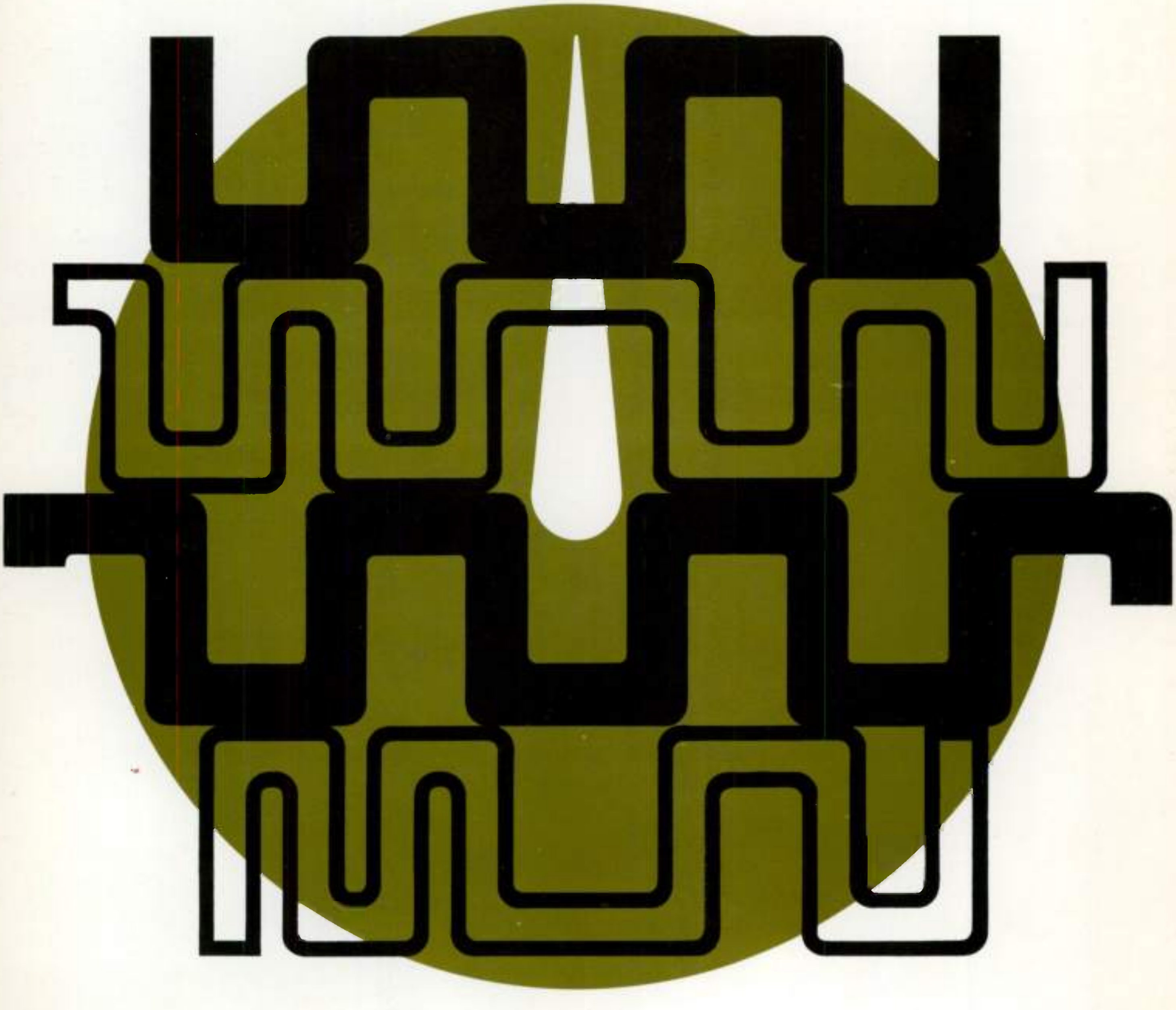
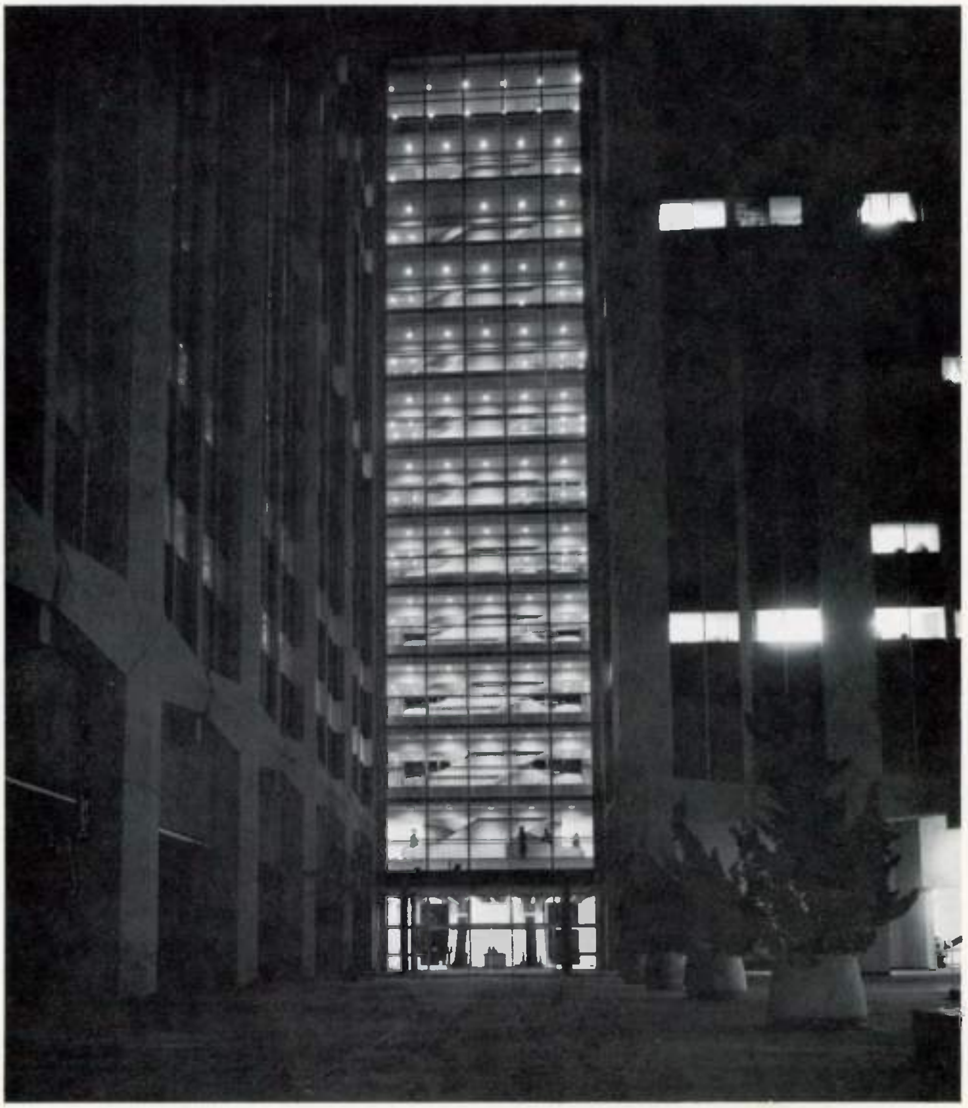
Westinghouse ENGINEER

January 1967



A "vertical bridge" of 26 electric stairways links the display rooms of two commercial buildings in downtown Los Angeles to give buyers fast and simple access to wholesalers' showrooms. Operating at 120 feet a minute, the stairways provide a total capacity of 91,000 passengers an hour.

The unique bridge is between a new building and an older one, both 13 stories high, that together make up the Merchandise Mart. (The new building also is served by a four-car bank of automatic elevators.) The buildings house showrooms to display wearing apparel, accessories, jewelry, linens, and other goods.



Westinghouse ENGINEER
January 1967, Volume 27, Number 1

Editor
M. M. Matthews

Assistant Editor
Oliver A. Nelson

Design and Production
N. Robert Scott

Editorial Advisors
T. P. Jones
Dale McFeatters
T. J. Murrin
W. E. Shoupp
Robert L. Wells

Subscriptions: United States and possessions, $2.50 per year; all other countries, $3.00 per year. Single copies, 50¢ each.

Mailing address: Westinghouse ENGINEER, P. O. Box 2278, 3 Gateway Center, Pittsburgh, Pennsylvania 15230.

Published bimonthly by the Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. Printed in the United States by The Lakeside Press, Lancaster, Pennsylvania. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48106.

The following terms, which appear in this issue, are trademarks of the Westinghouse Electric Corporation and its subsidiaries: Prodac 50; Ampgard.

Cover design: A new digital telemetering system (Type DT) described in this issue accumulates incremental impulses from an impulse device on a kilowatt-hour meter and periodically converts the accumulated impulse count to a binary-coded signal for transmission to the receiver. The process is symbolized on this month's cover by artist Tom Ruddy.

Digital Telemetering System for Data Logging

George B. Higgins

A digital telemetering system provides an accurate, reliable, and relatively high-speed method for telemetering kilowatt-hour interchange or generation data from remote points of measurement to central locations.

The growing number of interconnections between electric utility systems that has resulted from power pooling has created a need for accurate, reliable, and relatively high-speed telemetering systems for transmitting kilowatt-hour interchange information from remote points of measurement to central dispatching offices. To satisfy this need, a new digital telemetering system (Type DT) with self-checking coding will transmit readings from kilowatt-hour meters at the remote locations to the dispatching office with 100-percent accuracy. Thus, the telemetered data can be used for interchange billing or for revenue billing of large customers. The DT telemetering equipment has solid-state circuitry for reliability, high speed, and minimum maintenance.

Although the principal application of the DT system is the telemetering of kilowatt-hour data, the system can also be used to telemeter other integrated quantities, for example, fluid flow in a pipeline or production data from well fields.

Digital Telemetering

Two basic functions are performed by the DT telemetering system: incremental impulses from an impulse device are accumulated at the point of measurement, and this pulse count is transmitted at periodic intervals to the dispatching offices.

At the remote location, the basic transmitter consists of a counting register for each kilowatt-hour quantity to be measured and an encoder. The register counts and stores the impulses received from a pulse initiator on a kilowatt-hour meter. On command, the encoder converts the impulse count in each storage register into a series of binary-coded signals and transmits these signals to the receiver. At the dispatching office, the receiver decodes the signals and places the information into one or more receiver registers. The output of the receiver register is used to operate conventional readout devices.

The DT telemetering equipment is often an integral part of an overall data-gathering system, which includes such functions as automatically programmed readouts, data logging, and totalizing. Peripheral equipment is available to convert information to the forms needed for power system operation.

Signal Coding for Transmission

The DT system uses binary-coded decimal transmission, which provides flexibility in the number of digits that can be transmitted and simplifies conversion to other standard codes at the receiving end. To insure that the received signal will be identical to the transmitted signal, a self-checking, two-out-of-five binary code is used. Each decimal digit is represented by five binary bits consisting of two "1" bits and three "0" bits. The five bits are weighted *7-4-2-1-check*. For example, decimal digit 8 is coded 10010; decimal digit 7 is coded 10001. To detect incorrect readings caused by channel distortion or interference, the receiver applies the following checks to each received signal:

1) Each decimal digit must consist of five bits;

2) Each group of five bits must consist of two "1" bits and three "0" bits; and

3) Each transmission must consist of the correct number of decimal digits.

Each DT transmitter register and the transmitter encoder can store and transmit up to six decimal digits. These six digits may be divided into any combination of identification and data. Normally, only three digits are required for data so that the remaining three are available for identification. In many of the smaller systems, only four decimal digits are required—one digit for identification and three digits for data.

To guard against false starts or incorrect readings caused by channel noise, and to provide proper synchronization between the transmitter and receiver, each transmission begins with a unique five-bit digit. This synchronizing digit also serves as a transfer signal when the digital telemetering system shares a channel with continuous analog telemetering. As further protection, the receiver is synchronized with the transmitter during transmission of each information (or identification) digit.

Transmission rates from 15 to 200 bits per second are available, which permits the DT system to be operated over any of the commonly available transmission channels, such as a pair of line wires, leased telegraph, power-line carrier, microwave radio, or audio tone. The time required to transmit a 4-digit decimal number is approximately 1.7 seconds at 15 bits per second, or 0.13 second at 200 bits per second.

Two Basic Systems

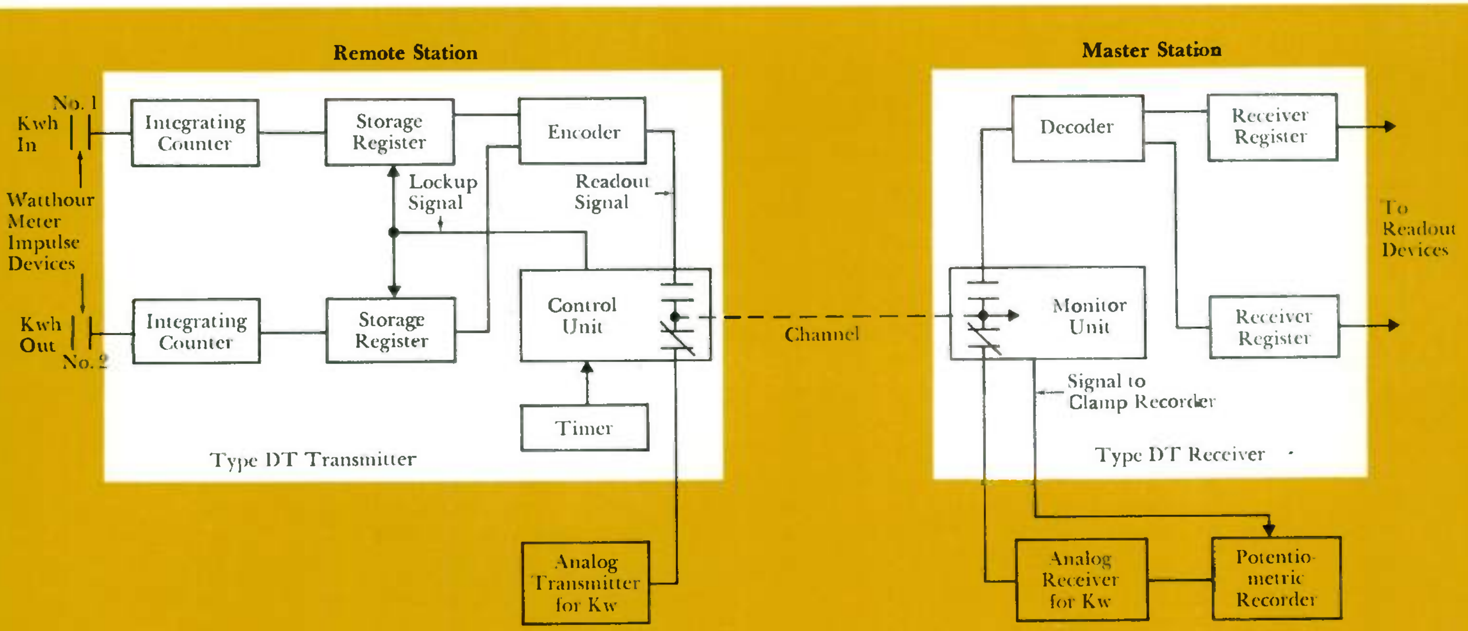
Two basic system arrangements are possible with DT telemetering equipment. The choice is determined by the channels available, the use to be made of the data, or both. The simpler system requires only a one-way channel between each remote station and the master station, and it uses a timer at the remote station to initiate readout. A more flexible system uses a two-way channel between the master and one or more remote stations, and the entire readout sequence is controlled by a programmer at the master station. The two basic schemes for these systems will be described, although a number of variations are possible.

One-Way Channel—The simplest application requires a one-way channel, which need not be continuously available for digital telemetering. A typical arrangement is one in which digital telemetering

1—Typical digital telemetering installation in which a single channel is time-shared with continuous analog telemetering.

2—Transmitting (*a*) and receiving (*b*) equipment required for a digital telemetering system for a one-way channel, as diagrammed in Fig. 1. The DT telemetering equipment is designed for mounting in standard 19-inch racks. Covers have been removed from the mounting cages to show the accessibility to the plug-in printed circuit boards.

George B. Higgins is with the Relay-Instrument Division, Westinghouse Electric Corporation, Newark, New Jersey.


Remote Station
Master Station
No. 1
Kwh In
Watthour Meter Impulse Devices
Kwh Out
No. 2
Integrating Counter
Integrating Counter
Storage Register
Storage Register
Lockup Signal
Encoder
Readout Signal
Control Unit
Timer
Type DT Transmitter
Analog Transmitter for Kw
Channel
Decoder
Receiver Register
Receiver Register
To Readout Devices
Monitor Unit
Signal to Clamp Recorder
Type DT Receiver
Analog Receiver for Kw
Potentiometric Recorder

a


TELEDAC
TRANSMITTER
ZERO
SPAN
CAL
UPDATE

b


TELEDAC
RECEIVER
SPAN
ZERO

is time-shared with continuous analog telemetering on a single channel between the remote station and the master station (Fig. 1). Briefly, the system operates as follows:

Power flow information (kw) is continuously transmitted over the channel by analog telemetering except for brief interruptions when power consumption (kwh) is transmitted by digital telemetering.

At the remote station, two integrating counters, one for *kwh-in* and *kwh-out*, continuously receive impulses from contact devices on two watt-hour meters. The impulses are accumulated in the integrating counters (at rates up to 25 pulses per second) until a reading is called for. The kwh/impulse ratio of the impulse device on the watt-hour meter should be such that readings will either be direct in kwh, or if multipliers are necessary, that the multipliers will be powers of 10.

At a regular preset interval (normally 15, 30, or 60 minutes), the timer at the remote station signals the control unit, causing both integrating counters to transfer their count to the associated storage registers. The integrating counter may be allowed to accumulate continuously or it may be reset to zero after transfer of count to the storage register. In either case, there is no loss of incoming pulses to the counter during transfer of count to the storage register.

The control unit at the remote station removes the analog transmitter from the channel and connects the digital telemetering encoder. The encoder sends the unique five-bit synchronizing signal, causing the monitor unit at the master station to disconnect the analog receiver and connect the digital receiver.

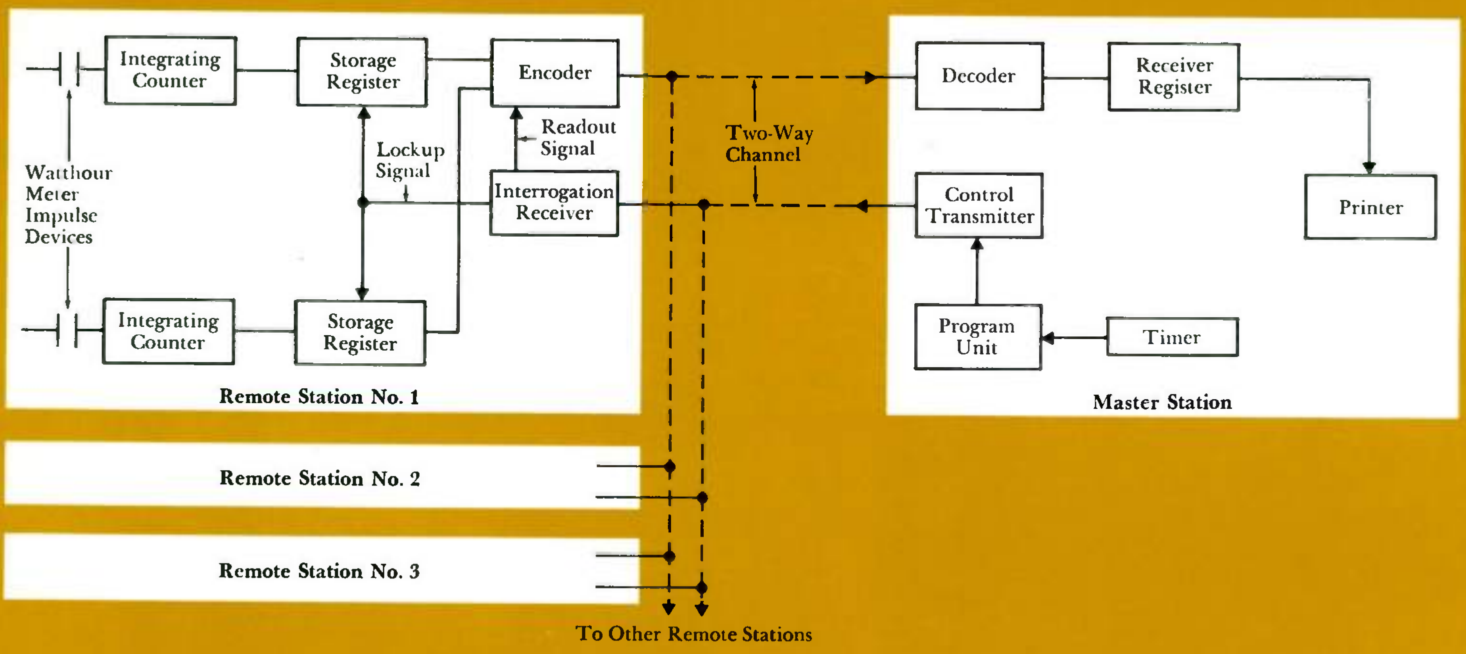
The storage register readings are fed in sequence to the encoder, where they are converted to a serial output of binary-coded-decimal pulses for transmission over the channel. Information in the storage registers is not destroyed by readout, but held in the storage register until the next reading and kept available for retransmission if required.

At the master station, the decoder checks the transmitted serial code for validity and converts it to a parallel binary output, which is fed to the receiver registers. The receiver register converts the code to a form (usually straight decimal) suitable for operating a visual display unit, line printer, or other readout device. Receipt of an invalid code in a reading causes the receiver to reject the reading and provide no output. A contact output indicates that an invalid code was received; it can be used to produce an alarm or lamp indication or to request a retransmission.

After both readings have been transmitted and checked, both stations are returned to analog telemetering.

In more complex applications where more than two kilowatt-hour readings are required from a remote station, the encoder can read out the required number of storage registers (one for each kilowatt-hour reading) in sequence, and the decoder at the receiving end can feed information sequentially into the required number of receiver registers. No external programming is needed.

Two-Way Channel—This arrangement, shown in Fig. 3, provides for telemetering of two or more kilowatt-hour readings



3—Typical digital-telemetering arrangement for telemetering two or more kilowatt-hour readings from each of a number of remote stations over one common two-way channel.

from each of a number of remote stations. Basically, the system differs from the one-way system only in the method used for initiating readout. Instead of responding to a timer at the remote station, each remote station transmits its readings in reply to a coded interrogation signal from the master station. Thus, all stations can be interconnected on one common two-way channel.

At a preset time, the timer at the master station signals the programming unit, which sends a readout-initiating signal to all remote stations. This causes the integrating counters at all remote stations to transfer their accumulations to the associated storage registers so that all readings are taken at the same instant. The master station programming unit then sends a coded interrogation signal, to which only the first remote station responds, and causes this station to transmit readings from each of its storage registers in sequence. As each reading is received at the master station, it is checked for validity and recorded on a line printer (Fig. 3). Other readout devices can be used, such as logging typewriters, line printers, or paper-tape punches depending on the requirements of the particular application.

When valid readings have been obtained for all quantities from the first remote station, the master station then sends a coded interrogation signal to cause the second remote station to transmit its readings. This procedure is repeated until the readings for all remote stations have been telemetered and recorded. When all readings have been recorded, the system comes to rest until the next readout is initiated by the timer.

A readout may also be initiated manually by the dispatcher. The remote station storage registers retain their readings until the next automatically initiated readout so that repeat transmissions may be obtained from any station if a reading is lost.

DT Equipment Features

The encoder and decoder are completely transistorized, using silicon components, to permit a high transmission rate and to provide maximum reliability even under continuous operation. Hermetically sealed, magnetic-latching reed relays are used in the transmitter register to prevent loss of stored information in the event of operating voltage failure. The life expectancy is more than one billion input pulse counts. The receiver register consists of transistor logic with silicon controlled rectifiers for operation of readout devices.

The equipment is of modular design and construction, with plug-in printed circuit boards, to provide flexibility and ease of expansion and permit simple maintenance procedures. The basic assembly package is a mounting cage approximately 19 inches wide, 5¼ inches high, and 8½ inches deep, suitable for switchboard or relay-rack mounting. This cage accommodates such typical combinations as: a basic transmitter package with two integrating counters of up to four decimal digits each and two storage registers of up to four digits each; a basic receiver package with two receiver registers of up to four digits each; three integrating counters and storage registers with up to three digits each; or three receiver registers with up to four digits each.

Cages can be interconnected with plug-in connectors so that additions can be easily made in the field.

DT telemetering equipment can operate in an ambient temperature range of −30 to +80 degrees C. Standard operating voltage is 48 or 125 volts dc. A rectifier power supply panel is available for operation from 115 volts, 60 cycles.

Data Logging

Various arrangements of printed readout can be obtained with an electric typewriter, an adding-machine type of printer, or a wide-carriage printer. Time of printout can be indicated by the use of a digital clock to provide time information in digital form. Identification of readings can be provided by printing decimal digits for identification or by using a logsheet with preprinted column headings.

For dispatching purposes, it is often necessary to provide totalizing to determine net interchange on an interconnection, total generation of several machines at a station, or system net interchange. It is also necessary in these cases to indicate the direction, *in* or *out*, of net power flow. These totals are required in addition to the individual readings.

The most commonly used method for totalizing employs an electrically operated adding machine, equipped with one or more accumulators to perform the addition or subtraction. A wide-carriage tabulating printer is frequently used so that all readings can be printed in a horizontal line. Where it is necessary to use an adding machine for totalizing, but where the printer does not have sufficient carriage width to accommodate all readings, an adding machine with an electrical output can provide calculated totals that can be fed to an electric typewriter for logging.

Computer Input

As digital computers become more widely used for dispatching, there will be more applications in which the telemetered kilowatt-hour readings must be fed directly to a computer for processing. The computer can make many computations that are not possible with an adding machine, and its large memory capacity can provide totalizing for a larger number of lines than would be practical with an adding machine.

The Type DT telemetering equipment can be easily adapted to systems in which the programming of data accumulation is controlled by a computer. The outputs of receiver registers can be fed directly into the computer or converted to a binary form compatible with the particular computer. Systems vary in arrangement, and each system must be worked out to meet the requirements of the particular application.

As utility systems continue to grow, it becomes less practical to gather and use the required data by the conventional manual methods. Consequently, a completely automatic and reliable method for collecting and recording data is both necessary and desirable. The Type DT telemetering system has been developed to fulfill this need.

Modern Cold-Rolling Mills Maximize Return on Investment

D. R. DeYoung
T. J. Dolphin

Recent technological developments in mill drive and control equipment increase the efficiency and capability of cold-rolling mills.

Electrical system techniques and equipment have reached the state of development where dc drives can be precisely controlled to the limit of the design capability of the drive motors. Moreover, great advances have been made in the past few years in information-handling techniques and in the practical knowledge of applying them in a metal-mill environment. The challenge now is in the application of these techniques and equipment in each cold-rolling mill to provide the most efficient production system—one that is both forward-looking and realistic and is aimed at providing maximum product quality and production for the investment.

The technological advances are applicable to any type of cold mill and to any size, because the performance requirements of the cold-rolling process are universal. These requirements are the precise control of strip tension under dynamic (speed-changing) and under steady-state (running) conditions. In both states, the unwinding and winding reels are constantly changing in diameter; this diameter change requires a continuous adjustment of reel motor speed and torque and also results in continuous inertia change. (See *Cold Rolling*, page 8.)

The principal technological advances in recent years have been the introduction of thyristor power systems for mill drives, speed-regulated drives to replace the earlier voltage-regulated drives, improved subsystems for controlling gauge and tension, various mill automation systems, and continuous rolling.

Thyristor Power Systems

The dc generator has been used as a drive power supply so long that it can be applied fairly routinely by following established rules and established ratings. Moreover, dc generators have thermal and instantaneous ratings similar to those of the dc motors they supply, and they have inherent four-quadrant operation (ability to supply positive and negative current and voltage). While the application of thyristors is not as routine, sufficient data and experience have been gained to permit successful application.

The basic thyristor power circuit, known as a converter, consists of six thyristors in a six-phase double-way circuit; it is a two-quadrant device capable of supplying positive current and supporting both positive and negative voltage when supplying an inductive circuit.[1] Almost all power supplies for cold-rolling mills require four-quadrant operation, so two converters are connected back to back to form a dual converter. The converters also are connected in parallel to meet the power requirements of the dc drive motor. To be more precise, in *nonreversing* mill stands and in all reel drives, the forward converter (the one operating during steady-state rolling) should be sized to be compatible with the motor to realize the motor's full potential. The drive can be asymmetrical (having forward and reverse converters of different ratings) because the reverse converter is only required to transfer the stored energy of the system. The stand drive of a *reversing* mill, however, must be supplied by a symmetrical dual converter.

The advantages of thyristor power systems include an efficiency at rated load at least five percent higher than that of m-g sets. Also, there are not any no-load rotating losses during coil changing and roll changing as there are with m-g sets.

Power-supply hardware can be of single-unit construction, combining the power supply, firing circuitry, regulators, control equipment, and critical wiring within a single package that is factory wired and tested (Fig. 1). No heavy foundations are required.

On main-drive equipment, failed units can be separated and production resumed at reduced power in a matter of minutes. Static parts are used throughout, eliminating the bearing, brush, and generator commutation problems associated with m-g sets. Spare parts are interchangeable, and the circuitry is modular and similar throughout to facilitate trouble-shooting.

Response time of the thyristor equipment is faster; voltage builds up almost instantaneously because of the absence of the long time constants of generators. This is not a vital advantage most of the time, since the normal operating demands are linear and well within the response capability of generators. However, the faster response is sometimes important, as when strip welds are passed through at high speed and for controlling current limit if the strip breaks.

The disadvantage of thyristor power stems from the inherent cold-mill requirement of controlled work force and tension during acceleration and deceleration from thread speed to run speed and back to thread speed. This requirement of controlled power flow to the motors from near zero speed (near zero dc motor volts) results in poor power factor. For small mill drives, the effect is usually insignificant relative to the total system, or the user has adequate corrective leading power factor. The problem also is diminished by the ratio of running time, when power factor approaches unity, to the accelerating and decelerating time. In addition, modern regulators that operate the mill motors at maximum possible field minimize reduced-voltage operation and in turn minimize reactive power demand.

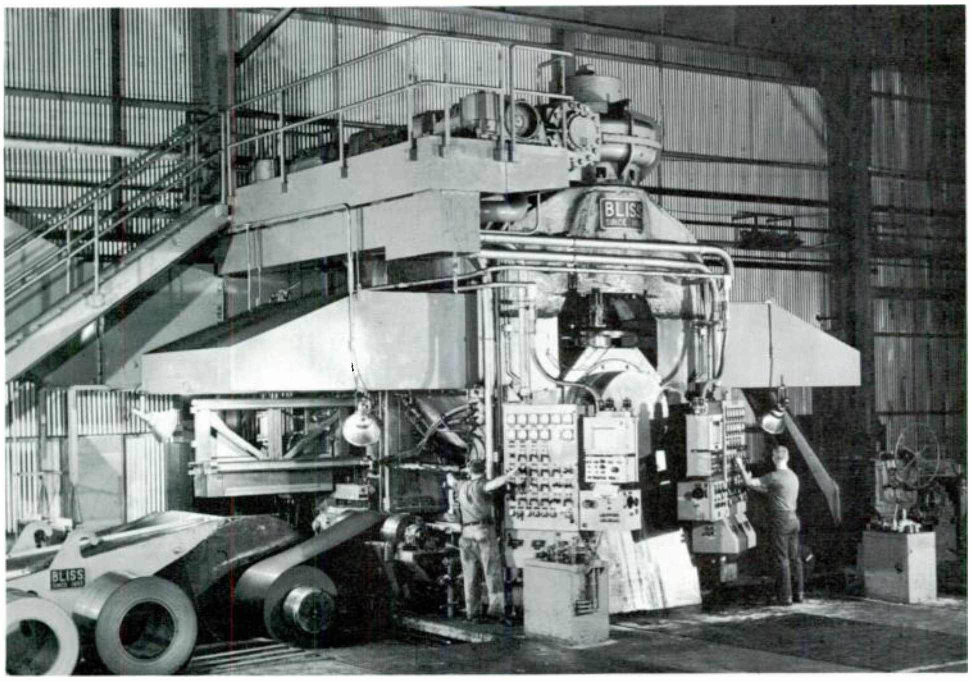
All factors considered, more thyristor power systems will be applied to cold-rolling mills for the benefits they bring. The application, however, must be made with a thorough understanding of drive and product requirements.

Speed-Regulated Electrical Drives

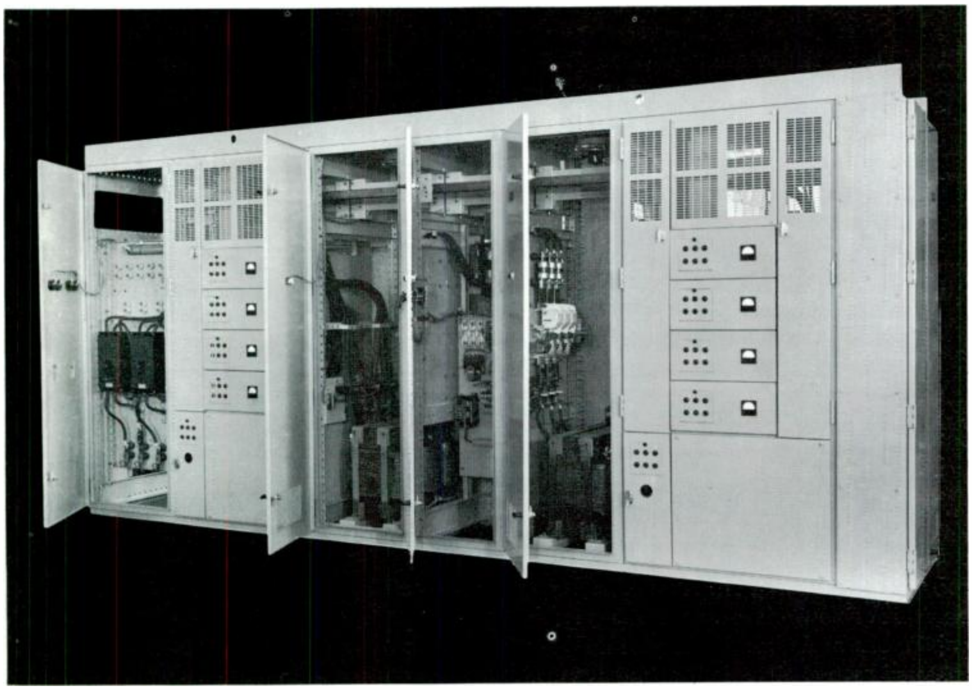
Mathematical analysis and analog computer studies of drives for cold-rolling systems have for years indicated that the ideal coordination control of such variable-speed process-connected mechanical drives would be by the use of speed-regulating systems instead of the conventional voltage-regulating systems. Speed regulation has much greater ability to maintain precise speed relationships

---

D. R. DeYoung is Manager, Cold Mill Systems, Industrial Systems Division, Westinghouse Electric Corporation, Buffalo, New York. T. J. Dolphin is Assistant Manager.



Four-high reversing cold-rolling mill is typical of the large modern mills that produce metal strip in high volume and at precise gauge accuracy. This one rolls strip 50 inches wide at 1700 feet per minute. Hot-rolled steel strip is fed into it from coils.



1—Thyristor power systems are compact and self-contained, and they do not require heavy foundations. This unit is the complete electrical package, except for the two 100-horsepower permanent-magnet mill motors, for a speed-regulated screwdown drive.

during velocity and load changes, with consequent advantages in production volume and gauge control.

A successful speed-regulating system requires a high-gain regulator with very short electrical time response. Until recently, however, the control designer did not have the required hardware. He has it now in such devices as transistor operational amplifiers, thyristor amplifiers, and thyristor power supplies.

While the speed regulation problem is most severe with multistand tandem mills, linear speed control from zero speed at maximum available motor torque to desired operating speed at some motor field weakening point is an optimum objective for all cold mills, including such specialty mills as the sendzimir mill where accurate control of wide ranges of reel tension are required for the wide ranges of product rolled.

The speed-regulating approach has recently been applied to a five-stand tandem cold mill of 40,000 horsepower, with performance exceeding expectations in interstand speed accuracy and in gauge control. This mill is powered by m-g sets, but the technique is as applicable to thyristor power systems and is always used with them.

A speed-regulated drive system for a mill stand has two regulators—a speed regulator operating on the power supply and a counter-emf regulator operating on the motor field (Fig. 2). The cemf regulator is made up of a motor field flux regulator and a cemf preamplifier. At values below dc-motor base speed, the regulator is biased to hold the motor at full field. Above base speed, the drive cemf is clamped at its rated value and the motor field excitation is decreased to hold this value as motor speed is increased. This results in the motor being operated at the maximum possible field and therefore maximum available torque and power for any operating speed.

The speed regulator consists of two loops—an inner loop to control armature current and an outer speed-control loop. Armature current limit is obtained by limiting the speed controller output, which is a reference to the armature current controller.

The speed controller has a proportional-plus-integral (PI) response and provides, together with the integral relationship between speed and current, a double integrating speed-control loop that responds to reference changes as a zero velocity error system. The result is a stand drive system with a number of advantages. First, the motor is operated at its maximum torque capability at all speeds, resulting in fast smooth starts and maximum rolling capability. Gauge is maintained accurately because the system tracks the speed reference without error during both steady-state running and ramp changes, and also because response to load changes is fast. Performance is essentially independent of motor speed-torque characteristics. Finally, the drive has inherent current limit to make it self-protecting.

Control of Gauge and Tension

Accurate gauge control is important because it means production of more saleable product. The basic electrical drive advances that have been discussed provide the building blocks for improved automatic gauge control (AGC). Systems employing both tension and screwdown adjustment have been applied to single-stand, specialty, and tandem cold mills.

The most significant advance made recently is the system illustrated in Fig. 3. It can be considered three subsystems:

1) An entry AGC system receives its intelligence from an x-ray gauge after stand *1* and operates on the screwdowns there to maintain constant gauge out of the stand. Its purpose is to correct for incoming gauge variations.

2) A delivery AGC system receives its intelligence from an x-ray gauge after stand *5* and operates on the speed of stand *4* or *5*, or both, to vary interstand tension so as to provide a vernier control of finished gauge.

3) Each interstand tension is controlled by a system that operates on the screwdowns of the stand following the tension sensor.

Subsystems 1 and 2 have been applied for a number of years to voltage-regulated tandem mills and have controlled gauge effectively in the body of the coil. However, when the voltage-regulated mills accelerate, there usually are varying acceleration lags between stands that cause tension changes between the stands and also cause the speed relations between stands to change. These variations of speed relations and tension, combined with changes in loaded roll gap as functions of speed, cause gauge changes during mill speed changes—especially in the low speed range.

The use of speed regulators in place of voltage regulators almost entirely eliminates stand acceleration lags, thereby eliminating tension changes due to changes in stand speed relations. Therefore, any tension changes during acceleration of a speed-regulated mill are caused entirely by changes in the effective roll gaps of the various stands. If the thickness out of any stand is constant and the speeds of all stands are maintained in the same relationship, then the thickness out of each stand is held constant and the thicknesses are inversely proportional to stand speeds. Stated mathematically,

$$fpm_1H_1 = fpm_2H_2 = fpm_nH_n$$

where *fpm* is strip speed and *H* is roll opening. Thus, by controlling stand speeds accurately and holding thickness out of stand *1* within a narrow tolerance band, the thickness out of each stand is controlled accurately.

As the speed of the mill is changed, the changes in loaded roll gap and stand roll forces tend to change gauge. Since the stand speeds are not allowed to change, the interstand tensions change to offset the roll force change and thereby hold gauge essentially constant. Interstand tension is monitored to prevent wide tension swings; if the tension change exceeds a preset value, the screwdowns of the succeeding stand are operated to bring tension back to the desired value. This maintains the same effective loaded roll opening on each stand.

An x-ray gauge after the last stand monitors delivered strip thickness and makes vernier changes in the speeds of the delivery stands to cause a tension change at the delivery end of the mill. This tension change is often sufficient to correct gauge errors caused by such things as changes in the complex interrelationships between strip tension, roll surface speed, and input and output strip speed. Where the band of tension correction is not sufficient to cause the gauge correction by itself, the tension increases (or decreases, depending on the error) causing the tension limit band to be exceeded. This makes the screwdowns operate from tension limit to correct the gauge and also returns interstand tensions to the proper level.

With a gauge control of this type, the mill is set at thread speed to deliver the desired strip thickness. The stand *1* gauge control is turned on as soon as stand *2* is threaded, and the tension-limit control on the screwdowns is actuated for each interstand tension at the time the succeeding stand is threaded. When the mill

Cold Rolling

Cold mills are used to roll finished flat products (sheet and strip) from hot-rolled coils of steel or nonferrous metals. The main reason for cold rolling usually is to reduce thickness to the desired value, since, for many applications, the hot-strip mill cannot reduce the material to the gauge nor the gauge tolerance demanded. (Thus, the cold-strip mill has increased in importance as lighter gauges have come into demand—as for thin tin-plate—and as users have come to demand ever-better quality, uniformity, and gauge accuracy.) Other reasons for cold rolling are to produce a smooth dense surface and to impart desired mechanical properties.

Cold-rolling mills are broadly classified as single-stand, tandem, and specialty types. Single-stand mills consist of a single set of rolls; they often are reversing mills, in which the strip is passed back and forth until it has been reduced the desired amount. Tandem mills consist of a number of stands placed closely together in line, with each succeeding stand reducing the strip. Specialty mills include temper mills that roll the strip mainly to impart stiffness, sendzimer mills that can roll a wide variety of materials including unusually hard and thin strip, and foil mills that roll to thicknesses of 0.001 inch or less.

has been completely threaded, it is running at thread speed and delivering on-gauge strip. It is then accelerated with tension-limit control operating on all screwdowns except at stand *1* to hold gauge as the mill is brought up to running speed.

Such a gauge control subsystem has been put into operation on a 5000-fpm 80-inch sheet mill in the Midwest. It has shown excellent results in production capability and gauge control.

Automation

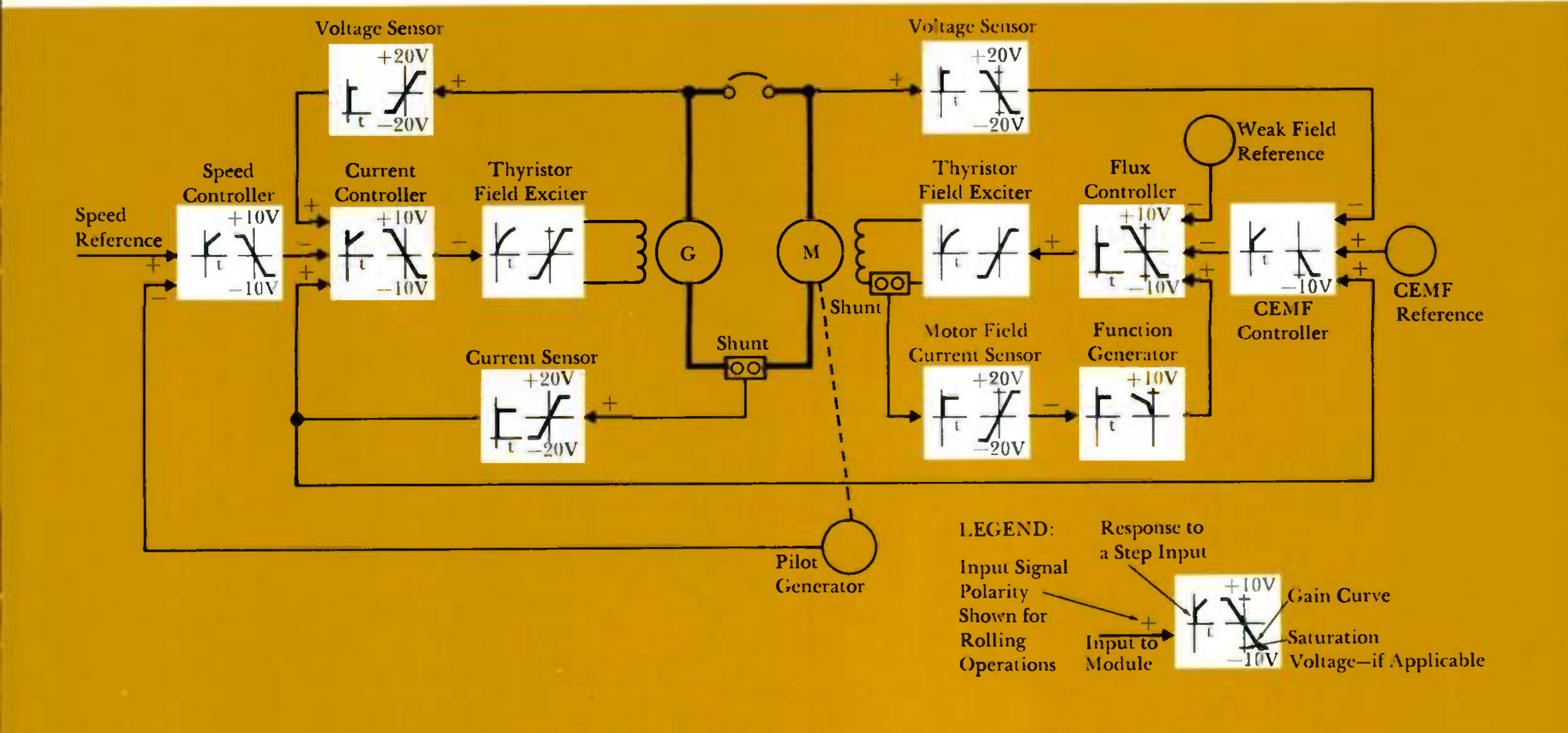
The objective of maximum return on investment can only be realized if performance of the overall mill system is optimum. This objective, therefore, demands both the drive improvements that have been discussed and increased use of automatic functions. The latter minimizes human error in the process and increases management direction and control over it. Some of the automation techniques being applied by Westinghouse to cold-rolling mills are automatic gauge control, extensiometer measurement and control, position regulation of auxiliary functions, constant-speed threading, automatic coil preparation and feeding, automatic mill slowdown, automatic coil stopping and positioning, automatic roll changing, programmed operations, and process computation and control of the mill. The justification for adding these functions is based on the initial investment for the mill and the effect they will have on quality and production volume.

The smaller single-stand and specialty mills have employed one or more of the functions through use of relay logic systems, static wired logic, or small computers. Some recent mills have computers operating on a time-shared basis to perform a number of the functions. A typical example is several auxiliary position regulators operating simultaneously to a desired setting and directed digitally by the computer.

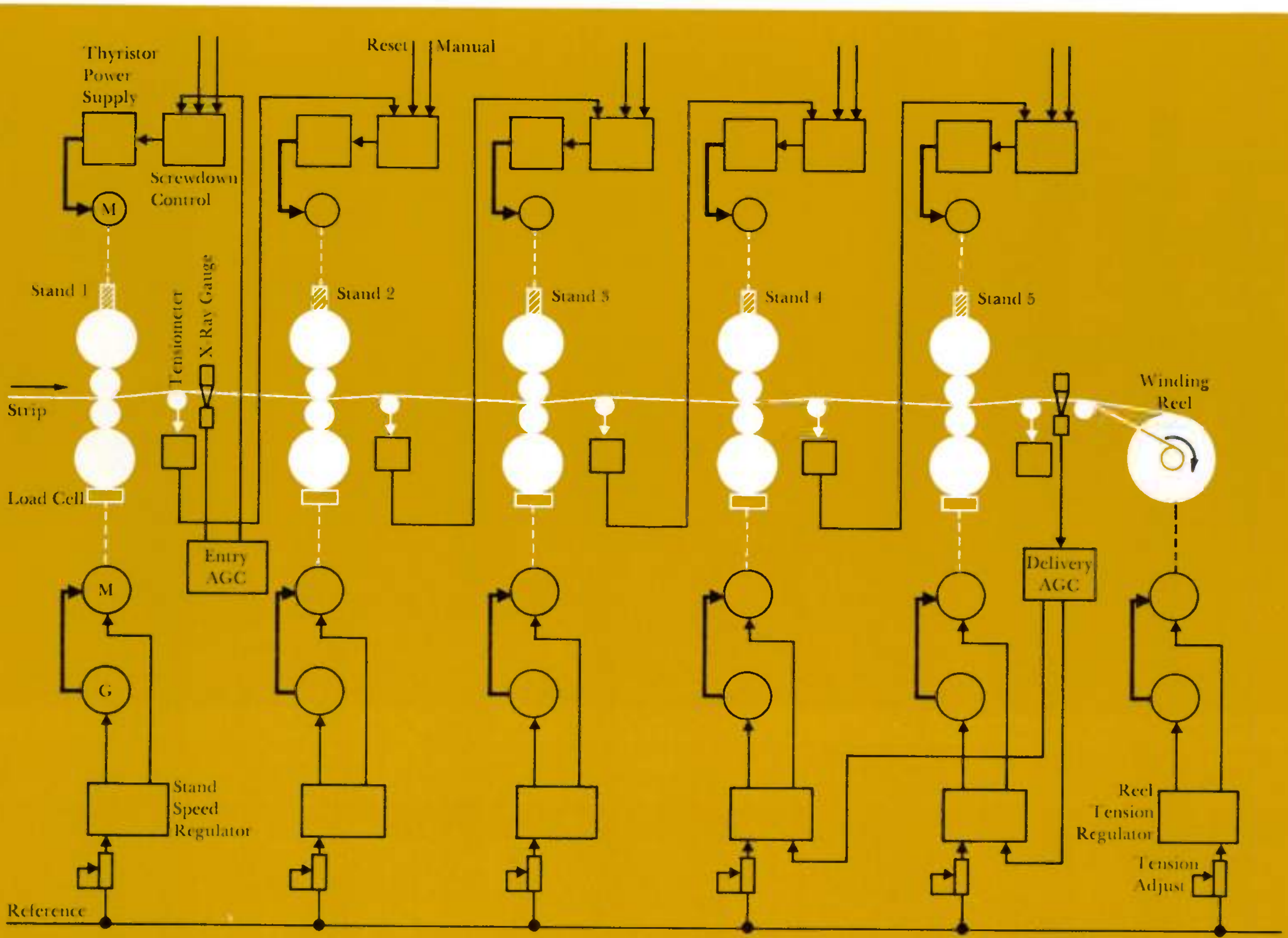
One five-stand mill has a Prodac 50 computer for programmed operation of the mill variables; it is the first cold mill with such computer control. The stored computer program sets the percent speed for each of the five stands, screwdowns for each stand, interstand tensions, x-ray gauge material composition adjustment, x-ray gauge setting, mill top speed, and entry and delivery bridle and winding-reel tensions. The computer can store up to 75 schedules, read in from paper tape or from a manual keyboard. After the operator has set up an optimum schedule manually, he can direct the computer to log the mill variables, assign a schedule number, and store this setup for future use.

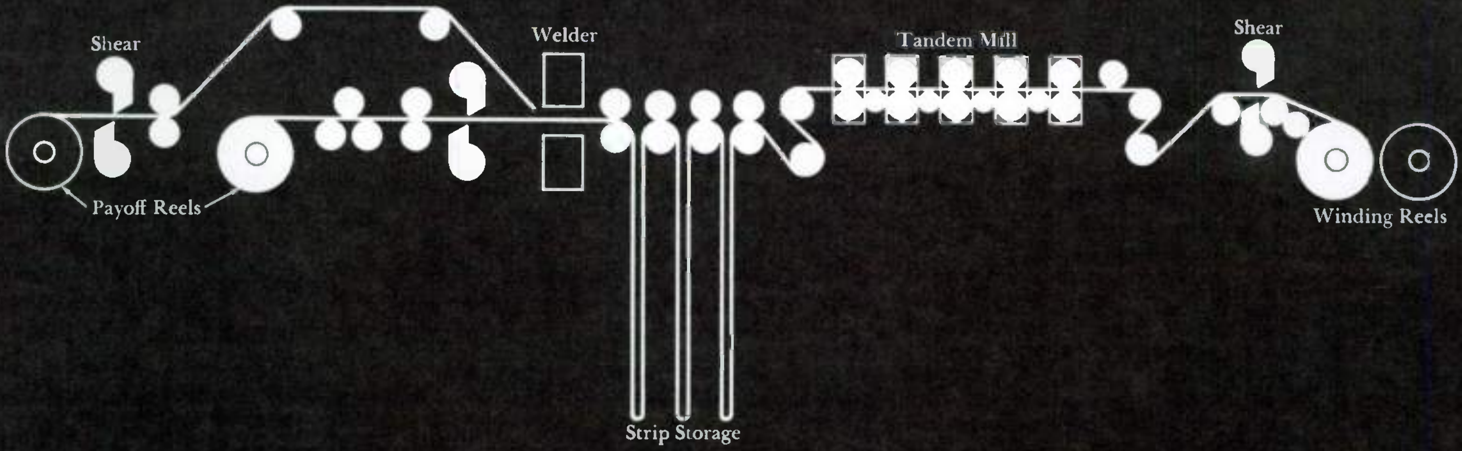
The stored-program approach realizes the major benefits of computer control with minimum interference to mill production objectives. All known schedule data is used, and it can be checked by the operators of the process before the process starts.

The ultimate in production control and optimizing will be realized with the application of the on-line digital control computer. This type of computer control upgrades the process toward an optimum goal by on-line sensing of process conditions. The production facility must be committed to this approach, as the com-



2—Speed-regulated stand drive operates the motor at its maximum torque capability at all speeds. Its power supply can be either a dc generator or a thyristor dual converter.


Thyristor Power Supply
Screwdown Control
Reset
Manual
M
Stand 1
Stand 2
Stand 3
Stand 4
Stand 5
Tensiometer
X Ray Gauge
Strip
Winding Reel
Load Cell
Entry AGC
Delivery AGC
M
G
Stand Speed Regulator
Reel Tension Regulator
Tension Adjust
Reference


Shear
Welder
Tandem Mill
Shear
Payoff Reels
Winding Reels
Strip Storage

puter operates in series with the actual process and therefore can only be proven out by sample operation on the mill with the product and total mill operation involved. Two optimizing computer control systems have been applied and are scheduled for start-up this year on six-stand tandem cold mills.

The objective with this type of computer is to compute, from model equations, the setup functions required to operate the mill. These include such items as each stand's screwdown position, stand speed, interstand tension, sideguard position, entry- and delivery-reel tensions, and AGC references. All of this will be accomplished by entering into the computer only the incoming product identification and dimensions and the desired finished product dimensions.

An important step in realizing this objective will be the period, during start-up and for some time thereafter, when the computer performs an engineering and production data-logging function off-line. Data will have to be accumulated for program analysis and updating because there are some unknowns in the mathematical relations between roll separation forces and strip reduction.

On-line computer control should eventually guarantee much faster start-ups because of the relative freedom from the operator learning period. Operation at any time, in fact, will be free from dependence on operator experience and from limitation by human deficiencies.

3—Speed regulation is exploited in a new automatic gauge control system. With stand acceleration lags almost eliminated, interstand tension can be sensed and used to control gauge accurately.

4—Continuous cold rolling is made possible by recent advances in technology, primarily in programmed control and speed regulation. At the front of the mill, the head end of a fresh coil of strip is welded to the tail end of the exhausted coil without stopping the mill. When a reel is filled at the delivery end of the mill, the strip is sheared and started winding on an empty reel. Continuous rolling maintains maximum mill production by keeping strip always in the mill. It also reduces material handling, eliminates the need for automatic threading equipment, and reduces marking of the work rolls and back-up rolls.

Application of computers to processes such as cold rolling opens the door to broader automation techniques and management control—not just of a mill, but of the entire plant business activity. Communication links will marry business computers with process computers to permit overall control of throughput from steelmaking to finished product. This concept is generally referred to as integrated production control; it is stimulated both by the application of computers to unit processes such as cold mills and by the need to maintain economic control of the whole plant to cope with the various economic pressures affecting the metals industry. Thus, computer application is an important step toward the goal of the total automatic plant.

Continuous Rolling

One of the major expenses in metals plants is that of handling the product, and it adds nothing to the product value. This fact has stimulated interest in the idea of continuous rolling, especially in the tandem mill. The concept is not new, but its implementation has been inhibited mostly by lack of the proper systems tools. Now, however, all of the electrical hardware is available, and this progressive step has already been taken with a five-stand mill for aluminum (Fig. 4). It could just as well be applied in the steel industry.

One of the main reasons continuous rolling is electrically feasible today is that better process control, in the form of the speed-regulated drive, is available. Also, availability of the schedule program computer permits fast setup of the many mill operating variables required for schedule changes. This is a must for continuous operation; in fact, it would be impossible or at least prohibitive in wasted strip to do it manually. The fast response of thyristor armature power supplies for the screwdowns and other positioned auxiliaries assures minimum time for schedule changes, and modern fast-responding static control amplifiers assure good control of the mill under the conditions of continuous operation.

Continuous rolling is attractive economically for several reasons. First, it greatly reduces material handling. It also eliminates the need for automatic threading, one of the most likely areas for mechanical and electrical problems. Marking of work and back-up rolls is principally caused by loading and unloading the mill, as is done in all conventional mills, so longer runs between roll changes and consequently more production should be expected from a continuous mill. Less off-gauge strip can be expected on schedule repeats as there is no loss of interstand tension control at tail or front ends as there is in conventional mill setup. Finally, maximum product capability in production per hour results from continuous rather than intermittent methods.

To achieve continuous rolling, the plant process flow and mechanical equipment must be designed to accommodate it. The mill needs an electrical system capable of continuous operation, and a computer to permit fast changes in schedules as product changes are demanded.

A continuous tandem mill could be coupled with the pickle line to further extend the continuous concept. Tonnage capacity of pickle lines has been increasing, and the continuous concept would permit volume production without the need for mill speeds as high as those for which some present five-stand mills are designed. While economic justification of the concept has not yet been proved, it would seem wise when planning facilities expansions to locate the pickle line and the tandem cold mill in line. Then they could be operated together when circumstances warranted and independently when the capacity of either might be limited by stoppages in the other.

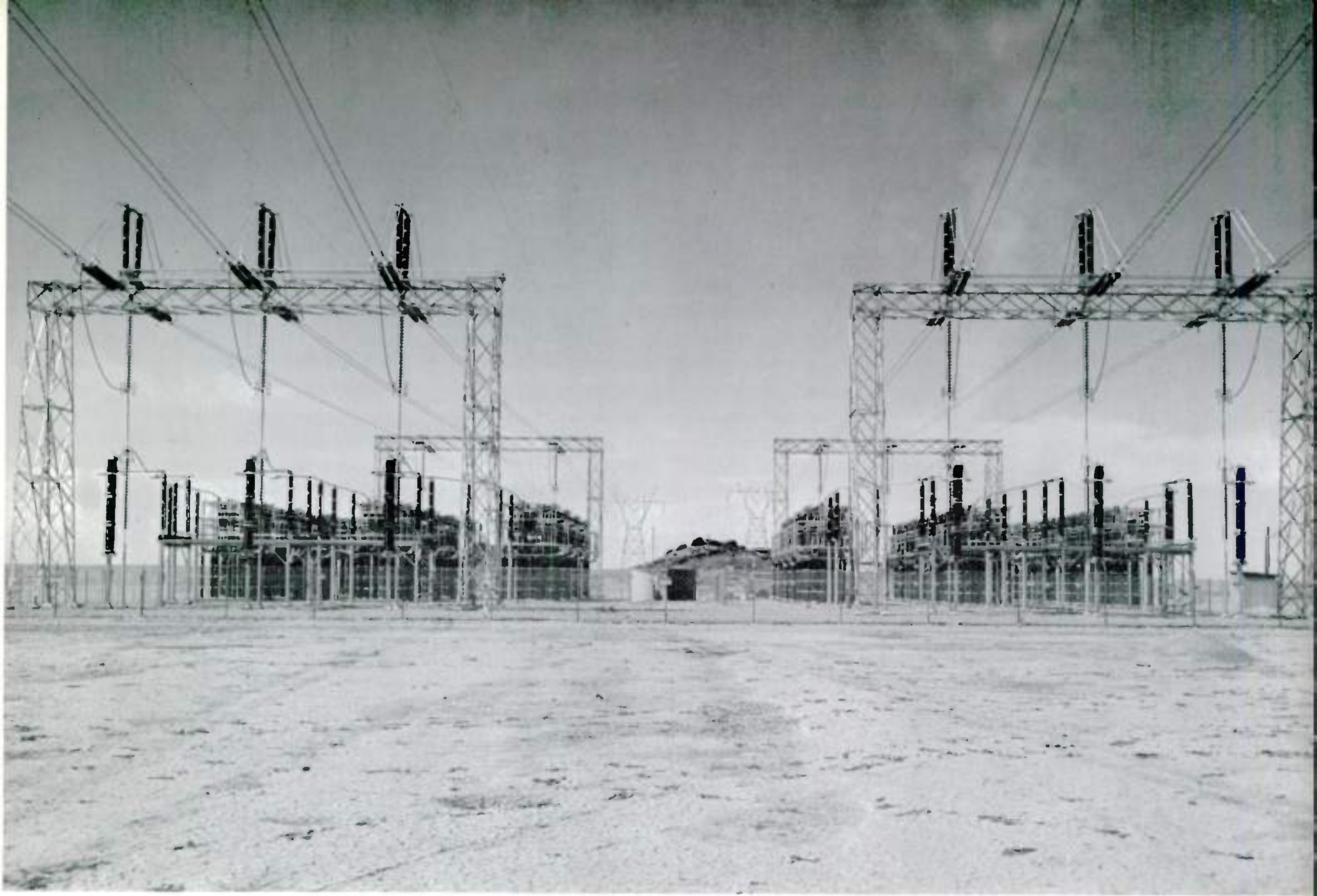
Conclusion

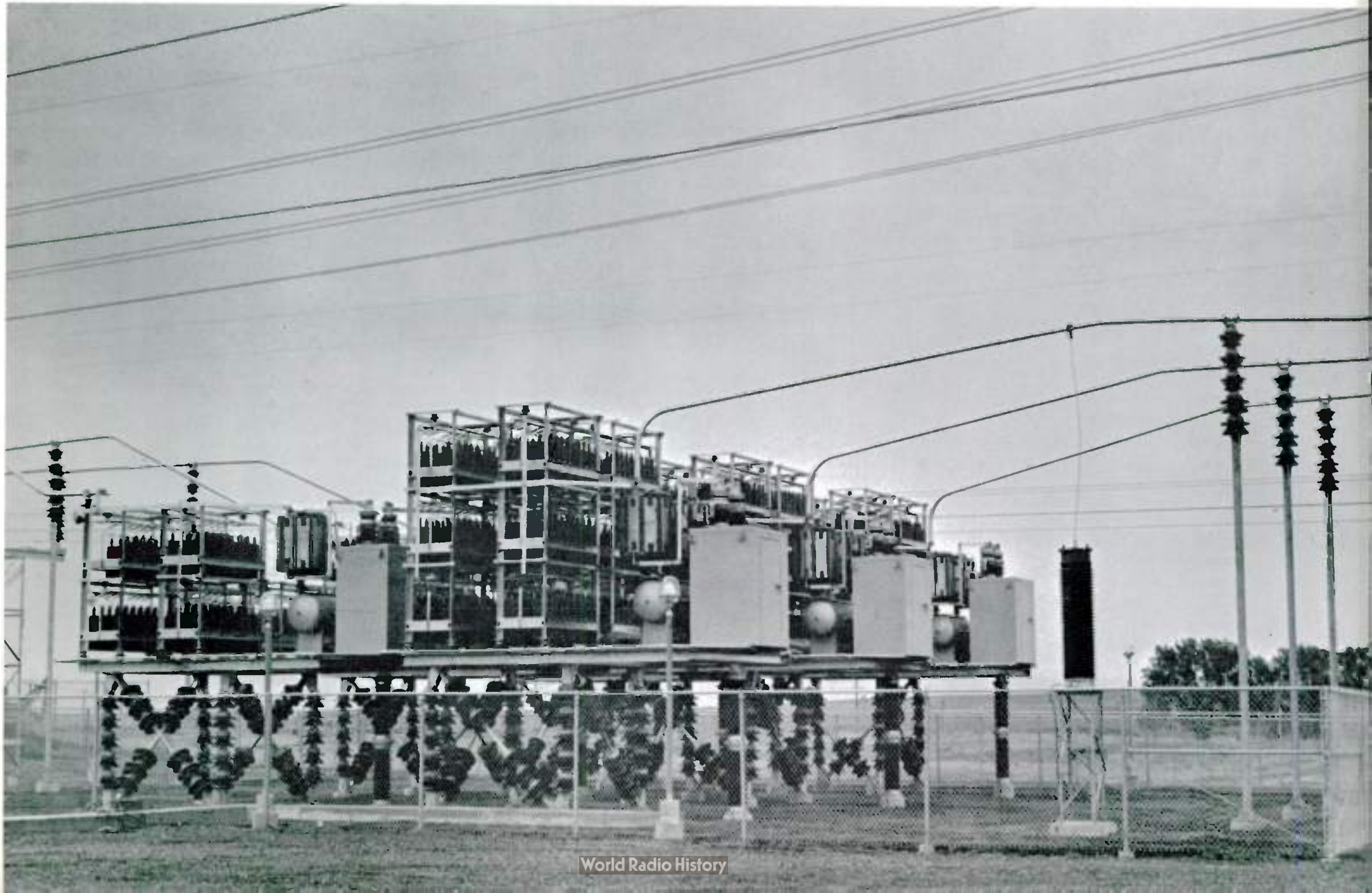
Recent technological improvements can improve cold-mill efficiency and thus maximize quality throughput for the investment. However, progress toward a completely automated product-producing system requires a planned realistic approach by the metal producer, mill builder, and electrical supplier.

Westinghouse ENGINEER **January 1967**

---

[1] Stringer, L. F., and Tresino, L. R., "Thyristor-Power DC Drive Systems," *Westinghouse ENGINEER*, September 1966, p. 154.





Series Capacitors for EHV Transmission Lines

W. H. Cuttino
J. E. O'Neil
A. B. Pyle

The accumulated years of service with series capacitor installations have demonstrated both the reliability and the favorable economics of this approach. When designed to fit a utility system, the series capacitor bank will permit larger blocks of power to be transferred over long EHV transmission lines, improve system stability, or both.

When the 500-kv Northwest-Southwest Intertie on the Pacific Coast goes into operation in mid-1967, over five million kvar of series capacitance will be installed in 30 separate banks to increase the load capability of the system. This decision to use series capacitors reflects the success of 20 years of reliable service accumulated with transmission series capacitors, beginning with a 10,000-kvar bank on a 66-kv line on the Duquesne Light Company system in 1947.

The series capacitor has proved to be an economical and useful tool when system stability is in question because of long lines, or because large blocks of power are to be transferred, or both. The series capacitor makes possible either an improvement in the transient-stability margin for a given power transfer or an increase in transmitted power for a given transient-stability margin.

The fundamental advantage of series capacitor compensation over shunt compensation is the instantaneous voltage regulation provided. Since the series capacitor carries full line current, the reactive voltage across the series bank changes instantaneously with line current (whereas the voltage across a shunt installation remains substantially constant). Thus, the reactive voltage across the series capacitor directly offsets the reactive voltage drop of line series inductance for all load conditions.

The power transfer capability of a transmission line can be expressed,

$$P=\frac{E_s E_r}{X_L-X_C}\sin\theta$$

where E_s is sending-end voltage, E_r is receiving-end voltage, θ is the angle between these voltages, and X_L is the series inductive reactance of the transmission line. Series capacitors (X_C) reduce the total transmission line reactance, and also the angle θ across the line for any given power transfer.

Another application for series capacitors on transmission lines is load division among parallel lines. Load division may be needed because of different thermal ratings of line conductors, different line lengths due to routing, different transmission voltages, or different conductor impedances. Series capacitors are preferable to inductive phase shifters for dividing load among parallel circuits because capacitors provide an overall increase in load-transfer capability of the system and have inherent balancing characteristics for all load conditions.

In addition to the technical and physical improvements in series capacitor banks over the years, an equally significant development has been the reduction in installed cost. Ten years ago, the cost of series capacitors exceeded \$10 per kvar; today, large ehv banks can be installed for less than \$4 per kvar.

Protection and Control

Since the series capacitor bank is in series with the line, the equipment must withstand both normal and abnormal electrical, as well as mechanical, conditions to which it may be exposed. If fault current exceeds the capacitor capability the installation must quickly bypass itself and permit the system to operate without compensation. The protective equipment must not only include self-protection for the bank, but to obtain maximum advantage from the series capacitor in maintaining system stability, the series capacitor should be reinserted with minimum delay after the fault is cleared.

Protective equipment is also required, in some applications, to increase the compensation after a fault by inserting additional capacitors. This is a recent innovation brought about by the increasing vulnerability of the power system to heavy faults.

The basic unit in the protective scheme for series capacitors is called a segment, a series-parallel grouping of capacitors protected by its own set of protective relays, controls, and bypass gap-switch. Each phase of the series capacitor bank consists of one or more segments, arranged to carry required load current and provide the necessary ohms of compensation.

Steady-State Protection is provided the basic capacitor segment by first designing a capacitor unit on the basis of thermal and dielectric strength requirements imposed. Sufficient units are paralleled to provide the necessary steady-state current-carrying capacity, and sufficient paralleled units are put in series to provide the desired capacitive reactance.

The number of units in parallel is usually large and this dictates the first protective device consideration—the capacitor unit fuse. Capacitor units and their connecting circuits have extremely low inductance, so that if a single capacitor fails, the discharge of paralleled units through it could exceed its case rupture watt-second capability in a few milliseconds. Therefore, the fuse and fusing technique is important, and individual unit fuses (Fig. 1) must be used. For large capacitor installations, the silver-sand current-limiting fuse (Type CLCO) is most frequently used.

If too many capacitor units in one parallel group are disconnected by individual fuse operation, the remaining capacitors can be damaged by unequal voltage distribution in the segment. To guard against this situation, a differential relay is used as shown in Fig. 1. Operation of the differential relay on any segment causes that segment of the capacitor bank

---

W. H. Cuttino is a Senior Design Engineer and A. B. Pyle is an Application Engineer at the Distribution Apparatus Division, Westinghouse Electric Corporation, Bloomington, Indiana; J. E. O'Neil is a Sponsor Engineer in Electric Utility Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

Above—This series-capacitor installation on the Arizona Public Service Company's system consists of two 345-kv, 147,000-kvar banks. Each 345-kv line has its own series capacitor bank. Each bank is composed of 3½ segments per phase, which can be expanded into 5 segments per phase in half-segment steps. Reactive compensation is presently 50 percent, but can be increased to 70 percent.

Below—One of two 230-kv, 79,200-kvar series capacitor banks installed at Idaho Power Company's Midpoint Substation in 1966.

to be bypassed when damaging overvoltages occur.

Another steady-state protective device shown in Fig. 1 is the voltage relay connected across each segment. This replica relay monitors voltage across the segment, and if the volt-time operating characteristic of the capacitors is exceeded, the relay operates, causing the segment to be shorted. A combination current-thermal element can also be used to perform the same function.

Whenever a segment is shorted for any reason, such as operation of the differential relay or replica relay, corresponding segments in the other two phases will be shorted automatically by the protective devices to maintain balanced compensation.

Capacitors are capable of operating above nameplate voltage ratings for specified lengths of time. It is possible to take advantage of this capability when designing the protective equipment and still protect the capacitors from thermal failure.

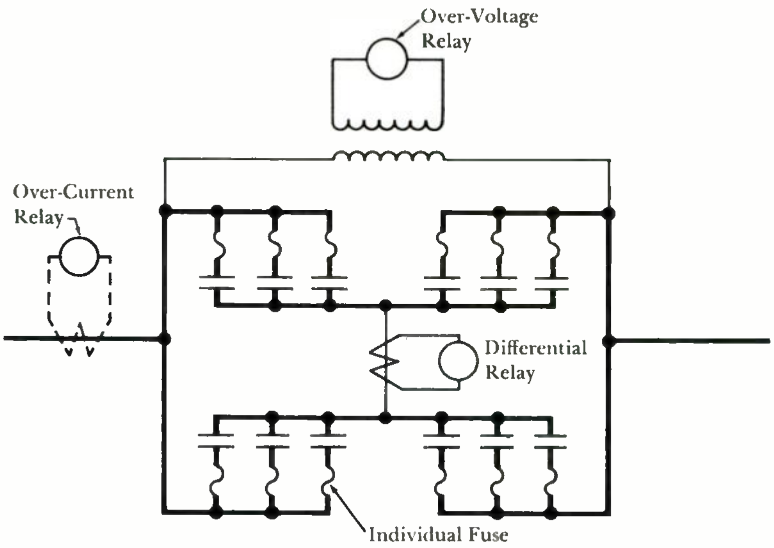
Transient-Voltage Protection

System switching and lightning surges produce voltage line-to-ground as well as along the conductor. The first consideration in protecting a series capacitor bank from these transients must be sufficient line-to-ground insulation to withstand the possible overvoltages. Lightning arresters can be applied at one end of the capacitor installation if desired.

The through impedance of the series capacitor is low to switching or lightning surges so that bypass protection against these transients is not required. However, high voltages across the capacitor bank will be caused by normal-frequency overcurrents. The bank or segment must be protected against these overcurrents. This protection is provided by the bypass gap arrangement shown in Fig. 2.

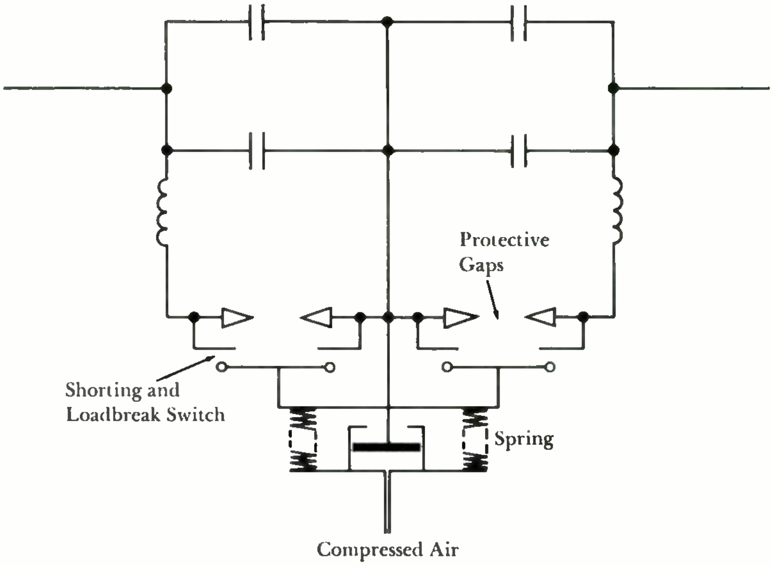
The transient condition most likely to cause sparkover of the bypass gaps is a system fault. Fault current through the

1



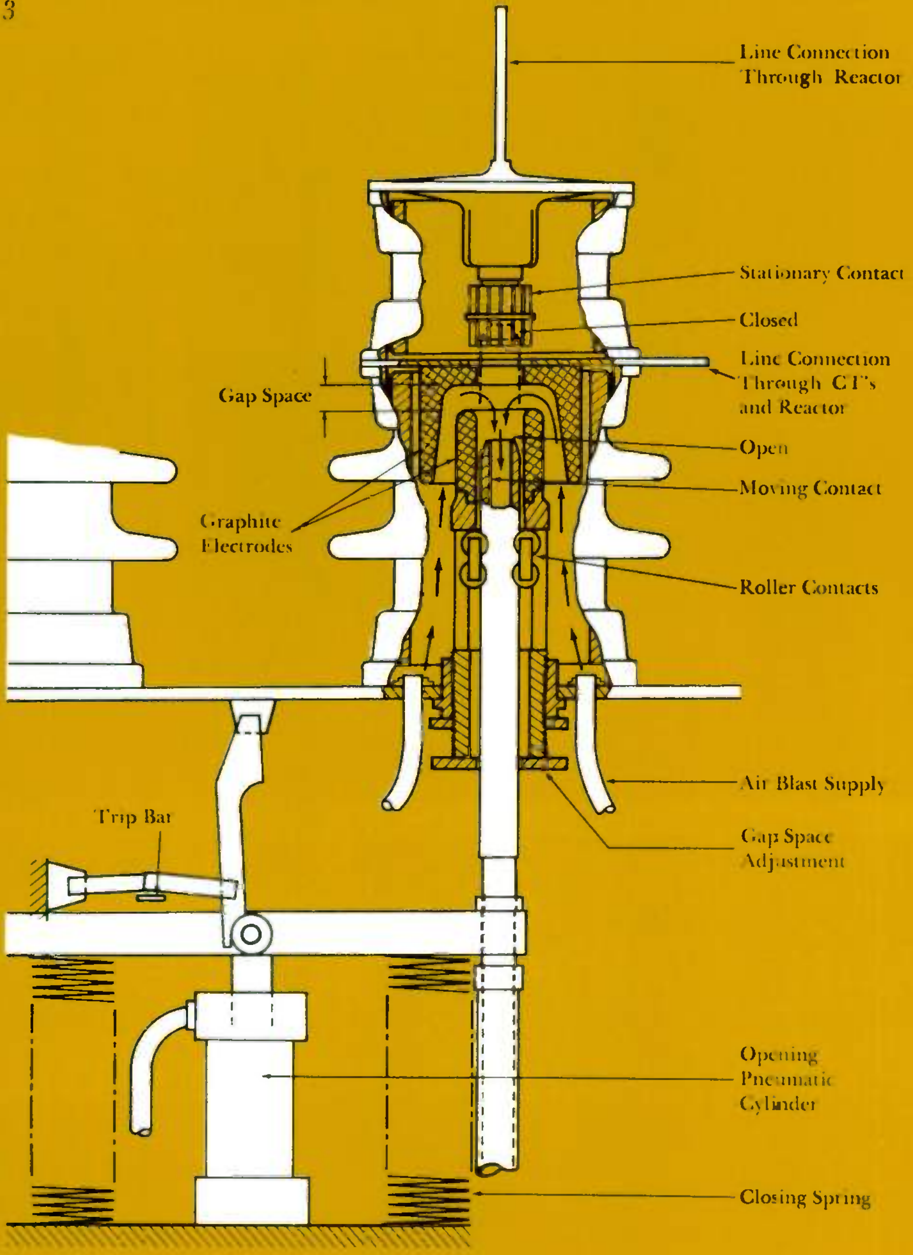
1—Protective scheme for series-capacitor segment.

2



2—Protective gap and shorting switch arrangement for series capacitor segment.

3



3—This series-capacitor bypass gap protects capacitors from damaging overvoltages. When high overvoltage occurs, the gap between carbon electrodes breaks down. An air blast interrupts load current to reinsert the capacitor when overcurent has decayed to normal values.

capacitor causes excessive voltage (IX_c) across the gap. Since the capacitor voltage has been raised to the gap sparkover value before the gap operates, reactance must be added in series with the gap to limit the capacitor peak discharge current to less than the fuse melting current and reduce the duty on the capacitor units during the discharge.

If the system fault clears normally, the protective gap interrupts the resultant load current, reinserting the capacitor bank. An automatically activated air blast system aids the gap in interrupting the load current.

If the system fault persists due to relay or breaker malfunctions, the bypass switch is automatically closed and the capacitor bank is removed from the system until manually reinserted.

Shorting and Load-Break Switch

The switch that is automatically closed to bypass the capacitor segment during extended system faults is the same switch that is operated by the steady-state protective devices already discussed. The switch mechanism (Fig. 3) has been a unique part of Westinghouse series capacitor banks for several years. The switch is opened by compressed air and closed by a spring charged during the opening operation. The switch normally remains open during faults unless the fault persists longer than considered safe for the gap, in which case it is automatically closed as mentioned above. The switch can be closed by signals from any of the protective circuits already discussed, or from ground level controls.

Compressed air for operating the switch is transmitted from ground level by an air column enclosed in one of the porcelain insulating support columns under each segment. Commands to close or open the shorting switch are sent through this air column. If, for any reason, a switch closes to bypass a segment in one phase, closing signals are automatically sent via these columns to the comparable capacitor segment in the other two phases so that all three phases maintain balanced compensation.

The protective and control circuits on each segment assure that the series capacitor banks are functioning properly, or if they are not, the bank is bypassed to permit the system to operate without compensation. These automatic protective circuits operate only when the series capacitor capabilities are being exceeded. Thus, the bank will be bypassed automatically by the switch only when maintenance is required.

Designing an Installation

The amount of compensation that one set of protective equipment can adequately protect is obviously restricted. In addition, the electrical configuration also influences the cost of the series capacitor, since the configuration will determine the number of protective equipments required. For example, two series capacitor banks, each containing the same kvar, might have the arrangements shown in Fig. 4. Although the kvar is the same in both examples, the dollars per kvar for bank (*a*) will be significantly higher than for bank (*b*) because twice as much protective equipment is used.

Many interrelated factors determine the ideal bank configuration and must be carefully evaluated before a configuration is selected. Some of the more important factors to consider in designing the bank are the following:

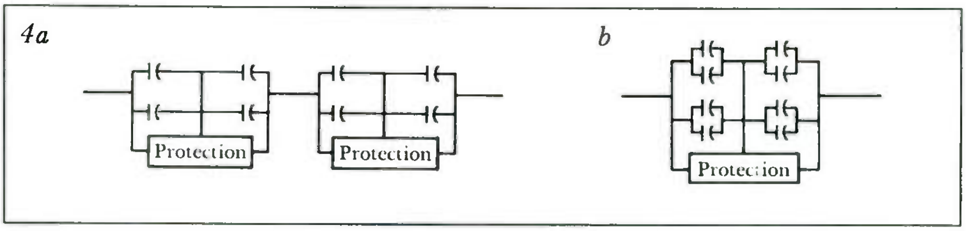
Continuous current and phase reactance—Most basic of all required information is the continuous-current rating and the reactance (X_c) per phase. Total kvar per phase (I^2X_c) provided by capacitors is the major determinant of total cost of large banks.

The voltage existing across the series capacitor (IX_c) is the major factor in determining how many sets of protective equipment will be required.

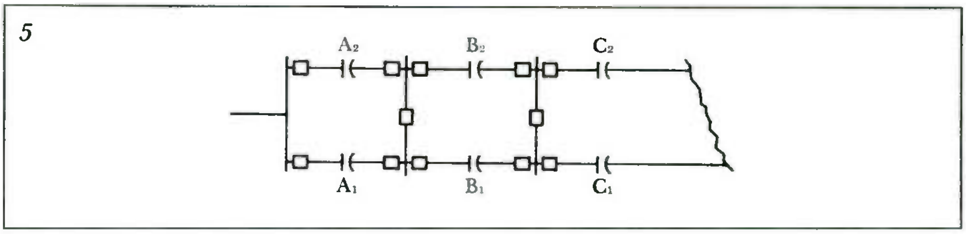
Both ohms and continuous-current rating should be considered in terms of initial and possible future requirements.

Table I—Large Series Capacitor Installations

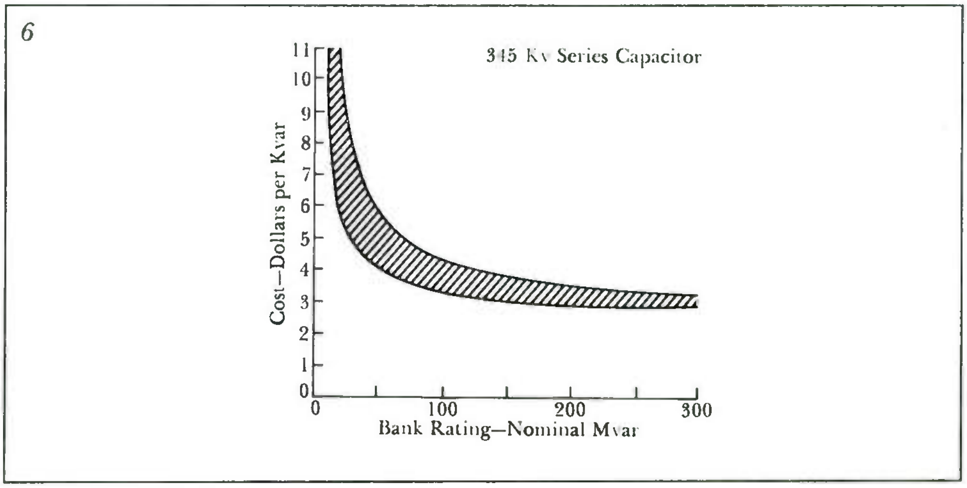
Year	Purchaser	Bank Ratings (Kv)	Size/Bank (Kvar, Approx)
1947	Duquesne Light Company	66	10,000
1951	Bonneville Power Administration	230	24,000 46,000 82,500
1954	City of Los Angeles	287	7,500
1956	Louisiana Power & Light Company	161	57,000
1958	Bonneville Power Administration	345	113,400
1961	Tennessee Valley Authority	46	18,000
1961	Arizona Public Service Company	69	9,600
1963	Pacific Power & Light Company	230	115,200
1964	Arizona Public Service Company	345	147,000 147,000
1965	Southern California Edison Company (Test Bank)	287	6,600
1966	Idaho Power Company	230	79,200 79,200
1966-67	Pacific Coast Northwest-Southwest Intertie (30 banks)	500	5,600,000



4—These two series-capacitor configurations have the same total kvar, but segment arrangement (*a*) requires more protective equipment than (*b*).



5—Paralleled transmission lines with series capacitors.



6—Typical cost per kvar of uninstalled series capacitors for 345-kv transmission line.

To provide for a future increase in continuous current, space must be provided on the insulated platforms for additional parallel capacitors. Adding capacitors in parallel will, of course, decrease the capacitive reactance. The substation layout should be planned to permit additional insulated platforms in series if the compensation is to be maintained or increased.

Maximum emergency current and duration—Assuming that the capacitors are designed to operate continuously at rated voltage, line currents in excess of that which produces rated voltage on the capacitor will subject the capacitor to potentially dangerous overvoltages. The ability of the capacitor to withstand these overvoltages without significant loss of capacitor life is a function of the degree of overvoltage, its duration, the capacitor unit design, and the prior load current.

It may be necessary, or desirable, to operate a series capacitor bank at more than rated voltage for limited periods of time. For example, in Fig. 5, if line section B_1 is removed from service by breaker operation in the section, the load could be transferred to section B_2, thereby theoretically doubling the line current through its series capacitor. The capacitor bank (B_2) can be designed to meet this condition assuming that it prevails only briefly, and that the line is unloaded on a programmed basis to some lower value of current close to the nominal line current. The desired overcurrent-time profile of the system must be known to adequately design the capacitor bank.

Actually, the capacitor bank could be designed to carry twice normal line current continuously, but this alternative would significantly increase the cost of the installation.

Protective Gap Setting—When a sudden large increase in line current occurs, such as a line fault, the protective gap will spark over and bypass the series capacitor. System parameters, including relaying considerations, determine the approximate gap setting (within the limits of 1.5 to 3.75 times rated current, ±10 percent tolerance). An important consideration is the coordination of individual fuses to handle the energy stored in the capacitors at the time of gap sparkover. This energy must be discharged through the protective equipment circuit, and since stored energy varies directly as E^2, capacitor banks with high gap-sparkover settings require careful consideration in the bank design.

Maximum swing current—Assuming that whatever condition caused the gap to spark over was transient and current quickly returned to residual line current, the protective equipment will function to extinguish the arc, restoring the capacitors to service. At this time, a transient swing current may develop between the source and load end of the line. The minimum gap sparkover setting should accommodate this swing current without sparking over.

Maximum reinsertion current—At the time the protective equipment functions to extinguish the arc, line current can be much higher than prior to the fault depending on total system load and the line sectionalizing involved. The recovery voltage across the gap, which is directly proportional to line current at the instant of current zero, is a major factor in determining the number of segments required.

Maximum fault current rating of protective equipment—Fault current flows through the protective bypass equipment only when the series capacitor is bypassed by gap sparkover or by closing of the gap switch. In either case, transmission line impedance is increased because the capacitor compensation has been eliminated. For proper application the system fault current with the capacitor bypassed must be less than the momentary rating of the protective equipment.

Speed of reinsertion following clearing of a fault on the system—The protective equipment is designed to automatically reinsert the series capacitor in the line within a few cycles after a fault has been cleared. The magnitude of the current just prior to arc extinction affects the degree of ionization in the arc chamber, which in turn affects the exact time required to deionize the chamber and reinsert the capacitor.

In some cases, the fault current through the gap may not be as high as the maximum available fault current, and for maximum economy in the bank design this should be considered.

Depending on system stability requirements, and the type of protective relaying, delayed reinsertion of the series capacitor may be desired. This can also affect the design of protective equipment.

System voltage and BIL requirements—Each combination of capacitors and protective equipment (segment) is mounted on a structural steel platform. This entire platform assembly is supported on insulation as required by system voltage and BIL requirements. The cost of insulation for any specific system voltage could be affected to a minor degree by special requirements of BIL, switching surge withstand, extra creep, etc.

Miscellaneous—Data on elevation above sea level, range of ambient temperature, availability of low-voltage control power, etc., is also required to complete the final design of the installation. Unless these requirements are unusual, they will not have a significant effect on cost.

Preliminary Estimates

Obviously, accurate data encompassing all of the above considerations is not available early in the planning stages of transmission lines and series-capacitor applications. However, some preliminary estimates of the cost of series capacitor installations can be made.

With present designs of series capacitor banks, and with normal technical requirements, the curve shown in Fig. 6 provides a reasonable estimate of the uninstalled cost for most series capacitor installations. This curve applies to 345-kv systems. The increase or decrease in cost for 500-kv or 230-kv applications would be less than 10¢/kvar for banks larger than 40 mvar.

In some recent applications, the installation of a series capacitor bank has increased the power handling capability sufficiently to eliminate the need for a parallel transmission line. Cost savings that have resulted have been as high as 10 to 1. Thus, the future should see an increase in the application of series capacitors at all transmission voltages.

Sunken Offshore Oil Platform Salvaged with Aid of Advanced Diving System

A hurricane-wrecked offshore oil-well platform was salvaged quickly, and the wells plugged, by divers working up to six hours at a time at depths exceeding 200 feet.

An offshore oil-well platform, demolished and submerged by a hurricane in 1965, was recently salvaged in record time through use of an advanced diving technique that permitted prolonged dives on regular shifts. Working in the Gulf of Mexico 30 miles off the Louisiana shore, divers put in up to six hours a day in water up to 235 feet deep.

Divers with conventional equipment have never been able to work at such depths for anything like six hours. The major limitations have been the complex physiological effects of gases dissolved under pressure in the blood and tissues (especially when air is used for breathing), the low temperatures in deep water, and time required to decompress slowly on the way up. If a diver with conventional equipment works 30 minutes at 200 feet, for example, decompression tables say he must spend 76 minutes decompressing to avoid "the bends."

The system that made the prolonged dives possible was built by the Underseas Division of the Westinghouse Defense and Space Center. It includes pressure chambers that keep a crew of divers at working-depth pressure at all times, a special mixture of gases for breathing, and heated diving suits.

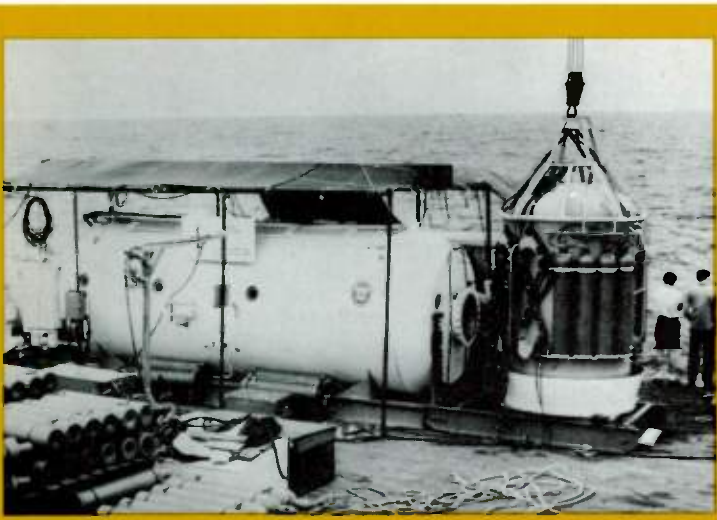
Some salvage experts had believed that the massive job might be impossible or, even if possible, that it could not be completed in one diving season. However, the Cachalot prolonged-submergence diving system enabled Marine Contracting, Incorporated, to do the job by keeping two crews of divers working around the clock six days a week through most of the period from June to mid-September.

This salvage operation was the second job for the new diving system. A three-month underwater repair project in the lake of Smith Mountain Dam near Roanoke, Virginia, was completed in December 1965. Divers worked in depths up to 200 feet on trash racks in the face of the pumped-storage hydroelectric dam.

Salvage Operations

The eight-leg offshore oil-well platform had been demolished by Hurricane Betsy in September 1965, and the eight producing wells under it were made useless by the damage. Storm chokes had shut off the oil flow, but the wells had to be permanently plugged.

The Cachalot system's surface chamber, a pressure vessel 27 feet long and 7 feet in diameter, was mounted on a derrick barge (see photos). It has an access lock that is big enough for two men and can serve also as a separate decompression chamber. The chamber itself is divided into two compartments that can be shut off from each other to form two additional independent chambers. There is room for three divers to eat, sleep, and occupy themselves in each of the two compartments while they are not working.



Cachalot diving system includes a surface pressure chamber, at left, in which the divers live when they are not working. The chamber eliminates the need for decompression in returning from the working depth and thereby saves much time. The diving chamber, at right, can be coupled to the surface chamber so men can pass from one to the other under full working-depth pressure. It carries two men to and from working depth. Long hoses connect the divers' breathing masks with gas cylinders on the outside of the chamber.

For the salvage operation, the Cachalot equipment was carried on a barge. A crane handled the diving chamber and brought up salvage.

Each of the two crews was kept under working-depth pressure for a week at a time. At the end of a week, that six-diver crew was replaced by the other crew. They lived in the surface chamber and were carried from there in teams of two by another pressure chamber, called the diving chamber, to the working depth.

At the end of their six-hour shift, the divers were brought up to be replaced by another of the three teams. By working three shifts, the divers were able to average 18 to 21 hours a day in the water. The rest of the time was spent in team rotation and in waiting for surface operations. Since the divers were at working-depth pressure at all times, they did not have to go through the time-consuming decompression process every time they returned to the surface.

The divers first did the bottom work necessary to plug the wells, making hose connections through which cement was pumped from the surface until its pressure equalled that of the oil in the wells. They then cut the wreckage apart with cutting torches and with shaped explosive charges. As pieces of wreckage were cut free, the divers attached cables to them and the derrick hoisted them to the barge.

System Operation

When a two-diver team goes to work, the men go through a pressurized transfer lock in the end of the surface chamber that is mated to a similar lock in the side of the diving chamber. They close the lock hatches and the support crew separates the diving chamber from the surface chamber. The diving chamber, which is nine feet in height and five feet in diameter, is lifted from its pad by the derrick, swung out over the water, and lowered to the work site. A heavy anchor makes the chamber sink, but in an emergency the anchor could be dropped and the buoyant chamber would rise.

The divers don their equipment while the submersible chamber is being lowered. They wear a special diving suit over which they put their breathing apparatus. The diving suit, also developed by Westinghouse, has internal tubes through which warm water is circulated to keep the diver warm. Water temperature at the working depth was about 50 degrees F; although this is not very cold, divers could work in it only for about an hour were it not for the suit.

The breathing apparatus consists of a breathing vest, two canisters of carbon-dioxide absorbant, and a face mask with an internal oral-nasal mask. The breathing vest has an inhalation bag and an exhalation bag. The inhalation bag is connected at its inlet to a gas pressure regulator that keeps the bag filled, and the regulator is connected to a line that runs back to the cylinders of premixed gas secured around the outside of the diving chamber. At its outlet, the inhalation bag is connected to the oral-nasal mask through which the diver receives his breathing mixture of oxygen and helium. The flexible bags store the breathing mixture at the working-depth pressure—the same pressure the diver's body is subjected to. This assures that there will be no pressure differential and consequently prevents injury to the diver's respiratory system; it also conserves gas.

The exhalation bag is connected at its inlet to the breathing mask. At its outlet, it is connected to the canisters of carbon-dioxide absorbant the diver wears on his back. The breathing mixture passes through the absorbant, the carbon dioxide is removed, and the "scrubbed" gas is returned to the inhalation bag for reuse. On the way to the canisters, about 10 percent of the breathing mixture is exhausted into the water by a pressure valve. This valve assures that the pressure in the exhalation bag also is at a safe level.

A special gas mixture is necessary in deep diving for two reasons. First, too high a concentration of oxygen under pressure is toxic. Second, nitrogen, which makes up a high percentage of air, gives divers nitrogen narcosis—the "rapture of the deep." Helium, though costly, is the safest known nitrogen substitute and is therefore used most widely in deep diving. In the Cachalot system, reusing most of the helium helps keep cost down.

When the diving chamber reaches working depth, the divers open the hatch in its bottom and step out. Long hoses supply their breathing mixture to the breathing-vest regulators. Attached to the gas hoses are a telephone line by which the divers can talk with the surface support crew, an electric power line for lights if needed, an instrumentation cable, and the line that supplies warm water to the diving suit.

After working their shift, the divers are brought back to the surface in the diving chamber, which is remated to the surface chamber. They remove their gear, clean up with a shower installed in the submersible chamber, and reenter the surface chamber. Another team takes their place and descends to work.

Setting Records

By the end of the Gulf project, the Cachalot system had long passed all records for man-hours of prolonged-submergence time. Westinghouse engineers estimate, on the basis of its performance in 4000 man-hours of prolonged submergence at Smith Mountain Dam and in the Gulf, that the system is about 80 percent efficient in terms of utilization of a diver's working and decompression time. By this standard, at the depths the Cachalot system has been working at, conventional decompression diving is only about five percent efficient.

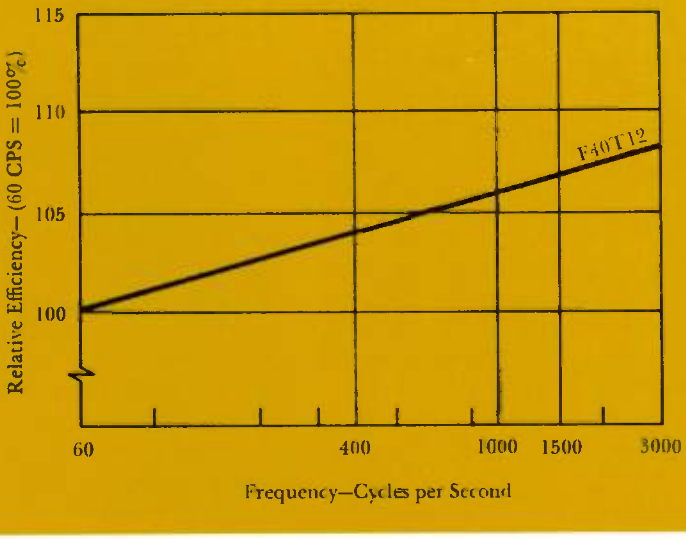
Another record set was in the number of saturation runs. A saturation run is a period of time during which a diver is exposed to a breathing mixture under pressure long enough to completely saturate his body with the mixture's inert gas. Since divers are usually brought out from pressure before they become saturated, there is not much data on saturation. With its 32 saturation runs to date, the Cachalot system proved that divers can withstand long and repeated periods of saturation with no apparent ill effects, and it supplied other information.

The Cachalot system is not limited to the depths at which it has been used so far; it is designed for diving to 450 feet. Moreover, by the time a capability for depths of more than 450 feet is needed, Westinghouse engineers expect to be ready with an 800-foot prolonged-submergence system now under construction.

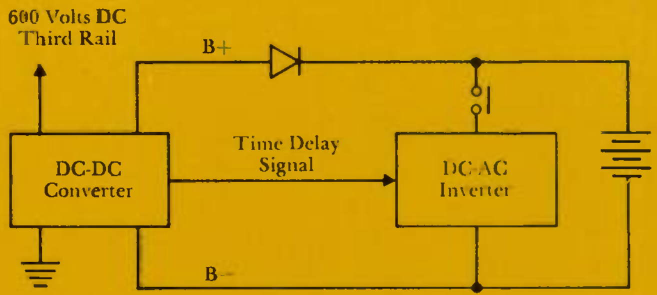
High-Frequency Fluorescent Lighting for Rapid Transit Service

T. D. Sanders

1



2



New power conversion systems using thyristors have made 1500-cycle fluorescent lighting economic and reliable.

Significant improvements in rapid-transit car lighting have been made possible by the advent of solid-state power switching devices. The potential advantages of high-frequency fluorescent lighting have long been known—higher lamp efficiency and reduced size and power loss of ballasts. But until recently, these advantages were offset by the need for cumbersome equipment to convert the high dc voltage used for propulsion equipment to a suitable high-frequency voltage for lamps. Using today's solid-state technology, small lightweight and efficient power conversion equipment now makes this voltage transformation practicable. As a result, the rapid transit industry has taken a major step in improving transit car lighting. The benefits expected include more light from the same number of lamps and reduced maintenance.

Conventional Lighting Systems

Until 1948, dc operated incandescent lamps were the primary means of illuminating rail cars. Even as late as 1964, when high-frequency fluorescent lighting was introduced, incandescent lamps continued to be used on more than half the transit properties in the United States. Incandescent lamps have the fundamental advantage of lower initial cost because conversion equipment or ballast is not required. Unfortunately, the efficiency of the incandescent lamp is poor. It provides only 14 lumens per watt (Table I), compared to about 200 lumens per watt for a white light with theoretically 100 percent efficient energy conversion.

A more efficient light source (about 80 lumens per watt) that also does not require power conversion equipment is the dc operated fluorescent lamp; however, it also has disadvantages. Because fluorescent lamps have a negative volt-ampere characteristic, some means of ballasting must be provided to limit lamp current. For dc operated lamps, ballasting is done with a resistor. Thus, while lamp efficiency when operated on dc is comparable to that obtained on ac, the greater I^2R loss in the ballasting resistor reduces overall lumens-per-watt efficiency of a dc fluorescent system to about 60 percent of an ac system.

Another disadvantage of dc fluorescent operation is that the steady flow of direct current in one direction forces the mercury molecules to one end of the tube, resulting in inadequate generation of ultraviolet energy required for the fluorescence of the phosphors at the other end. In other words—no light is produced from approximately half the tube length. This effect is minimized by providing a polarity-reversing relay with a timer for periodic reversal of lamp voltage. But voltage reversal adds to maintenance problems, and lamp life is still reduced by about 20 percent.

Still another disadvantage of dc fluorescent lighting is that, to provide a voltage peak for starting, an inductive ballast must be provided in series with the ballasting resistor. This results in even further power loss and expense.

Despite these disadvantages, about half of the rapid transit properties have decided that the advantages of a dc fluorescent system over an incandescent system outweigh its disadvantages and have adopted the dc system.

Standard ac (110-volt, 60-cps) fluorescent lighting has been used for a number of years on suburban multiple-unit cars. This system generally requires a double conversion—from 600-volts dc to 32 or 64-volts dc to 100-volts ac via a motor-alternator. Although these systems have generally performed well, rotating inverters and their attendant voltage and frequency regulators require frequent maintenance for reliable operation.

High-Frequency Lighting

Although 60-cycle fluorescent lighting is more efficient than a dc fluorescent system, much further gains could be obtained by going to higher frequencies. The increase in lamp efficiency with fre-

Table I—Efficiencies of Various Light Sources

	Approximate Lumens per Watt
Candle (Luminous Efficiency Equivalent)	0.1
Oil Lamp (Luminous Efficiency Equivalent)	0.3
60 Watt Carbon Filament Lamp (1905)	4.0
60 Watt Tungsten Filament Lamp (1961)	14.0
40 Watt Fluorescent Lamp (1963)	79.3*
40 Watt Fluorescent Lamp (1500 cps) (1964)	85.0*

*Lamp only

Table II—Comparison of High and Low Frequency Ballast

Type of Lamp	*Ballast Size In Cubic Inches*	*Weight*	*Watts Loss*	*Frequency*
Rapid Start 2-48T12 40 Watt	35	3.75	16	60 cps
Rapid Start 2-48T12 40 Watt	35	3.75	4.5	1500 cps
Slimline 2-72T12 58 Watt	76	13.5	32	60 cps
Slimline 2-72T12 58 Watt	23.5	2.25	6	1500 cps

T. D. Sanders is with the Transportation Equipment Department, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

***Photos*—The lighting system for the PATH rapid-transit car is dramatically illustrated in this nighttime photograph. Inside the car, high-frequency fluorescent lighting operated from solid-state power conversion equipment provides constant illumination completely free from third-rail gap interruptions.**

1—Fluorescent lamp efficiency is a function of frequency.

2—Basic circuit of the 1500-cps fluorescent lighting system.

quency is illustrated in Fig. 1. Perhaps an even more significant comparison is provided by the reduced ballast losses, shown for 1500-cycle operation versus 60-cycle operation in Table II.

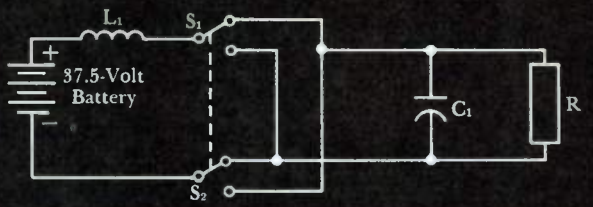
The first application of higher frequency lighting on rapid transit rail equipment in the United States came before static power conversion equipment had emerged from the development lab. Late in 1962, Westinghouse collaborated with the Chicago Transit Authority to equip a car with a 600-volt dc to 110-volt, 400-cps ac motor-alternator. Static voltage control was used and frequency regulation was accomplished by special motor design. A system dividend was obtained by rectifying the output for battery charging. This system eliminated all the disadvantages of dc fluorescent lamp operation and proved to be entirely satisfactory. Nevertheless, the rotating machine required regular maintenance. And since the maximum practical frequency obtainable with this method was only about 400 cycles, the real benefits of high-frequency operation were not realized.

The first 1500-cps application of high-frequency lighting on rail cars came in late 1963 when Westinghouse and the Long Island Railroad installed an experimental static inverter to replace a 32-volt dc to 110-volt ac motor-alternator in a double-conversion system. This 1500-cycle inverter was designed to fit into the space previously occupied by the motor-alternator control panel. The inverter weighed only one-fourth as much as the motor-alternator, and it had an efficiency of 85 percent, considerably higher than the rotating equipment. This system demonstrated real promise for eliminating routine maintenance and improving lighting levels.

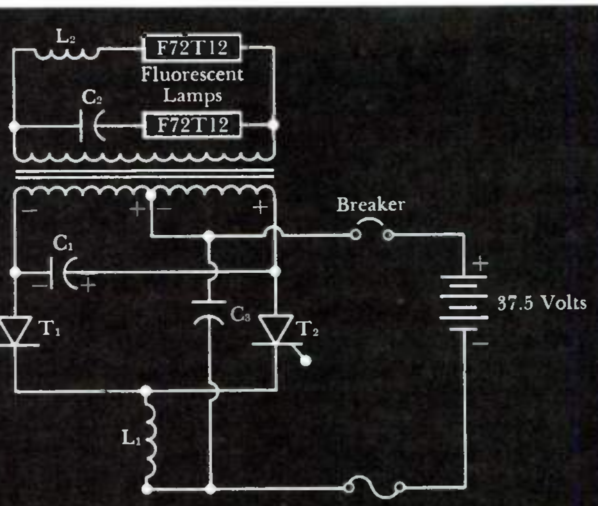
PATH Lighting System

In formulating a lighting system for the Port of New York Authority and their PATH cars, Westinghouse designers decided that to produce the most maintenance-free car, static components should be used wherever possible. A high-frequency lighting system was one area where static components could be used most effectively toward this end. Indeed, the PATH car specification called for the use of static components in this specific application. Such a system would avoid the disadvantages of dc operated lamps, and would have good lighting efficiency. A further goal was to eliminate the effects of third-rail gap (discontinuities in car

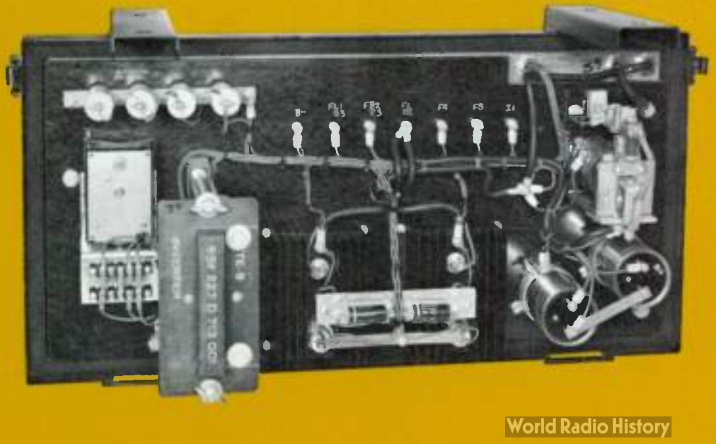
3a



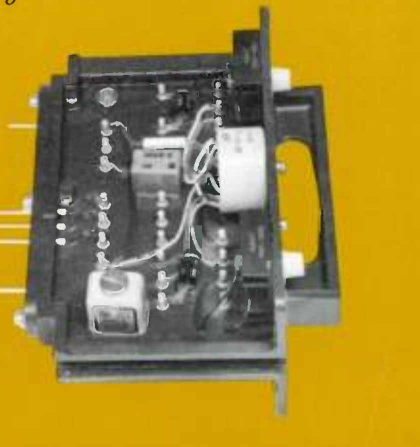
b



4a



b



electrical contact with power rail). And finally, designers wanted to use the simplest possible circuitry, consistent with good efficiency and reliability.

When a lighting system is operated directly from the third rail, so-called gap operation results. Besides inconvenience or annoyance to passengers when lights go out each time the train passes over a long third-rail gap, constant off-and-on operation severely reduces the life of a lamp. For example, the typical rated average life of a T8 Slimline fluorescent lamp is 7500 hours on a burning cycle of three hours per start. For two hours per start, life is reduced to about 6000 hours; at eight hours per start, life is increased to 10,000 hours; for continuous burning, lamp life is about 18,000 hours. This wide variation is due to the extra amount of emission material removed by the impact of the arc each time the lamp starts.

With direct operation from the third rail, gap effects are difficult to eliminate. The only practical approach is to trainline the third-rail voltage, i.e. distribute it along an electrical bus down the length of the train. However, trainlining high-voltage (600 volts) is usually undesirable and can be dangerous. Furthermore, when inverters are operated directly from the third rail, difficulties also arise because of high-voltage problems, not the least of which is the difficulty of designing inverters to withstand voltage surges on the third rail.

To avoid the inherent difficulties of direct third-rail operation, the PATH lighting system inverters are operated from relatively low-voltage batteries, whose charge is maintained by a second inverter, a dc-dc static inverter working from 600 to 32-volts dc. This method requires double conversion—from 600-volts dc to 32-volts dc, and then from 32 volts dc to 550-volts, 1500-cycles ac—similar to the standard 60-cycle fluorescent lighting systems mentioned earlier. The key difference in the PATH application, however, is that both the dc-dc converter and the dc-ac inverter are highly efficient, reliable and maintenance-free static equipment.

3—Simplified circuit diagram of the solid-state inverter used for high-frequency lighting. (*a*) Thyristor operation is illustrated by switch S_1-S_2, which operates at lighting frequency. In actual circuit (*b*), thyristors T_1-T_2 are pulsed to provide high-frequency switching.

4—(*a*) Inverter panel for high-frequency lighting system. In the center are heat sinks with thyristors and the associated protective networks. In the upper left is the commutating capacitor and in the lower right the filter capacitor. Not shown but mounted directly behind the panel are the power transformer, the inductor, and other heat-producing components. To the left of the heat sink is the plug-in card (*b*), which contains the frequency-setting oscillator and the thyristor pulse generation circuitry.

A block diagram of the system is shown in Fig. 2. The gap problem is eliminated with the battery, which carries the lights over the gaps. The low battery voltage (and isolation from voltage surges) permits uncomplicated inverter circuitry, small size and weight, and relatively low initial cost. Also, since converter output voltage is regulated, the inverter only needs to regulate frequency to obtain an essentially constant illumination level.

A simplified schematic of the high-frequency inverter power circuitry is shown in Fig. 3. The principle of operation is illustrated in Fig. 3a, where the thyristors (silicon controlled rectifiers) T_1 and T_2 are represented by a ganged switch, S_1 and S_2. As the switch is moved from one position to the other, the voltage across the load (C and R) is reversed. Thus, if S_1-S_2 is operated at a high repetition rate, an ac voltage appears across R and C. This voltage will be a quasi-sinewave because of the combined reactive effect of inductor L and capacitor C.

In the actual inverter circuit (Fig. 3b), T_1 and T_2 replace S_1 and S_2, the capacitor C_1 is used to turn off (or commutate) T_1 and T_2, and inductor L_1 limits current during switching so that the thyristors can be commutated.[1] The transformer steps the input voltage up to the proper voltage level for lamp operation.

The inverter panel is shown in Fig. 4a. The inverter cubicle, which houses the panel, is designed for undercar mounting with all components readily accessible when the cover is removed.

A close-up view of the control card is shown in Fig. 4b. Next to the control card on the panel is a static time-delay relay that de-energizes the inverter 10 to 15 seconds after the battery charger ceases operation. This arrangement carries lights over all gaps, but prevents complete discharge of the battery if battery charging stops.

Future of High-Frequency Lighting

Since 1500-cycle lighting offers advantages for commercial building applications similar to those for rail-car lighting, and these advantages have been demonstrated in pilot systems, there has been a consistent effort to promote the use of higher frequencies in commercial installations. Included in this effort is the exploration of an extended range of frequencies, the result of which is a static frequency converter that delivers power in a range of frequencies from 1000 to 4000 cycles. This range is obtainable by a smooth and continuous adjustment of a small rheostat.

The higher lamp efficiencies and lower ballast losses of high-frequency lighting would reduce air-conditioning loads for large office buildings. Coupled with this advantage is that large blocks of high-frequency power can be located at the point of usage with a minimal change in load-distribution circuitry.

Thus, with the superior performance of high-frequency fluorescent lighting established, and with the known favorable effects on initial cost and operation of air-conditioning systems, the economics of the situation indicate a future for high-frequency commercial lighting.

For rapid-transit car lighting, on the other hand, the economics of high-frequency lighting is already a proven reality because of the inherent disadvantages of dc lighting and the need for some form of power conversion from third-rail voltage to a more suitable ac lighting voltage. Solid-state converters and inverters now provide the efficient, reliable, and maintenance-free transformation needed to make 1500-cycle lighting economically attractive.

Westinghouse ENGINEER **January 1967**

Reference:

[1] For more complete description of thyristor operation, see "Static Fixed-Frequency Inverters," by K. M. Watkins, *Westinghouse ENGINEER*, July 1966, p. 101.

Forcing A Good Decision

M. J. Gelpi

This mathematical decision-making process differs from many others because it derives rather than assigns a relative ranking for each aspect of the problem being considered.

Good decisions don't "just happen." They are not the result of instinct, common sense, or experience—by themselves. Rather, good decisions result from weighing the relative values of each requirement against all possible solutions.

When one requirement is all-important, the right decision may be obvious. However, most decisions are not this simple. A combination of many requirements must usually be compared with several possible solutions. It becomes more difficult under these circumstances to make decisions with a high degree of confidence. The greater the number of variables, the greater the risk of neglecting an important factor, or assigning too little importance to some key aspect of the problem.

A number of means have been devised to aid the process of making good decisions. Comprehensive detailed statistical analyses can provide a sound decision-making basis. This may not be either practical or economical. Cost analyses, weight analyses, reliability analyses, and many others can be used to guide decision making. But, it is often necessary to make decisions weighting the merits of all of these requirements and more, in a short time, using a limited amount of data. It is also often necessary to make the best decision possible with information that *is* available. In any case, the objective of the decision maker is to be certain that the information that *is* available is evaluated in an orderly fashion. A simple mathematical process has been devised to aid in this evaluation.

Two basic steps are involved in this mathematical procedure for decision making:

1) Determine the relative importance of each performance or specification requirement;

2) Evaluate each possible solution against each of the above requirements.

For both of these steps, evaluations are arranged so that only two alternatives are considered at a time. Every possible combination is submitted for comparison. In this way, no shades of choice are required—only a *yes* or *no* decision for each evaluation.

The decision-making process can be illustrated by applying it to a typical problem. Assume that the military services require a component of electronic equipment. In designing the equipment, the supplier attempts to develop a unit that will meet military specifications and at the same time have a minimum overall cost (initial cost plus maintenance) to the military services. In designing the equipment, a decision is required whether to use existing printed-circuit boards from a previously designed unit, new printed-circuit boards designed especially for the present unit, or a newly designed "standard universal" board. To determine the lowest overall cost to the military services, the alternatives are evaluated for these requirements:

1) Low design cost
2) Low manufacturing cost
3) Low maintenance stock cost
4) Low maintenance work cost
5) Low shock-resistance capability cost
6) Low vibration-resistance capability cost
7) Low cost for future systems.

The procedure used to establish the relative importance of each requirement is illustrated in Table I. The seven requirements are listed in the left-hand column and comparisons are made in the columns to the right. In comparing any two items, numeral one (1) indicates the more important requirement and zero (0) indicates the lesser requirement. For example, when comparing design cost to manufacturing cost in the first column, manufacturing cost is the more important consideration *for this particular project*. Similarly, for this hypothetical example, design cost is more important than maintenance stock cost, and design cost is more important than maintenance work cost. Thus, each evaluation is made by comparing only two items at a time, and every possible combination of the seven items is considered.

The total positive decisions for each requirement is tabulated in column N. The summation of these total positive decisions equals 21, which checks with the total number of possible decisions.

A *relative emphasis coefficient* for each requirement is obtained by dividing the number of positive decisions for each requirement by the total number of possible decisions, as shown in the right-hand column of the table.

Table I—Weighting of Requirements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	*Positive Decisions (N)*	*Requirement Emphasis Coefficient (E = N/21)*
1. Design Cost	0	1	1	1	1	1																5	0.238
2. Manufacturing Cost	1						1	1	1	1	1											6	0.285
3. Maintenance Stock Cost		0					0					0	0	0	1							1	0.048
4. Maintenance Work Cost			0					0				1				1	1	1				4	0.190
5. Shock-Resistance Cost				0					0				1			0			1	1		3	0.143
6. Vibration-Resistance Cost					0					0				1			0		0		0	1	0.048
7. Future System Cost						0					0				0			0		0	1	1	0.048
																						21	1.000

Total number of possible decisions $= \frac{n(n-1)}{2}$, where n = number of items under consideration; i.e., $\frac{7(7-1)}{2} = 21$ total possible decisions.

M. J. Gelpi is on the Value Engineering Staff of the Surface Division, Westinghouse Defense and Space Center, Baltimore, Maryland.

Table II—Evaluation of Solutions for Each Requirement

	1	2	3	*Positive Decisions*	*Solution Emphasis Coefficient*
1. Design Cost					
Existing Boards	1	0		1	0.33
New Boards	0		0	0	0.0
Standard Universal Boards		1	1	2	0.67
2. Manufacturing Cost					
Existing Boards	1	1		2	0.67
New Boards	0		1	1	0.33
Standard Universal Boards		0	0	0	0.0
3. Maintenance Stock Cost					
Existing Boards	1	1		2	0.67
New Boards	0		0	0	0.0
Standard Universal Boards		0	1	1	0.33
4. Maintenance Work Cost					
Existing Boards	1	1		2	0.67
New Boards	0		1	1	0.33
Standard Universal Boards		0	0	0	0.0
5. Shock-Resistance Cost					
Existing Boards	1	1		2	0.67
New Boards	0		0	0	0.0
Standard Universal Boards		0	1	1	0.33
6. Vibration-Resistance Cost					
Existing Boards	0	0		0	0.0
New Boards	1		1	2	0.67
Standard Universal Boards		1	0	1	0.33
7. Future System Cost					
Existing Boards	1	1		2	0.67
New Boards	0		0	0	0.0
Standard Universal Boards		0	1	1	0.33

Table III—Decision Matrix

	Existing Boards	*New Design*	*Standard Universal Package*
Design Cost 0.238 ×	0.33 = 0.078	0.0 = 0.0	0.67 = 0.160
Manufacturing Cost 0.285 ×	0.67 = 0.190	0.33 = 0.094	0.0 = 0.0
Maintenance Stock Cost 0.048 ×	0.67 = 0.0325	0.0 = 0.0	0.33 = 0.0159
Maintenance Work Cost 0.190 ×	0.67 = 0.128	0.33 = 0.068	0.0 = 0.0
Shock-Resistance Cost 0.143 ×	0.67 = 0.095	0.0 = 0.0	0.33 = 0.047
Vibration-Resistance Cost 0.048 ×	0.0 = 0.0	0.67 = 0.0325	0.33 = 0.0159
Future System Cost 0.048 ×	0.67 = 0.0325	0.0 = 0.0	0.33 = 0.0159
	0.556	0.1945	0.2547

Σ*(Weighting Emphasis Coefficient × Solution Emphasis Coefficient) = Figure of Merit*

The second step in the process is illustrated in Table II. For each requirement—design cost, manufacturing cost, etc.—the three possible solutions are evaluated, one against another. The number of positive decisions for each solution is converted to a *solution emphasis coefficient*, as shown.

The preferred solution is then determined by summarizing these emphasis coefficients in matrix form, as shown in Table III. The product of each requirement emphasis coefficient (Table I) and each solution emphasis coefficient (Table II) is found, and these quantities are summed for each of the three possible solutions. These sums become "figures of merit" for the solutions. In this example, the use of existing printed-circuit boards is the best decision.

By breaking the decision-making process down into a simple step-by-step application of logic, an orderly decision-making procedure is insured. Thus, the decision-maker knows that his solution is as good as the accuracy of his input information. In the example illustrated, the decision-maker can have a high degree of confidence in his choice because the cost of the various requirements can be either calculated or estimated rather accurately; thus, the yes-no evaluations of the various requirements can be made with high assurance. In other cases, a decision might be required where it is difficult or even impossible to assign direct costs or dollar values to all aspects of the problem. In these circumstances, the degree of confidence in the final decision must be tempered by the decision-maker's confidence in his yes-no evaluations. But by applying an ordered process in making the evaluations, the decision-maker knows that all aspects of the problem will be accounted for, and that the final decision will not be subject to inconsistencies in his analysis of the problem.

Westinghouse ENGINEER **January 1967**

References:

Denholm, Donald H., "Decisions for Dollars," *Proceedings of the Value Engineering Symposium*, U.S. Army Missile Command, Redstone Arsenal, Nov. 18-19, 1964.

Fasal, John, "Forced Decisions for Value," *Product Engineering*, April 12, 1965.

Fallon, Carlos, "Practical Use of Decision Theory in Value Engineering," *Journal of Value Engineering*, Vol. 2, No. 3, May 15, 1964.

Progressive Draw Control Coordinates Sectional Speed Changes

W. H. Watson

A new system makes simultaneous, accurate, and proportional changes in the settings of separate potentiometers. One of its uses is for adjusting draw through a number of the sections of a sectional process machine.

Where two or more potentiometers must be operated simultaneously and it is not practical to link them mechanically, electrical connection is the answer. However, the electric actuators must start and stop positively, reliably, and accurately for maximum utility. Such action is achieved in a new system that employs stepping motors as actuators instead of the arrangement of induction motors and slip clutches formerly used for this purpose.

The major use for the new system is in progressive draw control for the electric sectional machines used in various industries (paper machines, for example). Such machines consist of several speed-regulated sections controlling a common web of process material. A common reference bus supplies a speed signal to all section speed regulators, so overall machine speed is controlled from one master reference source.

However, because of the nature of the web, means must be provided for altering the speed of each section individually. Paper, for example, may stretch when it is wet and shrink as it dries, so the speed of each section must be adjustable in relation to its adjacent sections to maintain the desired web tension. The speed difference between two sections is called "draw," and the individual speed of a section is commonly altered through use of a multiturn potentiometer known as a "draw pot."

Five sections of a typical machine are illustrated in the diagram. If the web is running slack between sections *A* and *B* (and no progressive draw system is provided), the section-*B* draw pot has to be adjusted to raise the speed of that section. However, this causes the web to run slack between sections *B* and *C*, so the section-*C* draw pot is then adjusted to raise the speed of that section. Each successive draw pot is adjusted in this manner to work the slack out the end of the machine.

Progressive Draw System

The Westinghouse progressive draw system eliminates this need to adjust the speed of several sections individually when changing the draw between any two sections. If a control unit of this system is added to each section in the example just given, only one switch (at section *B*) need be operated to adjust the speeds of sections *B*, *C*, *D*, and *E* simultaneously and proportionally. Or, if the draw *B-C* is to be changed, operation of a switch at section *C* causes simultaneous and proportional speed changes in sections *C*, *D*, and *E*. In other words, the operation of a single switch changes draw between any two sections by causing simultaneous and proportional speed changes in all downstream sections while not affecting any upstream sections.

On some sectional machines, one section is designated the lead section and is not provided with draw control. (This section usually is near the mid-section of the machine.) A *regressive* draw system can be provided for such a machine by adding a progressive draw unit, identical to the units discussed above, to all sections ahead of the lead section. Then if a draw change is to be made between two sections ahead of the lead section, a single switch operation at the proper section causes simultaneous and proportional speed changes in all upstream sections while not affecting any downstream sections.

Each progressive draw unit contains the draw pot, a stepping motor and gear unit for driving the draw pot, two selector switches, a counter to indicate draw-pot setting, and a unique limit switch to prevent damage to the end stops of the draw pot. (See photographs.)

The use of a stepping-motor drive is the key feature of the unit. Its positive action provides accurate tracking among the units, thereby insuring equal draw-pot changes in all affected sections. The almost instantaneous starting and stopping of the stepping motor also contribute to positive control of the draw pots, both for individual section draw settings and for progressive draw settings.

The stepping motor, moreover, provides a means for computer control of the settings. Pulses from a computer could move the draw pots discrete amounts in response to needs calculated from various inputs. The computer memory could easily store the positions of all draw pots at all times.

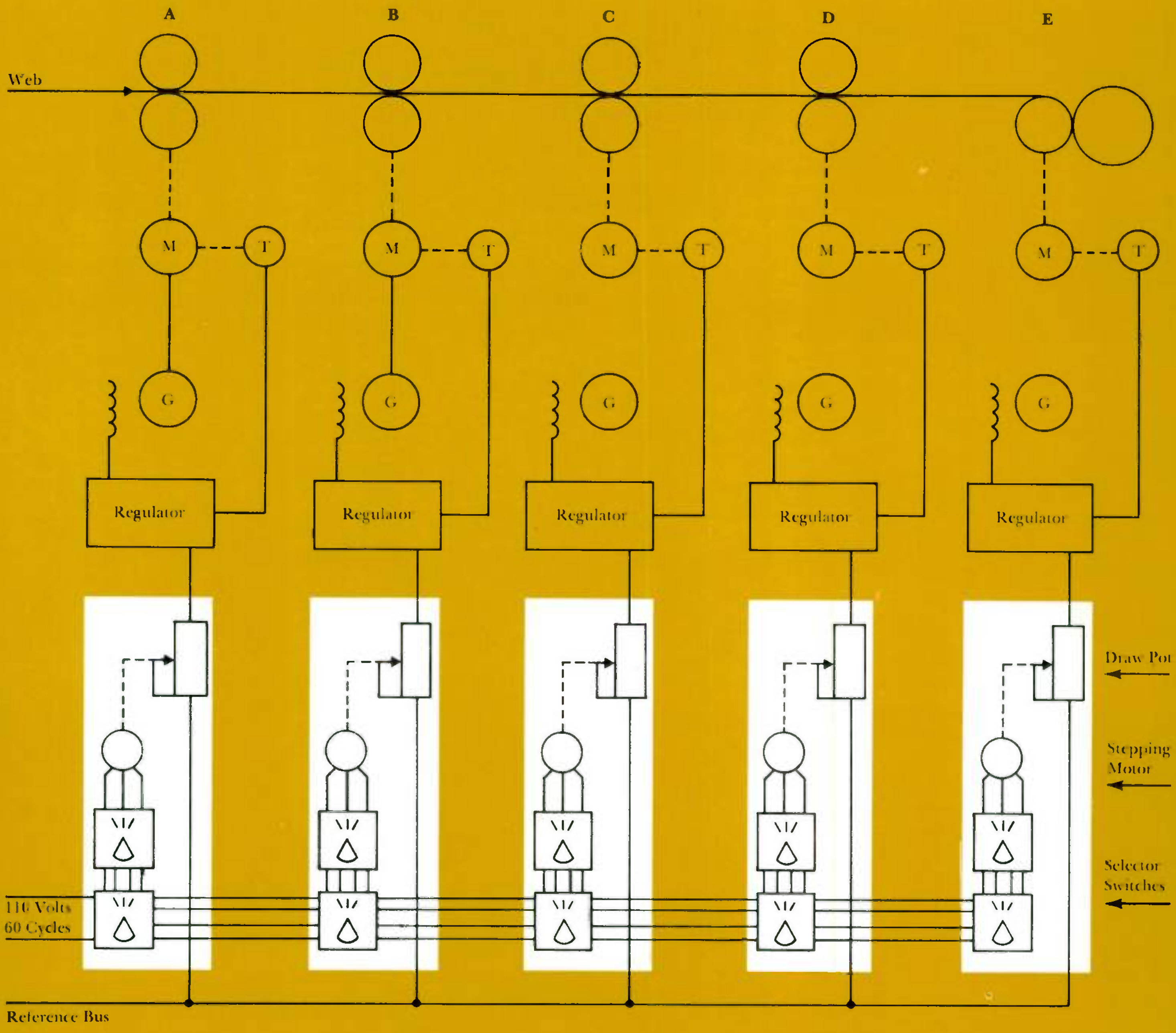
One of the two selector switches on each unit provides the individual section draw function by energizing only that particular section stepping motor; it is used for making the initial section speed adjustment and also may be used during operation if conditions change or if the initial section speed setting was not quite correct. The other switch provides the progressive draw function by applying power simultaneously to the stepping motors of that section and all subsequent sections.

Both switches have three positions: *off*, *decrease speed*, and *increase speed*. The stepping motors move one increment for each pulse of input power. Since the "pulses" in the system illustrated are the alternations of the 60-cycle supply power, the motors move in one direction or the other as long as the switch is held in the *increase speed* or *decrease speed* position; they stop when the switch is returned to the *off* position. To eliminate slack between sections *A* and *B*, for example, the operator would hold the section *B* progressive-draw switch in the *increase-speed* position until tension there reached the desired value. Meanwhile, the stepping motors downstream would have moved their draw pots the same amount to change the speeds of their sections by the same percent.

The counter that indicates draw-pot setting is a three-digit unit; it shows the position of the pot at all times. It is

Progressive draw control unit on each section of a sectional machine adjusts the speed of its own section and, simultaneously, the speeds of all sections downstream from it in a proportional manner. This capability is used to make corrections in the draw between two stands without introducing errors in the draw between succeeding stands.

W. H. Watson is a Senior Design Engineer in General Industries Systems, Industrial Systems Division, Westinghouse Electric Corporation, Buffalo, New York.


A
B
C
D
E
Web
M
T
G
Regulator
Draw Pot
Stepping Motor
Selector Switches
110 Volts 60 Cycles
Reference Bus

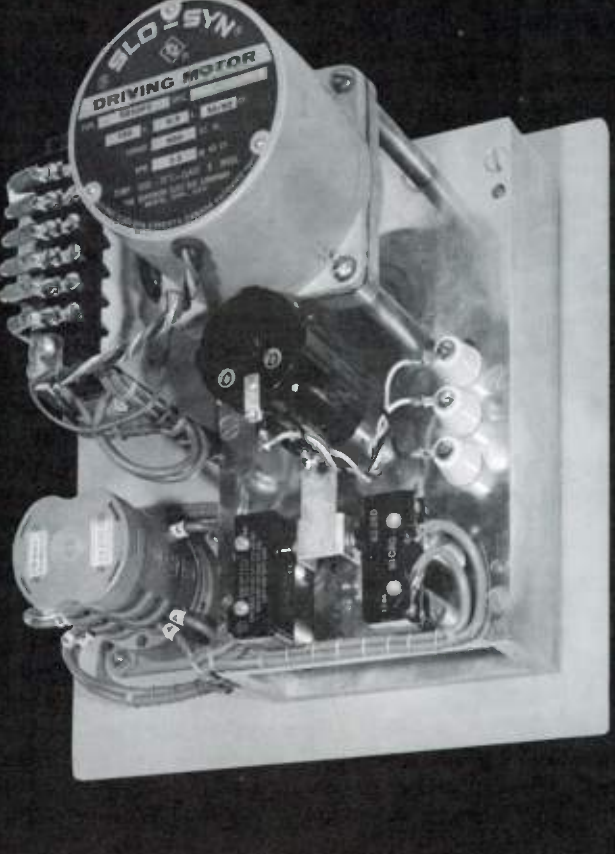
especially useful when changing products, as the operators can set the draw pots to the positions used when that product was last run and get into production more easily.

The limit-switch arrangement prevents damage to the end stops of the draw pot. Once the draw pot reaches its end of travel and the switch opens, no appreciable reverse travel is required to reset the limit switch. Therefore, full bidirectional control of the progressive draw unit is retained between the extreme ends of the draw pot. This feature is accomplished by mounting the draw pot on a shaft, with a lever attached to the face of the pot. The end of the lever floats between two microswitches. As the draw-pot slider reaches its end of travel and strikes its end stop, the entire pot starts to rotate. However, rotation is so magnified by the lever that rotation of less than one degree causes actuation of the microswitch, which removes power from the stepping motor. The end stops of the draw pot can withstand many times the torque required to actuate the microswitches.

Conclusion

Although the example used in this article has concerned progressive draw control of electric sectional paper-machine drives, the system certainly is not limited to that one application. It can be used for progressive draw control of various machines in other processes, such as off-machine coaters, conveyors, and a number of metal processing lines. The progressive draw system should be considered, in fact, in any application where two or more separate potentiometers must be operated simultaneously.

Westinghouse ENGINEER **January 1967**



Operator's station *(above right)* for one section of a sectional machine includes a progressive draw unit (the smaller panel in the right center of the station). The lower switch adjusts draw of that section, and the upper one adjusts progressive draw. The progressive draw unit *(lower right)* contains the potentiometer that adjusts stand speed. It is driven by a stepping motor for positive and accurate tracking of the several units affected by any change in a draw setting.

High-Temperature Plastics for Structures and Adhesives

High-temperature plastics that retain much of their strength up to 650 degrees F and are lighter than comparable metal structures could lead to new techniques for producing missile and aircraft components. Laminates of the new plastics, when exposed to high temperatures, are stronger than aircraft aluminum and compare favorably with stainless steel and titanium even after 1000 hours of continuous exposure to air.

When used as adhesives, the plastics bond sheets of titanium and stainless steel under the same conditions of time and temperature with hot strengths greater than 1000 psi. Such adhesive properties could be most advantageous, since titanium is difficult to join to other metals and to itself by conventional bonding techniques.

The plastics are being developed under contract with the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, to demonstrate that organic structural compounds can be designed to withstand the environment of supersonic flight. Hundreds of different formulations were prepared and screened for thermal stability, strength, shrinkage, flexibility, and other properties.

Like most organic resins, the exact chemical structure of these copolymers of aromatic polyamides and polyimides is complex. Basically, they consist of rings of six carbon atoms linked together into long chain-like molecules by atoms of carbon, oxygen, nitrogen, and other elements, all joined in a repetitive pattern.

The most promising laminating resins were formed into glass-reinforced sheets under high temperature and pressure in a hydraulic press by dry bonding, a technique that eliminates the usual solvents and molten stages of a resin.

Metals were joined with adhesive resins by impregnating glass cloth with the resin, placing it between the surfaces to be joined, and applying a pressure of 200 psi at 750 degrees F. Tensile shear strengths in excess of 3000 psi were attained in these bonds at room temperature, and more than 50 percent of this strength was retained at temperature after 1000 hours in air at 500 to 600 degrees F.

The bonds between titanium alloys have lower initial strengths than those for stainless steel. However, they degrade less over a period of time at high temperatures, so both reach a tensile strength of about 1000 psi after the 1000-hour exposure to 600-degree air.

In addition to the structural potential of these plastics, their electrical insulating properties could lead to electrical equipment able to withstand temperatures beyond the limitations now imposed by available organic insulators. Motor windings and flexible printed circuitry are among the potential applications.

Thin-Film Method Makes High-Frequency Transistors

Experimental thin-film transistors fabricated from an unconventional material, indium arsenide, are a major step toward devices that should outperform conventional silicon transistors in high-frequency response, resistance to damaging space radiation, stability over a wide temperature range, and cost. The thin-film transistor also points to a new capability in integrated circuitry.

Integrated circuits are now fabricated on tiny wafers of silicon in such a way that they perform entire electronic functions that would normally be carried out by perhaps dozens of resistors, capacitors, transistors, and other components. Another approach to integrated circuitry is through thin films, which are inherently easier to fabricate. However, this technique has had little impact on microelectronics since there has been no satisfactory thin-film amplifier that compares in performance with the transistors now used. At best, thin-film integrated circuits have been "hybrid circuits" in which separate transistors and diodes have been connected with the thin-film elements. Eventually, the new thin-film transistors should change this picture, leading to development of complete thin-film integrated circuitry.

The key to the development is the new transistor material indium arsenide. Films of this material only a few millionths of an inch thick are made by evaporating controlled amounts of indium and arsenic inside a vacuum chamber. Vapors of the two metals combine chemically and deposit as a thin layer on a substrate of glass or quartz. Thin-film transistors are made by successively depositing layers of the indium arsenide, a metal, an insulating material, and another metal.

At present, the comparatively crude transistors operate in a frequency range of eight megacycles, with constant performance over a temperature range from −452 degrees to 300 degrees F. Work is under way to increase this frequency response 100 times. Ultimate performance lies well within the microwave region of several kilomegacycles.

The prime reason for this high-frequency performance is the high mobility of the charge-carrying electrons in the indium arsenide. Mobility is 100 times greater than that in the cadmium sulfide traditionally used for thin-film transistors. High-frequency response is also improved by making the device smaller in size, since the electrons then travel smaller distances. The 100-times increase in frequency expected will be achieved primarily by reducing the dimensions to microelectronic size.

High-Voltage Motor Starters Now Fit the Application

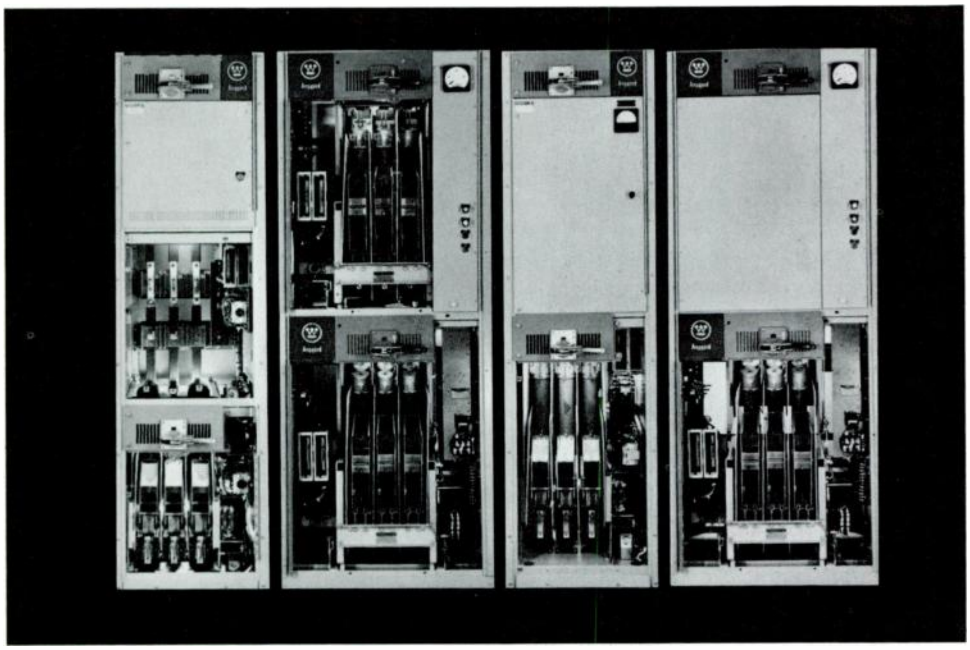
Industry has long had a complete line of low-voltage motor starters, the familiar NEMA 0 to 9 sizes, for motors rated up to 600 volts. But for 600 volts up, limitations in materials capability and in knowledge of how to apply existing materials have caused high-voltage control manufacturers to standardize on one starter design. That design has been engineered for the maximum 3000-horsepower motor applications but used for the lower-horsepower motors as well.

This practice of providing only one high-voltage starter rating is wasteful in materials and space, since an estimated 70 percent of commercially used motors are rated below 800 horsepower. Now, however, advances in materials and technology have made the practice obsolete by permitting design of a line of high-voltage motor starters in a choice of ratings and applicable to all types of high-voltage ac motors from 25 to 3000 horsepower.

The advances consist mainly of development and application of much better insulating materials plus a functional approach to the electrical and mechanical design of the starters. Internal components are connected directly to each other wherever possible, a design that minimizes space requirements and reduces by half the number of current-carrying junctions with their potential for over-heating and corrosion.

The first starter in the line was the Ampgard 2500-volt 200-ampere starter, which was introduced in 1961 and was the first starter specifically engineered for 2300-volt motors rated up to 700 horsepower. Now the line has been completed by introducing three additional Ampgard starters in ratings of 2500 volts 400 amperes, 5000 volts 200 amperes, and 5000 volts 400 amperes.

All of the starters have the same circuitry and physical characteristics so that they can all be specified, installed, operated, and maintained in the same way. Cabinets for all ratings are 90 inches high and 30 inches deep; those for the 200-ampere units are 26 inches wide, while those for the 400-ampere units are 36 inches wide. The 2500-volt 200-ampere starters can be either wall-mounted or mounted two or three to a cabinet; the others are mounted either one or two to a cabinet.



High-voltage motor starters are made in a range of ratings and yet are uniformly designed to facilitate application. They are also designed in such a way that all inspection and virtually all maintenance can be done without any disassembly. From left to right, mounted two to a cabinet, are starters rated 200 amperes 2500 volts, 400 amperes 2500 volts, 200 amperes 5000 volts, and 400 amperes 5000 volts.

Radar System for Missile Research

A radar target measuring system, only one of its kind in the free world, supplies accurate and detailed cross-section measurement data on missiles in flight. The system was developed for the U.S. Army's Missile Electronic Warfare Technical Area and went into operation recently at the White Sands Missile Range.

New radar system's large antenna helps supply measurement data on missiles in flight.

The system's high performance stems mainly from its large antenna that tracks automatically, wide bandwidth, high data rate, and powerful transmitter. Data rate is a billion data words per minute with a data word length of six bits. The dish antenna is 85 feet in diameter and has a mesh surface; it operates in the 150- to 500-megacycle frequency range. The system has a wide dynamic range and can monitor targets over a range of radar cross-section areas as small as 15 square inches and as large as a large airplane. Its antenna beam width varies from 1.5 degrees to 5 degrees over the system's frequency range.

Measurements made by the radar are processed and put into digital form on the system site. They are then recorded on a seven-channel tape recorder for subsequent analysis.

The system will enable users to study the nature of the atmosphere and to observe frequency- and time-dependent phenomena in addition to obtaining accurate cross-section data at a high data rate. These secondary functions are made possible by the characteristics of the radar that permit simultaneous transmission on three frequencies.

Light-Activated Silicon Switch for High-Power Switching

An experimental light-activated silicon switch (LASS) with high power rating could eventually replace the conventional thyristor in many applications. It was developed specifically to overcome the two major limitations associated with thyristors: difficulty in simultaneously turning on a large number of units, and possibility of damage due to initial current surge.

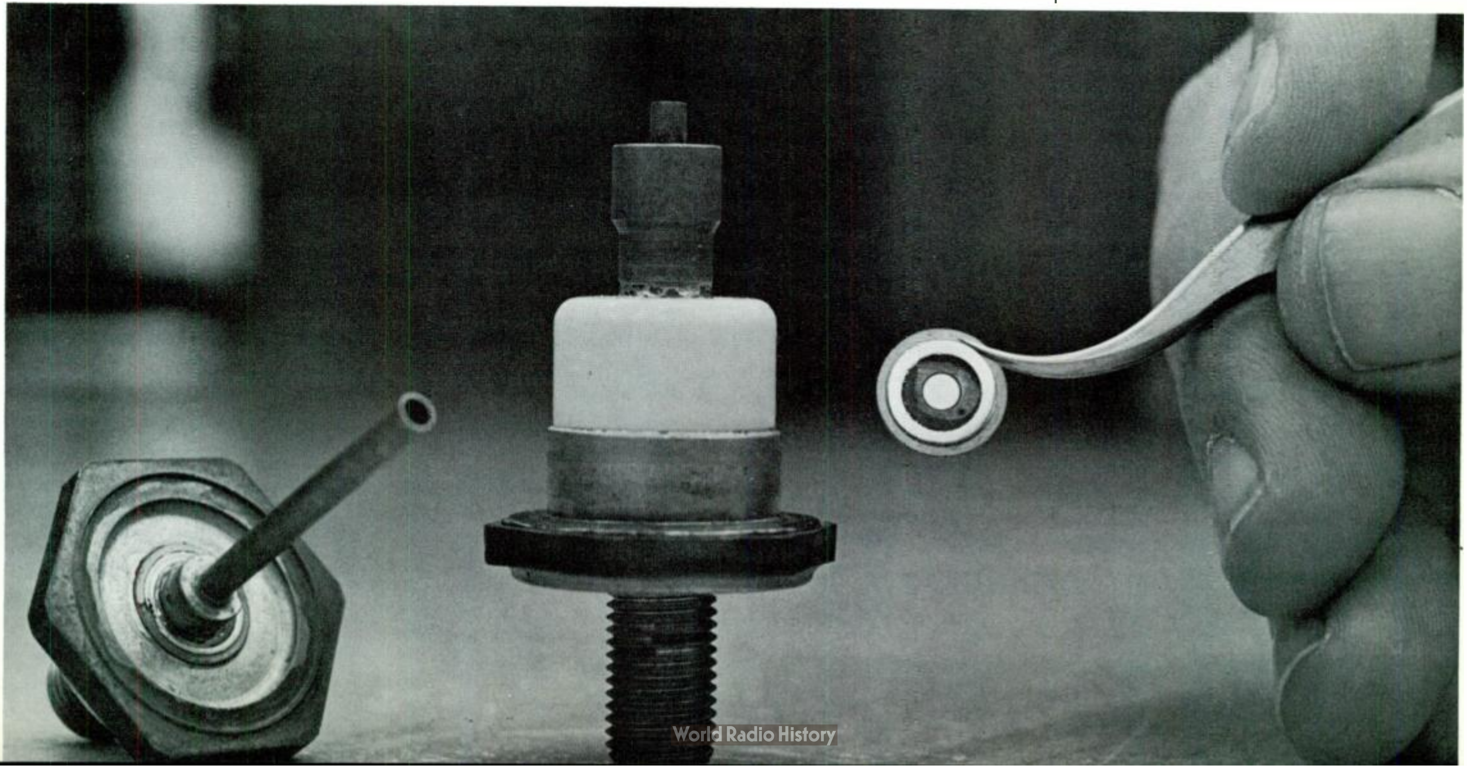
The first limitation is overcome by turning the switch on with a pulse of infrared light from a gallium arsenide laser diode; flexible fiber-optics "light pipes" about half the diameter of a lead pencil transmit the light from the laser to the switches. This change permits simultaneous firing of many switches, and it also simplifies the thyristor (by eliminating the thyristor gate electrode) and isolates the switch electrically from its firing source.

The second problem with thyristors, that of possible damage due to initial current surge, is caused by the thyristor's slow current buildup rate (low *di/dt* value). Earlier light-activated switches also had this limitation, because they were triggered from the rim. Solid-state switches, however, are about 100 times as broad as they are thick, so by shifting the light so that it floods the upper flat surface, the *di/dt* value was increased 100 times over that of the earlier light-activated switches. The LASS has demonstrated a *di/dt* rating of 400 amperes per microsecond, more than 10 times as fast as conventional thyristors.

The LASS has many potential applications, including generation of extremely short high-energy radar pulses. Typically, these pulses are a millionth of a second in length, a switching speed the LASS can easily handle.

Another important application is in high-voltage dc power transmission, which is being used more and more to deliver large amounts of electric power over long distances. To be practical, dc transmission requires large switching installations at both ends of the transmission line. At the generating station the ac power must be rectified to dc, and at the receiving end the dc must be inverted back to ac for distribution and use. This switching function is now being accomplished by electronic means, but the introduction of the LASS makes available to the design engineer a new concept with numerous advantages including reduced cost, simplification, improved reliability, and increased efficiency.

Light-activated silicon switch consists essentially of a wafer of silicon *(right)* that is switched to the conducting state by a pulse of light. Fiber-optics "light pipes" direct laser light onto a number of switches for simultaneous turn-on. A switch assembly *(center)* consists of the wafer, terminals, and a tube *(left)* that directs light onto the wafer's face.



New Recipe for Moonshine

From time to time, at certain places on its surface, the moon shines with a self-made light that can be almost as bright as the sunlight it reflects. This glow, which is usually red, may last for a minute or for more than an hour and may come from parts of the moon ranging in area from a few square miles to several hundred square miles.

One of the more popular theories attributes this glow to high-energy protons from solar flares, which strike fluorescent meteorites on the moon. These meteorites, called achrondritic enstatites, glow under the proton bombardment for much the same reason that a fluorescent lamp emits light.

Another possible source for this self-generated glow has been proposed by Westinghouse research physicists. Essentially, they suggest that the solar "wind" as well as solar flares can cause the luminescence. (The solar wind consists of relatively low-energy protons continuously emitted from the sun.) The moon's meteoric dust particles absorb energy from the solar-wind protons during the long cold lunar night. Then, at lunar dawn, the surface of the moon heats rapidly, releasing the stored energy to produce the moon glow. This type of glow is called thermoluminescence, meaning that the energy is released only when the material is heated.

Some 4 million billion solar-wind protons hit one square inch of the moon's surface during a lunar night of 14 earth days, resulting in an energy dose of more than one kilowatt-hour per pound. This amount of energy, in the form of thermoluminescence, would be released rapidly, since at lunar dawn the moon's surface swings from very cold to very high temperatures in a relatively short time.

To test their theory, meteorites at −320 degrees F were irradiated with high-energy electrons. (Electrons were more readily available than protons and for this experiment provided the necessary radiation characteristics.) When the meteorites were heated, red and blue light was emitted. Further study showed that four distinct peaks of blue luminescence occurred at −171, 41, 221 and 392 degrees F. Similarly, four peaks of red luminescence were found at −98, 28, 315 and 419 degrees F.

Products for Industry

Model 207 oxygen analyzer uses a fuel-cell sensing element to achieve instant response and sensitivity greater than one ppm at low concentrations. Sensing element is a pencil-size ceramic tube, coated inside and out with platinum electrodes, through which test gas flows. It provides a signal strong enough to drive a voltmeter or potentiometer recorder without an amplifier. The cell operates as an oxygen-concentration battery, with ambient atmosphere providing the reference. At the operating temperature of 850 degrees C, it produces a voltage whenever there is a difference in oxygen pressure between test gas and ambient air. The output signal drives an integral panel meter for direct readout of oxygen content in either ppm or percent. An output connection for driving an external recorder is also available. Response time for the sensing element is one millisecond. Four models provide a variety of ranges. *Westinghouse Scientific Equipment Department, 7800 Susquehanna Street, P.O. Box 8606, Pittsburgh, Pennsylvania 15221.*

Model 207 Oxygen Analyzer

Industrial Ac-Dc Arc Welder

Pad-mount power center, three-phase 1000-kva, with 125-kv BIL is for wye-wye operation on a 34.5-kv grounded-wye system. Its high-voltage terminal compartment has space for current-limiting fuses and arresters, and eight cables per phase can be terminated in the low-voltage chamber. All cooling tubes are on the rear of the unit. The power center weighs about 8560 pounds and is 82½ inches high, 72½ inches wide, and 75 inches deep. *Westinghouse Power Transformer Division, Muncie, Indiana 47305.*

Industrial ac-dc arc welder type WST 300-ampere for TIG and stick welding has resistor control for both ac and dc welding. Resistor control gives an inherently balanced waveform, which results in a highly stable arc and also eliminates need for power-factor correction. The unit can make welds with direct current as low as five amperes and with single-phase alternating current as low as three amperes. It has an adjustable high-frequency oscillator for initiating and stabilizing the arc. Standard primary rating is 230/460 volts, single phase, 60 cycles, but other ratings are available. *Westinghouse Welding Department, Box 225, Buffalo, New York 14240.*

About the Authors

George B. Higgins came to Westinghouse on the graduate student course after obtaining his BEE degree from the University of Louisville in 1942. He worked in the switchboard engineering department of the Switchgear Division until 1944, when he left for service in the U.S. Navy to serve as an Electronics Specialist, Lt. (jg). He returned to Westinghouse in 1946 and entered Supervisory Systems design engineering in 1947. He was called back for another Navy hitch in 1951, again as an Electronics Specialist, Lt.

In 1953, Higgins returned to Westinghouse to the Supervisory Systems design engineering section. He moved to supervisory system sales in 1956.

Higgins left Westinghouse for a brief period in 1964 but returned to the supervisory and telemetering systems department (which had been moved to the Relay-Instrument Division) in 1965. As a marketing development engineer, his responsibilities include product and market planning of such telemetering and remote control equipment as the Type DT telemetering system described in this issue.

D. R. DeYoung and **T. J. Dolphin** pool their talents to describe modern cold-rolling mills. They are, respectively, manager and assistant manager of the Cold Mill Systems group in the Industrial Systems Division.

DeYoung left Western Michigan College in 1942 to enter the U.S. Army. After his discharge in 1946, he returned to college at the State University at Iowa, graduating the following year with a BSEE. He joined Westinghouse on the graduate student program and accepted a position in the Systems Control Division, serving from 1947 to 1956 as a design engineer on various metal mill control systems. In 1956, DeYoung was appointed supervisory engineer for mill auxiliary control systems. He then served as engineering section manager of Standard Products and the General Mill and Marine Section, and later as associate manager of the Single Stand Metal Mill Product Group. He was made manager of the Cold Mill Systems group when it was formed in 1964.

Dolphin joined Westinghouse in the Systems Control Division in 1951, where he worked in engineering and management positions on the design of automatic control systems for the metalworking industry. He holds a BEE degree from Rensselaer Polytechnic Institute, and an MS in electrical engineering and an MBA from the State University of New York at Buffalo. Dolphin was appointed to his present position in Cold Mill Systems in 1964.

The article on series capacitors is the combined effort of **W. H. Cuttino** and **Albert B. Pyle,** of the Distribution Apparatus Division, and **James E. O'Neil** of the Headquarters Electric Utility Engineering Department.

Cuttino graduated from Clemson College with a BSEE in 1928. He came with Westinghouse in mid-1929 as a tester in the company's test department. Later that same year, he moved to the engineering department of Westinghouse Supply to begin a career of designing and applying power capacitor equipment. Cuttino transferred to the Circuit Breaker Engineering Department in 1934 to work with capacitor potential devices, coupling capacitors, and shunt and series capacitor equipment.

When the Distribution Apparatus Division was formed in 1949 and given the responsibility for power capacitor equipment, Cuttino came along with the new division. He is presently responsible for high-voltage shunt and series capacitor equipment.

O'Neil is a graduate of Washington State University with a BSEE degree (1951). He joined Westinghouse as a graduate student but shortly thereafter was called into the service, where he spent two years in electronic countermeasures with the U.S. Air Force, including duty in Korea.

He returned to Westinghouse in 1953 and joined the advanced development group of the Electric Utility Engineering Department to work on the Tidd 500-kv Test Project. In 1956, he was put in charge of the Westinghouse program at the Leadville 500-kv High Altitude Test Project.

O'Neil transferred to the sponsor engineering section in 1962 and worked with utilities in the Atlantic and Southwest Zones on systems planning and operation problems. He has had his present assignment as Sponsor Engineer for the Pacific Coast Zone since 1965.

Pyle graduated from Norwich University with a BSEE degree in 1949. After his Westinghouse graduate student course assignments, Pyle joined the marketing department of the Distribution Apparatus Division. His work here with capacitor applications has been interrupted only by a military leave of absence for the Korean War. He has handled all negotiations for Westinghouse installations of transmission-line series capacitors. Pyle is also responsible for special EHV projects, such as capacitors for dc transmission. His territory for conventional shunt-capacitor installations includes the western half of the United States.

T. D. Sanders came to Westinghouse after graduating from Louisiana State University (1960) with a BSEE. After several assignments on the graduate student course, Sanders joined the Traction Equipment Department in 1961. There he has worked on the application of solid-state devices to equipment for the rapid transit industry. He was design engineer for the equipment developed for the PATH cars, some of which he describes in this issue.

Sanders is presently working on a 400-horsepower chopper, a solid-state stepless motor control being developed for the New York City Transit Authority.

Off the job, Sanders prefers canoe transportation. He is commodore of the Sylvan Canoe Club, an organization that includes many other Westinghouse people of the Pittsburgh area. He is also active in the Red Cross water safety program.

Maurice J. Gelpi came to Westinghouse in 1941 after graduation from Tulane University with a BE in mechanical engineering. After completing the graduate student course program, he was assigned to the Electronics Division in Baltimore. His experience there included project responsibility for a line of radio-frequency induction heaters, a line of audio-frequency induction heating transformers, and numerous other special electronic equipment designs. In 1960-63, he was responsible for converting developmental prototypes of ultrasonic cleaning equipment into a reliable product line and eventually supervised this design group. Major contributions to product cost improvement were made during this time.

Gelpi is presently on the Value Engineering Staff of the Surface Division of the Westinghouse Defense and Space Center. He is responsible for teaching and providing guidance in the application of value engineering principles and procedures throughout the division.

Away from work, Gelpi is an amateur enologist (the product of this activity is homemade wine). And while the wine is fining, he has time for surfboard building, Boy Scout work, sound-movie making, and music.

W. H. Watson is a senior engineer in General Industries Systems, Industrial Systems Division. He has contributed to the development of many modern drive and control systems, including a dc crane drive, planer drives, a 400-cycle magnetic-amplifier paper machine drive, the T-100 regulating system, and the progressive draw system described in this issue. Most of his work in recent years has been in design of drive systems for sectional paper machines.

Watson served as a radio operator in the U.S. Merchant Marine from 1944 to 1947. He then entered Louisiana State University and graduated with a BS in electrical engineering in 1951. He joined Westinghouse on the graduate student program and, in 1952, was assigned to the Control Engineering Department (later the Systems Control Division). The U.S. Army called Watson into service in 1954, and he spent two years testing and evaluating antiaircraft radar fire control systems. He returned to the Systems Control Division, and in 1964 he moved to the Industrial Systems Division. He has done graduate work in electrical engineering at the State University of New York at Buffalo.

Light-activated silicon switch operates much like a thyristor except that it is turned on by a pulse of light instead of by an electrical pulse. This method of turn-on makes it simple to operate many switches simultaneously by directing light onto them with fiber-optics "light pipes" as shown. Potential applications include rectifier and inverter systems for high-voltage dc power transmission. (For more information, see *Light-Activated Silicon Switch for High-Power Switching,* page 31.)