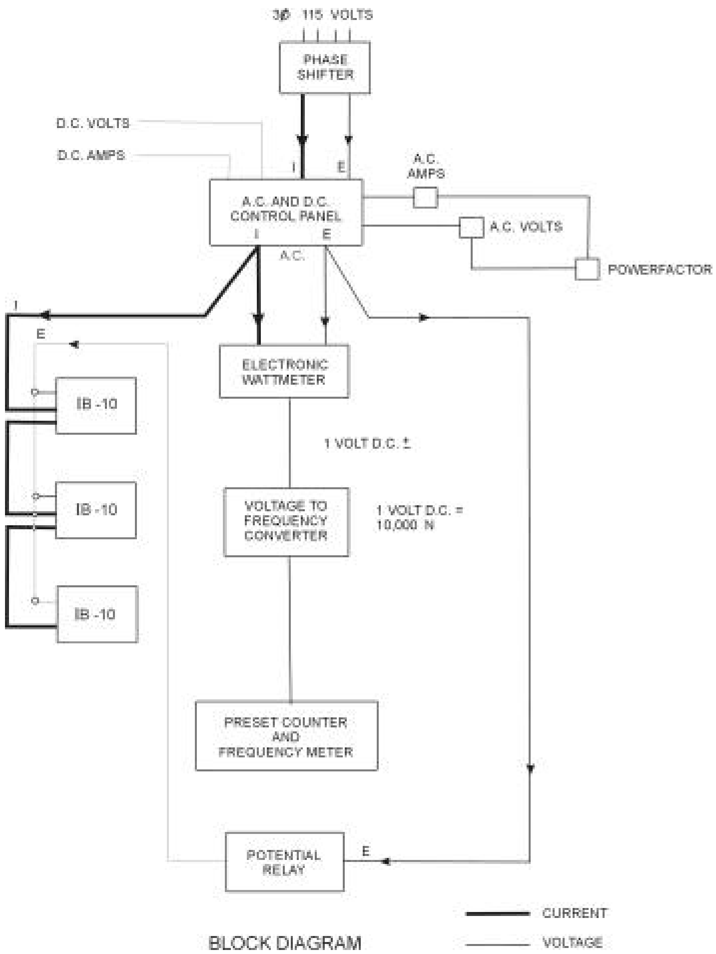


Figure A-3. Calibration of rotating standard, electronic method.

5 amps, 115 volts per second
= 600 watt-seconds
= 10,000 counts

or

$$600 \text{ watt seconds} = \frac{600}{3,600}$$

= 1/6 watt-hours = 10,000 counts

or

1 watt-hour = 60,000 counts.

Since the IB-10 has a K_h = 0.6, one revolution equals 36,000 counts. The count for other values of amperes, volts and power factor would be proportional to the watt-seconds involved.

(bb) Calibration of the test equipment. - The watt-hour calibrator is tested as a unit. Accurately measured values of dc voltage and current are fed into the watt converter (115v, 5 amp., for 600 watts).

The output of the watt converter is fed into the voltage-to-frequency converter whose output is fed into the preset counter operating in the frequency counter mode. The average of the forward and reverse readings is determined. Then, average watt X 1000 over 600 equals the desired count.

Formula:

$$\text{Desired count} = \frac{\text{average watts x 1000}}{600}$$

Correction Factor = C. F.

$$= \frac{\text{Desired Count}}{\text{Average Count}}$$

This correction factor must be combined with any other correction factors involved in the equipment such as CT correction factor, correction factors for the d-c potentiometer, etc., to arrive at the over-all correction factor for the watt-hour calibration standard.

The preset counter has sufficient capacity to permit a check of 600 watts being measured for 3 minutes (1800 watt-minutes).

(cc) *Calibration of rotating standards. -* The preset will be set on the counter, thus allowing the rotating standard to operate for a given number of watt-seconds, for a predetermined voltage and current, the counter representing the true value of watt-seconds. The correction factor for the rotating standard is determined by comparing the reading on the standard to the true watts which it should have read.

(6) *Calibration Reports. -* Each field office should maintain a complete file on the calibration of its standards. One copy of the calibration report should be included with the report of revenue meter tests whenever tests are made at the major interconnections only.

A. PRECISE METER TESTS

A-4. TEST PROCEDURE.

a. Warmup. - Warm up to the standard for at least 1 hour immediately prior to meter tests.

b. Final Clearance. Immediately prior to removing the revenue metering equipment for tests, obtain final clearance from the Power System Dispatcher. Record data required.

c. "As Found" Tests. - Connect the test equipment for single-phase testing and make "as found" tests described below. The demand recorder is to be retained in service throughout the tests unless repairs are necessary. Its indicating register should be reset to its original "as found" reading upon completion of the tests. Do not remove meter covers or disturb the meters prior to the "as found" tests, Record all necessary metering data just prior to removing the metering equipment from service.

(1) *Performance.* Perform "as found" tests for the meters connected:

(a) Potential elements in parallel; current elements in series.

(b) Single phase, single element (when required).

(2) *Tests to Be Performed. -* Test each condition for 0.5, 2.5, and 5.0 amps, unity power factor and 5.0 amps, 50-percent lagging power factor at normal metering voltage. The average of three tests for each current value shall be considered the "as found" correction factor.

d. "As Left" Tests. - Clean, perform maintenance, and adjust the meters as necessary. Make "as left" tets for the same test currents listed in Paragraph c(2) above. The maximum permissible errors allowable are given in Paragraph e below.

e. Permissible Error. - The following limits are to be observed when calibrating metering equipment:

(1) With the potential coils connected in parallel and energized at average metering voltage, and the current coils in series:

	Percent registration
(a) Full load (5 amps) unity power factor	99.7 to 100.3
1 amp unit power factor	99.7 to 100.3
(b) Half load (2.5 amps) unity power factor	99.7 to 100.3
(c) Light load (0.5 amp) unity power factor	99.7 to 100.3
(d) Full load (5 amps) 50% lagging power factor	99.3 to 100.7

(2) Individual elements, tested at average metering voltage: Usually laboratory tests or after major overhaul, not required if "as found" test shows no significant change.

	Percent registration
(a) Full load (5 amps) unity power factor	99.7 to 100.3
(b) Half load (2.5 amps) unity power factor	99.7 to 100.3
(c) Light load (0.5 amp) unity power factor	99.3 to 100.7
(d) Full load (5 amps) 50% lagging power factor	99.3 to 100.7
(e) Stator balance, full load (agreement between individual elements)	99.3 to 100.7

A customer should be permitted to install his standard in the test circuit for comparison purposes *only* if he provides satisfactory evidence that his standard has been properly calibrated within the past 12 months. If this comparison shows an average deviation of more than 0.2-percent between the customer's standard and that of Reclamation, further meter testing will be suspended until the difference has been resolved. If any standard in a group of standards shows a deviation of more than 0.2-percent from the average, or if it appears that it is inaccurate, that standard should be removed from the test and not be used in any tests.

For information on adjustment of General Electric watt-hour meters, see Bulletin No. GET-813G "How to Test and Adjust General Electric A-C Watt-hour Meters."

f. Comparison of Data. - If possible, compare the kwh recorded on the watt-hour meter during the tests with that recorded on the demand meter and/or totalizer cyclometers. Account for any difference. Record all data.

A-5. CONCLUSION OF TEST. - Upon completion of the test:

(1) Check all meter connections, being sure that all voltage and currents from the instrument transformer are restored to the meters. Make stopwatch check of meter as final proof of proper operation.

(2) Replace all seals.

(3) List all test personnel and witnesses and have at least one representative from each party sign the test data.

(4) Immediately report all data taken in Paragraphs A-4 d and f.

(5) Mail three copies of the original handwritten test report to the appropriate office.

B. SUPPLEMENTAL INFORMATION

A-6. METERING CORRECTION FACTOR. - In computing the factor to be used to correct for instrument transformer error, the following procedure should be adhered to:

(1) The agreed upon transformer ratio correction factors and the phase-angle correction factors for each of the CTs and PTs will be used. These should be determined to the nearest one-ten thousandth (0.0001) for the ratio and one-tenth of one degree (0.1o) for the phase-angle.

(2) The net transformer correction factor should be computed to the nearest one-ten thousandth (0.0001) at unity power factor.

(3) Computations to compensate for the effect of the combined instrument transformer correction factors on the meter under test should be carried to the nearest one-ten thousandth (0.0001).

(4) The correction factor of the standard watt-hour meter should be to the nearest one-ten thousandth (0.0001).

(5) The metering correction factor should be recorded to the nearest one-ten thousandth (0.0001).

(6) The results of the tests should be plotted on the graph paper using the following standard coordinates:

abscissa: 1 inch = 1.0 amperes
ordinate: 1 inch = 0.01 = correction factor

These are to be included with the test report.

A-7. METERING VOLTAGE. - The metering voltage to be considered when calibrating the rotating standards should be the average bus voltage which exists during normal Icad conditions referred to secondary side of the potential transformers used for metering.

A-8. DATA. - All pertinent data are to be recorded immediately prior to removing the equipment from service for testing and immediately after restoring equipment to service.

C. ROUTINE METER TESTS

A-9. INTRODUCTION. - This procedure applies to the testing of revenue meters at preference agencies and project loads but excludes major power interchanges. Unless otherwise instructed, instrument transformer correction factors need not be incorporated into the test adjustments.

Routine tests are to be performed in accordance with the schedule set up in Paragraph A-2 of this appendix and whenever repairs are made to the watt-hour meter. Special tests should be made whenever requested by the customer, or if the operation of the meters becomes questionable.

Laboratory tests are to be made before placing new meters in service. The watt-hour and var-hour meters should be tested by individual element, as well as by all elements combined with the single-phase series-parallel method. The demand meter should also be laboratory tested and adjusted. All equipment should be operated in the laboratory for 7 days on phantom Icad before placing in service, time permitting.

A-10. PRELIMINARY. - Approximately 10 days prior to the test, notify the customer so that arrangements may be made to witness these tests, if they so desire.

Immediately before the regular annual meter tests, the portable rotating standard used should be calibrated in the laboratory and final correction factors or curves established. The procedure for calibrating rotating standards and equipment is covered in Paragraph A-3 of this appendix.

The customer should be permitted to install his standard in the test circuit during warmup time for comparison purposes. No credence will be given to the equipment unless evidence is produced to show that the standard has been recently calibrated for use at the currents and voltage involved; also, that satisfactory care is taken in handling and transporting of the standard.

A-11. TEST PROCEDURE.

a. Instrument Connections. - Connect the test instruments to perform single-phase tests. Where feasible, the demand recorder should remain in operation during the tests and will record test energy.

b. Warmup. - Warm up the standard for at least 30 minutes immediately prior to the tests.

c. Equipment Removal From Service. - Record the exact time and the data specified in a test report at the time the revenue metering equipment is removed from service for testing. Watt-hour meter register readings are to be estimated to the nearest 0.1. DO NOT advance a magnetic tape to identify the test period. This would result in the balance of the tape being out of proper timing.

d. "As Found" Tests. - With the current elements in series and the potential elements in parallel, make "as found" meter test, being sure the meter is not disturbed in any before the test. Determine the average correction factor for three runs at each of the following test points: 0.5, 2.5, and 5.0 amperes, unity power factor.

Similar tests shall be made for each element when required (see Paragraph A-1, Types of Meter Tests). The calibration curve used with the standard shall be that obtained for a voltage with ± 2-1/2 percent of the metering voltage existing at the time of the test.

e. Maintenance. - Clean and perform any other maintenance work on the meter that may be found necessary. Give brief description of work performed in the test report.

f. Indicating Demand Register. - The indicating demand register, if so equipped, should be checked by using a register self-checker and the procedure outlined in Chapter 16, Electrical Metermen's Handbook, Seventh Edition. The results of these tests shall be reported under "Remarks" on the regular test form.

g. "As Left" Tests. - Make "as left" tests at the same test points as listed for the "as found" tests (Paragraph Al I d above) and adjust, if required, until the correction factors for all test points are within the limits specified in Paragraph A-11 h.

h. Permissible Error. - The following limits are to be observed when calibrating metering equipment.

(1) With the potential coils connected in parallel and energized at average metering voltage, and the current coils in series:

	Percent registration
(a) Full load (5 amps) unity power factor 1 amp unity power factor	99.7 to 100.3
(b) Half load (2.5 amps) unity power factor	99.7 to 100.3
(c) Light load (0.5 amp) unity power factor	99.7 to 100.3
(d) Full load (5 amps) 50% lagging power factor	99.3 to 100.7

(2) Individual elements (when required), tested at average metering voltage:

	Percent registration
(a) Full load (5 amps) unity power factor 1 amp unity power factor	99.7 to 100.3
(b) Half load (2.5 amps) unity power factor	99.7 to 100.3
(c) Light load (0.5 amp)	99.7 to 100.3
(d) Full load (5 amps) 50% lagging power factor	99.3 to 100.7
(e) Stator balance, full load (agreement between individual elements)	99.3 to 100.7

Note: Individual element and 50% power factor tests are not normally required - only when rebuilding the meter or making tests in the laboratory.

For information on adjustment of General Electric watt-hour meters, see Bulletin No. GET-813G "How to Test and Adjust General Electric A-C Watt-hour Meters."

i. Equipment Return to Service. - Record the exact time and readings at the time the metering is restored to service. Compare the kWh recorded on the watt-hour meter(s) during the test with:

(1) That calculated from the stampings on the printed demand tape and the associated cyclometer readings; or

(2) That calculated from the demand register readings if magnetic-type tape.

If a totalizer is installed, its cyclometer readings should also be checked against the watt-hour meter registrations. The reason for any discrepancy should be included in the test report whenever possible.

A-12. CONCLUSION OF TEST.

(1) Check all meter connections, being sure that all voltage and current conductors from the instrument transformers are connected to the metering equipment. Make stopwatch check of meter and check potential lights to assure that the meter is operating properly. DO NOT reset the watt-hour meter register to compensate for estimated unmetered energy.

(2) Replace all seals.

(3) List all test personnel and witnesses and have at least one representative from each party sign the test data.

(4) Report all data taken in Paragraphs A-11 c and i to the designated supervisor for use in making adjustments in demand and energy.

D. PERIODIC OR MIDMONTH INSPECTIONS

A-13. REQUIREMENT. - Periodic or "midmonth" inspections should be made at times other than regular meter reading dates to inspect, repair, and maintain the equipment. All adjustments and/or repairs should be reported. These inspections shall be scheduled approximately midway between meter reading dates.

a. Inspection Schedules. - Period or "midmonth" inspections shall be scheduled as shown below for installations having:

(1) *Printing demand meters*

(a) *Pumping plants not operated during off season.* - Inspect immediately before start of pump season and at end of season

(b) *Project loads less than 100 kW*- every sixth month

(c) *Loads to 50 MW* - every third month

(d) Loads *over 50 MW* - monthly or oftener, as required

(2) *Indicating demand registers*

(a) Newly installed - monthly until reliable operation is attained

(b) *Thereafter* - semiannually

(3) *Magnetic tape recorders*

(a) *Newly installed* - monthly for first 3 months, or until such time as reliable operation has been attained

(b) *Thereafter*- semiannually or at time of meter inspection or test

(4) *Single-phase service* - annually

b. Inspection of Metering Equipment. - Since different types of recorders are used at various locations, inspection procedures will vary. Check the following and repair as indicated:

(1) *The demand counter.* - Check its registration with that on the watt-hour meter since last inspection. If not in agreement, either the counter or the contact device in the watt-hour meter could be faulty.

(2) *The timing on the demand meter.* - If in error by more than 3 minutes, correct and mark the tape accordingly. DO NOT obliterate any present or future printings. If magnetic-type, advance the tape by means of the capstan. Do not adjust the clock except at start of demand period.

(3) *The tape for distinct, legible, properly positioned printings.*- Dirty print wheels and/or dried, used carbon tapes, or improperly installed tapes may be found. The proper tape is General Electric Company Catalog No. 4210493P1, color: black. DO NOT substitute as high temperatures may dry out less expensive tapes.

(4) *The record gage for ample tape.* - Proper tapes are:

PD-5 through 8: General Electric Company Catalog No. 1796688G17

PD-55F and 57F: General Electric Company Catalog No. 9889524G16

All are 24-hour tapes for 30-minute demand intervals.

c. Magnetic Tape Recorders. - With the recorder *in service* (DO NOT open "change tape" switch), check the following and repair as indicated:

(1) *The timing on the register.* - If off by more than 3 minutes, advance to proper time by turning the capstan tape drive. DO NOT turn the hour pointer by hand to the proper time use the capstan tape drive for this purpose. This is necessary to provide the correct number of demand intervals when translating the tape. Record time and date on meter reading card.

(2) *The tape for proper operation.* The supply and take-up reels should have approximately the same amount of tape at midmonth.

(3) *Demand and time pulses.* - Use high impedance earphones to determine if each are being transmitted to the tape.

(4) *Registration on demand counter ('dials).* - This should be equal to that on the watt-hour meter register for the inspection period involved.

(5) For dirt, insects, or other foreign materials.

d. Watt-hour-demand Meters. - Check for and repair as necessary.

(1) Dirt, insects, or other foreign materials.

(2) That the indicating demand is not off scale. Clock failure or overload is possible.

A-14. REPORTS. - Special report forms should be developed for each region. These should be revised from time to time as required. Record wherever possible the following data:

(1) Name of customer and ADP number (if available).

(2) Time.

(3) Day.

(4) Watt-hour meter register readings, difference and kwh.

(5) Counter readings, difference and kwh.

(6) Maximum demand dial reading.

(7) The difference between the kwh calculated under (4) and (5) above.

If the operation of the contact device and demand meter has been correct, these should agree within the watt-hour meter multiplier.

(8) The time in seconds for two revolutions of the disk of the watt-hour meter and the var-hour meter. Show N.L. when the load is zero. These are required to compute instantaneous power factor and to check the recorded demand.

(9) The metering potential voltage. (Essential in recommending the application of capacitors.)

(10) A description of work done or adjustments made.

(11) Notation of outages known to have occurred. Give date, time, and duration if possible.

E. MANUFACTURERS' CATALOGS AND INSTRUCTION BOOKS

A-15. GENERAL. - The technician inspecting the metering installations should be thoroughly familiar with the publications listed below which are applicable to equipment for which he is responsible.

A-16. GENERAL ELECTRIC COMPANY.

a. Instruction Books.

(1) *Single-phase Watt-hour Meters.*

Types 1-50 and 1-55 Watt-hour Meters GEH-1550D

(2) *Polyphase and Switchboard Watt-hour Meters.*

Constant and Register Ratio Data GET-1887B

V-type Polyphase Watt-hour Meters GET-1191D

Types DS-19 to DS-44 Polyphase Switchboard Meters GEH-764AC

DS-50 and DS-60 Series Switchboard Watt-hours Meters GEH-2762B

V-60 Series Polyphase Watt-hour Meters GEH-2758B

(3) *Accessories for Watt-hour Meters.*

Type IB-10 Watt-hour Meter Standard GEH-1215C

Types MC-21, MC-22, and MC-27 to MC-34 Phase-Shifting Transformers GEH-1537A

Types MC-63, MC-65, MC-66, and MC-67 Phase-Shifting Transformers GEH-2766

Types MC-23, MC-24, and MC-25 Phase-Shifting Transformers GEH-1552B

(4) *Watt-hour Demand Meters and Demand Registers.*

Type M-30 Demand Register GEH-1529K

Type M-60 FS-2 Demand Register GEH-2778A

Type M-60 FS-1 Demand Register GEH-2768A

(5) *Demand Meters and Associated Devices.*

Types PD-5 to PD-8 Printing Demand Meters GEH-1038N

Types PD-55F and PD-57F Printing Demand Meters GEH-2764E

Types D-5, D-12, and D-13 Contact Devices GEH-224L

Types D-20 and D-30 Contact Devices GEH-2754B

Type D-41 Impulse Generator GEH-2767A

Types DT-3 and DT-4 Totalizing Relays GEH-828F

Type MD-3 Totalizer . . GEH-1050E

Type D-51 Impulse Generator GEH-2781A

(6) *Miscellaneous***

How to Select Contact Devices and Impulse Generators GET-3048A

How to Test and Adjust G.E. AC Watt-hour Meters GET-813G

Manual of Watt-hour Meters GET-1840

Instrument Transformer Accuracy Standards . . GET-1526

Manual of Instrument Transformers GET-97C

Instrument Transformer Burden Data GET-1725D

Manual of Demand Meters GET-2327

Application of Watt-hour Meters GET-1905

Guide for Installing Watt-hour Meters GET-2669

b. Spare Parts Catalogs.

(1) *Single-phase Watt-hour Meters.*

Type 1-30 Watt-hour Meter GEF-2745D

Types 1-50 and 1-55 Watt-hour Meters . . . GEF-3590E

Types 1-60-S Watt-hour Meter GEF-4100B

(2) *Polyphase and Switchboard Watt-hour Meters.*

Types V-3, V-5, and V-6 Polyphase Watt-hour Meters GEF-2721D

Types V-62, V-63, V-65, V-66, and V-68 Polyphase Watt-hour Meters GEF-4132A

Types V-4, V-7, V-9, V-10, and V-16 Polyphase Watt-hour Meters GEF-2904B

Type V-64 Polyphase Watt-hour Meter GEF-4300

DS-50 and DS-60 Series Polyphase Switchboard Watt-hour Meters . . GEF-4139B

Drawout-type Switchboard Watt-hour Meters Types IS and DS GEF-3159C

(3) *Accessories for Watt-hour Meters.*

Type IB-10 Watt-hour Meter Standard GEF-3148B

Photoelectric Watt-hour Meter Tester GEF-3705B

Photoelectric Watt-hour Meter Tester, Catalog No. 4153711 . . . . GEF-4329

* Note: GET-2291 Instruction Book provides information on most of these items.

(4) *Watt-hour Demand Meters and Demand Registers.*

Types M-30 and M-31 Demand Registers GEF-3594B

Type M-60 FS-1 Demand Register GEF-4184B

Type M-60 FS-2 Demand Register GEF-4333

(5) *Demand Meters and Associated Devices.*

Types PD-5 to PD-8 Printing Demand Meters GEF-3361A

Types D-5, D-12, and D-13 Contact Devices GEF-1967E

Types D-20 and D-30 Contact Devices and Type D41 Impulse Generator . . . GEF-4091

Types PD-55F and PD-57F Printing Demand Meters GEF-4165

Types DT-3 and DT-4 Totalizing Relays . . . GEF-3173B

Types MD-3, MD-4, MD-5, and MD-6 Outgoing Contact Devices D-6 and D-7 . . . . GEF-3677A

Type SS-2 Solid-State Impulse Totalizer GEI-52440

Note: Renewal-Parts Bulletins for Watt-hour Meters and Demand Meters, GET-2290, provides information on most of the above meters.

c. Address. - The address for securing the above catalogs and instruction books is:

Distribution Services
General Electric Company
Schenectady NY 12305

A-17. WESTINGHOUSE ELECTRIC CORPORATION.

a. Instruction, Operation, and Maintenance Catalogs.

Watt-hour Meter Calibration Information IL42-100B

Switchboard Watt-hour Meters, Types D2B, etc IL42-201.3A

Instructions for Cartridge-Tape Change for Surface Mounted WR-2 and WR-4 Recorders IL42-503.5

Flexitest Case (semiflush) WR-2 and WR-4 Recorders IL42-503.6

Test Counter for use with WR-2 and WR-4 Recorders . IL42-503.4

Types WR-2 and WR-4 Demand Recorders P2, P3 Surface Mounted Cases IL42-503.8
Flexitest (semiflush) Case IL42-503.9

Type WLT-121 Tape-to-Card Translator . . . . I L42-505.1 A

WT-1 and WT-2 Pulse Totalizing Relays IL42-530.6

Mechanical Pulse Initiators for use with Watt-Hour Meter IL42-950.3

CV-1 Impulse Device . IL42-950.1B

Photoelectric Pulse Initiators, Types CD-11 and CD-21 . . . . IL42-950.4

Types WR2C and WR4C in Flexitest Case . . . . I L42-565WR2

b. Descriptive Catalogs.

Mark I Dual Range Demand Recorders DB42-302

Pulse-O-Matic Computerized Metering Systems DB42-550

Pulse Receivers and Recorders DB42-565

Pulse Initiators DB42-555

Translators DB42-570

CV-1 Impulse Device . . . DB42-950

c. Renewal Parts Catalogs.

DB and CB-F Switchboard Watt-Hour Meters 42-201A1

Types WR-2C and WR-4C in Flexitest Case 42-565WR-2

d. Address. - The address for secur ing the above catalogs is:

Westinghouse Electric Corporation
Meter Division, Raleigh Plant
PO Box 9533
Raleigh NC 27603

A-18 BECKMAN INSTRUMENTS, INC.

a. Instruction Book.

Model 6003A-11 Accumulator
(Used in WLT-121 Translator)

b. Address. - The address for secur ing the above catalog is:

Beckman Instruments, Inc.
Electronic Instrument Division
2200 Wright Avenue
Richmond CA 94804

A-19. DUNCAN ELECTRIC COMPANY.

a. General Information.

BRT Billing Tape Recorder 310

b. instruction Manual,

Type BTR 860

c. Address. - The address for securing the above materials is:

Duncan Electric Company
Box 180
Lafayette IN 47902

A-20. EDISON ELECTRIC INSTITUTE.

a. Handbook. - Electrical Metermen's Handbook, seventh edition

b. Address. - The above handbook is available from:

Edison Electric Institute
750 Third Avenue
New York NY 10017

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