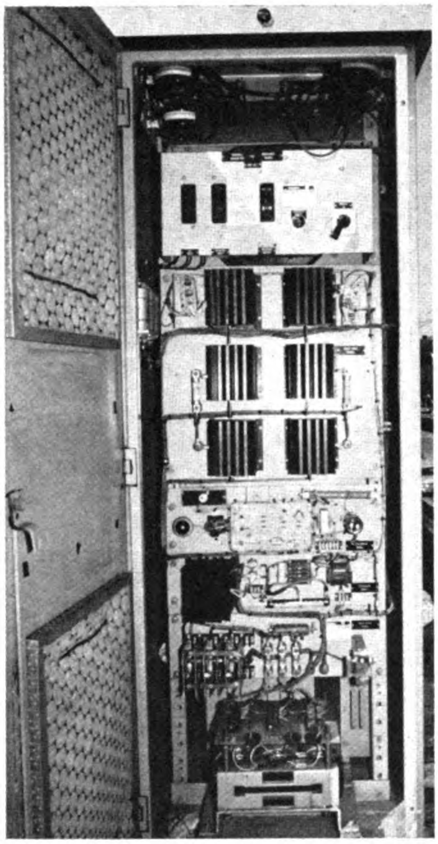
Commuter trains have ATC.

C&NW's ATC uses 100 cps ac



Front view of single converter unit.

By Ross L. Bush
and
Kenneth Watkins

Chicago & North Western has a two-speed automatic train control system in service between Chicago, Ill., and Council Bluffs, Ia., 480 miles. It was installed in the mid-1920s at the request of the ICC, which at that time had required many Class I roads to install ATC on their lines. Power to operate the system was obtained from local sources every 8 to 12 miles with closer spacing toward the more congested Chicago area. Power was received at 220 volts, single phase, 60 cps and was stepped up to 440 volts for the transmission on the signal pole line. Automatic switching boards were set up at each power source to feed eastward normally and to provide stand-by power westward should the location to the west be out of service for any reason. A transmission line of No. 6 hard drawn copper supplied energy for battery charging as well as for the ATC system.

This is an abstract of a paper presented at the Communication and Signal Section, AAR, meeting Sept. 13-15. Mr. Bush is assistant signal engineer, Chicago & North Western, and Mr. Watkins is supervisor of engineering, static devices, Westinghouse Electric Corp.

Over the years a number of locations evolved where high voltage transmission lines were established either crossing or closely paralleling the railroad. This power frequency was, of course, 60 cps. From time to time these transmission lines and associated ground return currents created some interference in the ATC track circuits, generally resulting in restrictive train speeds, but sometimes false proceed conditions were encountered.

Discussions with the train control equipment manufacturers developed the idea of changing the frequency used for ATC control circuits to avoid these 60 cps ground-return current interferences. A frequency of 100 cps was suggested as this frequency could be obtained readily from rotary converters having a 6-pole, 60 cps motor directly coupled to a 10-pole alternator to obtain the 100 cps desired. Also, transformers and other associated equipment would work equally well at 100 cps as at 60 cps, except it would be necessary to retune the locomotive pick-up circuit to match the new frequency of 100 cps to be used.

About four years ago, C&NW made a long term lease with the Commonwealth Edison Co., for a longitudinal occupation of the railroad right-of-way providing for a two circuit, 138 kv, 60 cps transmission line. This occupation is about two miles in length paralleling our Proviso freight yard approximately 12 miles west of Chicago. This is in suburban service territory between Chicago and Geneva, Ill., about 36 miles. At this particular location there are 60 scheduled trains per day.

It was recognized that interference could be expected in the communication and signal lines, so all of the railroad's pole lines were placed underground and in addition the beginnings of our railroad's microwave system was established. This microwave system also carries the controls and indications for three sections of multiple track CTC, all controlled from the dispatcher's office in Chicago.

The very first time one of the 138 kv, 60 cps circuits was energized for test purposes, all of our trains received train control restrictions over this two mile section. The power company made some extensive changes in its overhead protection system and it was found necessary to raise the ATC track circuit energy levels. When the second power circuit was energized, additional corrections were required to counter the ground currents and whenever the power company wished to work on one of their circuits the railroad had to be notified and special orders issued concerning the restrictions that would be encountered in this area.

Our management has insisted that on-time performance be maintained in this vital suburban service and delays are not to be tolerated on this district. It was clearly seen that other steps must be taken. Inquiries were made of several electrical manufacturers for quotations on 60 cps to 100 cps conversion units. However, we did have some mis-givings about rotary conversion units because of the additional expense required to inspect and maintain the units in operation.

One manufacturer suggested a different approach. Their engineers

(Please turn to page 28)

(Continued from page 26)

advised us of recent developments in solid state devices for frequency conversion units which would eliminate the necessity for the weekly inspections and attention required by the more conventional rotating type equipment. A higher first cost of the static devices would be partly off-set by the elimination of special housings and foundations needed for rotating equipment as these newer conversion units would include their own NEMA standard outdoor type housings and allow the use of ordinary type foundations regularly stocked for signal instrument cases.

A second manufacturer's suggestion was to retain the 60 cps transmission line and convert to 100 cps using small solid state conversion units at each distribution feed point. However, it was just not possible to make this change economically as there were too many of these smaller units needed and the individual units could not be produced at a competitive price. So, it was decided to stay with the idea of changing the transmission line frequency by the use of larger and fewer converter units.

CLEAR 100 CPS LINE

In order to reduce the load on the railroad's transmission line and thus reduce the number of conversion units needed, it was decided to clear this 100 cps line of all battery charging loads and reserve the line for train control energy exclusively. At this point, the expansion of the electric power industry was to our advantage as power was available at many points along the railroad and very little pole line work was required in the way of a distribution line for battery charging purposes. Also, it was decided to raise the 100 cps line voltage from 440 volts to 575 volts; this would reduce the IR (voltage) drop on the line for a given load and would allow us to further lengthen the distance between conversion units. The 575 volts was chosen for this circuit because step-down transformers of this voltage rating and required size are a standard item with signal manufacturers.

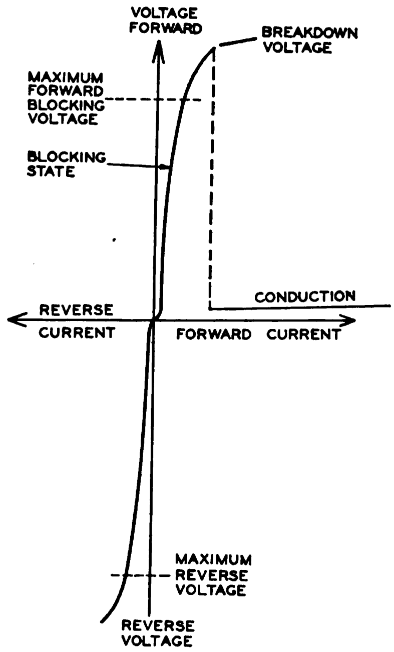


Figure 1: Thyristor characteristics.

With these features in mind, the number of power conversion units needed in the 137 mile territory between Chicago and Clinton, Iowa, could be reduced from 28 to 11. This section of railroad includes more than the previously mentioned suburban service but was chosen because it is a complete operating district and mechanics are available at Clinton to switch the locomotive tuning units on long-haul trains from 100 cps to 60 cps on westward movement, or vice-versa on the eastward movements.

General requisites for the system were to convert commercial power at 60 cps, 220-volt, three phase to 100 cps, 575-volt, single phase. Power output of individual units was set at 3 kva as being sufficiently large to serve the ATC needs over a section of track and still not run into any difficulties due to low voltage (account voltage drop) at the far end of a transmission line section. Output frequency must be maintained at 98 to 100 cps to match the optimum locomotive pick-up, and voltage wave-form must be sinusoidal in shape. Voltage regulation must be held with ±5% from no load to full load and from unity to 0.8 lagging power factor.

The converter location at the Chicago end of the system would require one 3 kva unit, normally feeding to the west. All other locations would have two 3 kva units each; one normally feeding to the west and a second as a stand-by unit ready to feed energy to the east, automatically, should the line voltage from the east fail for any reason. Automatic restoration to the normal feed would not be necessary. Output current must be automatically regulated on overloads, such as shorted transformers on the line.

The static power equipment section, general controls division of Westinghouse Electric Corp., has designed and built one single unit and ten double units. A description of the pertinent features of the inverter and its controls follows.

CONVERTING AC TO DC

Silicon rectifiers are now universally accepted by industry for conversion from AC to DC. Soon after the introduction of the silicon rectifier, a controlled version was produced with a third electrode. This was originally called a silicon controlled rectifier. However, today this is referred to as a thyristor. The basic characteristics of a thyristor are shown in Figure 1. From the voltage/current characteristics, it can be seen that the device blocks voltage in both the forward and reverse directions. Flow of current is blocked in either direction, other than a small leakage current, so long as the forward blocking or maximum reverse voltages are not exceeded.

If a voltage in excess of the blocking voltage is applied, the leakage current increases until break down of the device occurs. This is a non-destructive condition but is not a recommended method of use.

When the reverse voltage rating is exceeded, leakage current again increases until breakdown occurs but in this direction it is destructive and the device can be permanently damaged.

Application of a positive energizing signal to the gate electrode causes the device to conduct when it has positive voltage on the anode. When the signal is applied with negative voltage at the anode, conduction is not initiated; however, an increase in the leakage current through the device takes place with consequent increase in the power dissipation in the device. This can

(Please turn to page 30)

(Continued from page 28)

be a harmful condition resulting in reduced life and care must be taken to make sure this does not occur.

Removal of the gate signal has no effect unless the current flowing through the device is very low (of the order of 1/100th ampere) and less than the holding current. Turn off is achieved by reverse bias of the anode to a negative potential for a short period of time. This period is known as the "Turn Off Time" and varies from one device to another and from one type to another. In general, this period is less than 30 μsec but can exceed 40 or be as low as 10 μsec for an extremely fast device.

In the equipment provided for C&NW, the incoming AC 60 cps supply is converted to DC by use of a 3-phase silicon rectifier bridge. A silicon controlled rectifier inverter then converts the DC into a 100 cps square wave. This is regulated and filtered by a ferro-resonant transformer before going out to the line through a relay sensing system.

The inverter can be split into two parts, control functions and power generation (see Figure 2). The control functions take place with transistors and a resistor zener diode arrangement to develop a low voltage power supply. A highly stable transistor oscillator acts as the frequency determining unit; it feeds into a Class C type of power amplifier which gives a sharp rise time to the thyristor's gate signals. Output from the amplifier is fed alternately via a transformer to the gate circuits of the two inverter thyristors.

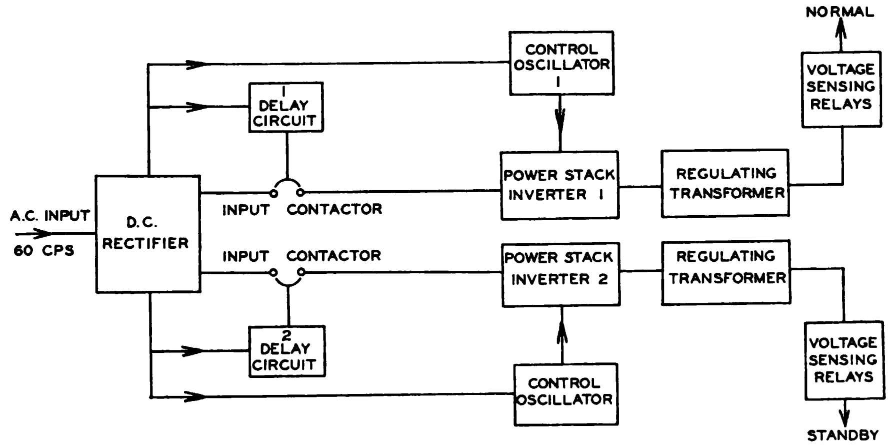


Figure 2: Block schematic diagram of dual inverter system equipment.

A static timer circuit is included in the control section to delay operation of the main DC contactor for a few seconds. The control circuits are thus allowed to settle down upon initial application of the main supply, and avoid the possibility of erratic operation should the main supply only partially return. When two inverters are running off one DC supply, this also allows one inverter start to be further delayed avoiding simultaneous starting surges on the filter.

A simplified version of the inverter stage can be seen in Figure 3. The main components as shown are two thyristors, SCRI and SCR2, a center tapped transformer H1, H2, and H3, a choke L1 which acts as a surge current limiter, two diodes D1 and D2 which provide regeneration, and the commutation capacitor C1.

The operation is as follows: Assume that gate drive is applied to SCR1 and it is conducting; current flow is then from E+ thru L1 to anode of SCR1, terminal H1 of the transformer, out of H2 to the negative line. Potential drops across SCR's and diodes and elsewhere can be ignored. A voltage of E+ is then developed at terminal H1 with respect to the common terminal H2 of the transformer. At terminal H3, by transformer actions, a voltage of −E is developed. The combination voltage developed across H1 to H3 is thus 2E, and hence 2E is also developed across C1.

After SCR1 has been on for a half-cycle, the gate drive is removed and applied to SCR2. This SCR now comes on, terminal H3 and hence C1 now reverse biases SCR1 for the period of time taken by C1 to discharge through the transformer and into the load. Capacitor C1 then recharges to 2E again, but with reverse polarity. The period during which SCR1 is reverse biased is that referred to earlier as the Turn-Off-Time.

At the end of this half-cycle, SCR1 is gated on again and SCR2 now loses its drive and is turned off, the cycle then repeats itself until such time as the unit loses its supply.

When an active load is driven by the inverter (motor or ferro-resonant transformer) there are sometimes periods during the cycle when current flow is into and not out of the inverter. A regenerative circuit is formed by diodes D1 and D2 that provide a clamping path from the load to the DC filter.

(Please turn to page 32)

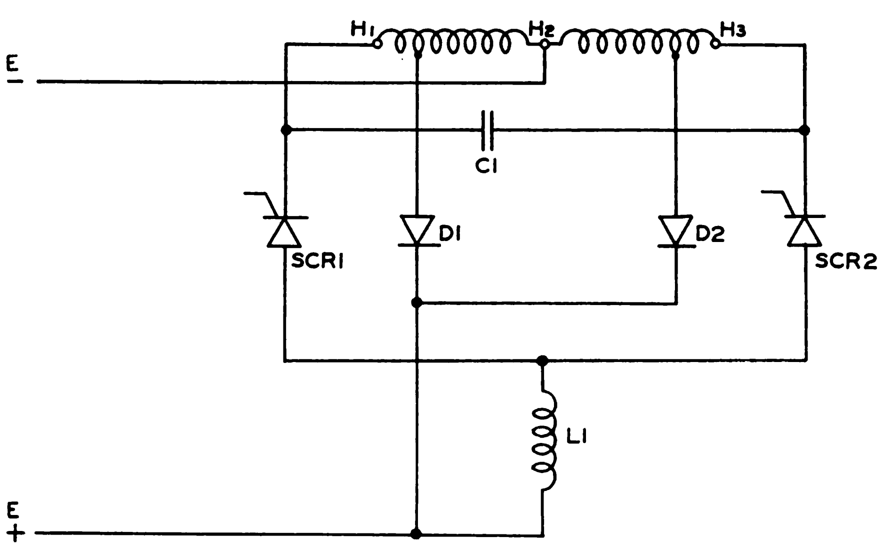


Figure 3: Diagram of simplified inverter power stage.

(Continued from page 30)

Assume that SCR1 is conducting, when the load regenerates the cathode of SCR1 is taken positive with respect to its anode, and it stops conduction due to the reversal of polarity. No load now exists for the regenerating load and the EMF rises until the anode of D1 goes more positive than E+, the diode then conducts and clamps the regenerated voltage to E+.

On the reset half cycle, D2 performs the same function. The regenerated power is stored in the DC filter and is thus not wasted.

A ferro-resonant transformer is used to combine regulating and filtering requirements. There is also an overload current limit feature which protects the inverter from short circuits on the output. This is a more frequent occurence due to falling trees or branches overhanging than on the public utilities where the lines are higher.

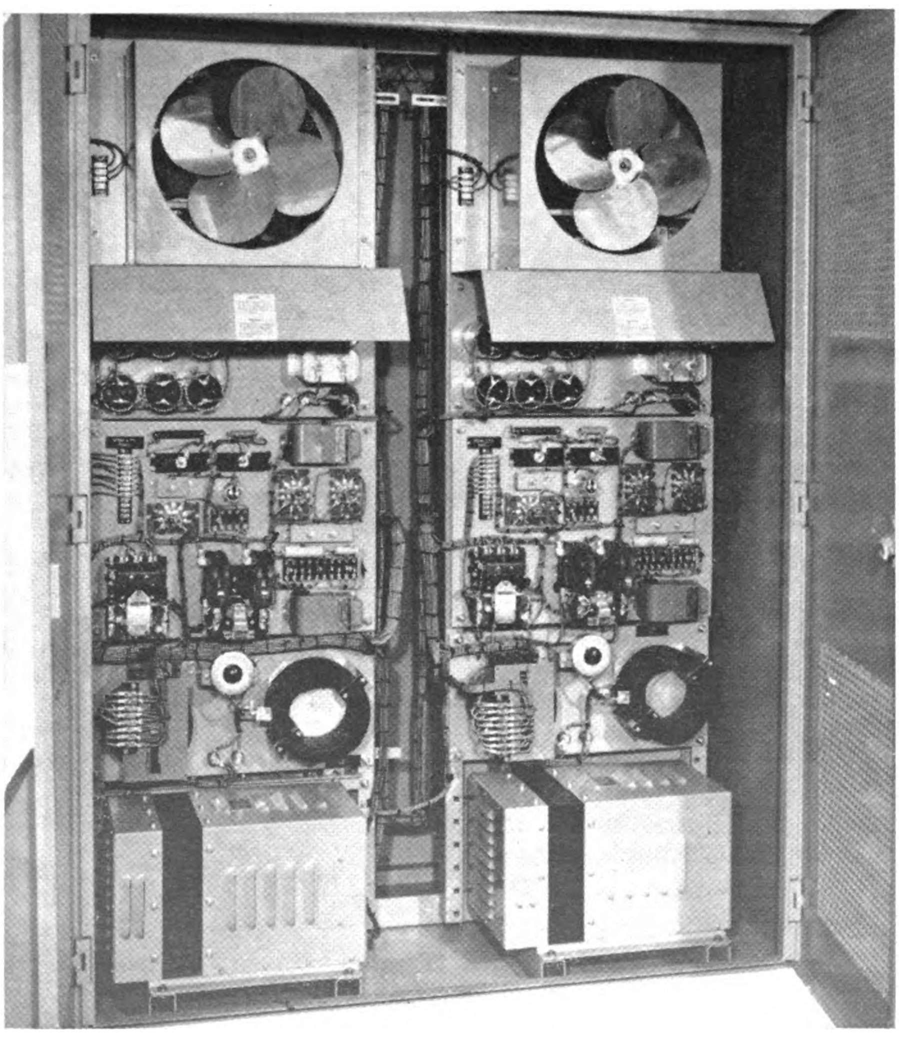
Over any section of line there are two inverters located at each end of the section. For convenience, one of them is called Normal and the other Standby. The Normal unit is energized on the line first and locks itself via a sensing relay. At the Standby unit, another sensing circuit locks out the unit from the line and when energized, it runs but does not supply any power to the line. Should the potential on the line be lost due to either a power failure or overload, the Standby unit is automatically connected to the line.

When the Normal unit comes back, it will act as the Standby until loss of power at the Standby occurs when the Normal unit will take over again.

When a short circuit occurs on the line, both units are connected to the line and work into the short. When the short is removed, due to slight frequency difference between the two units, a difference frequency modulation of the output from zero to full voltage will occur. As the output voltage falls slowly, one of the holding relays will be de-energized and the voltage is restored to regular operation.

This is particularly advantageous because a section of line can be removed from service and returned without assistance being required to disconnect power at either end during replacement.

Physically, the NEMA-type instrument cases housing these units are approximately the size we commonly term as high single-door or high double-door cases, and both the track and field sides of the cases are used. There are two pilot lamps mounted on the track side of the case, just above the doors. They indicate to a maintainer passing by on a motor car which units (normal or standby) are in service. When the normal unit is actually feeding the line, a green lamp is lighted. When the standby unit is energized, but not feeding the line, a red lamp is lighted. Should either of these normally lighted lamps be dark, the maintainer will know that something is in trouble and should be investigated.



Rear view of typical dual unit with normal converter (left) and standby (right).

The units were received and installed late last year. There have been some minor problems; one is noise, both audible and radio. The main source of the audible noise was from the final output, or regulating, transformer and a secondary noise was from the current limiting choke coil. It was necessary to send the transformers back to the manufacturer for correction. This was done one transformer at a time but only for those locations where homes were located nearby and the noise would cause some irritation or ill will. The backboards on which the choke coils were mounted seemed to act like a sounding board and by changing the mounting brackets the noise from these coils was greatly reduced. The radio noise was eliminated from all units by the addition of three filter coils—one between each phase and ground on the input power supply.

Not long after the installation was placed in service, a line distribution

(Please turn to page 51)

C&NW 100 CPS AC FOR ATC

(Continued from page 32)

transformer located at a point about midway between power feed locations shorted out. Output current on the normal unit was found to be 5.5 amp (ordinarily the current at this point was 2.5 to 3.0 amp) but the output voltage had dropped to 220 volts. A similar instance occurred sometime later with the short very near the power feed; again the current was only 5.5 amp but output voltage had dropped to only 30 volts. So, we do have good protection against overload currents and excessive power requirements that might overheat some of the equipment.

Another interesting point concerns those times when a section of the 100 cps transmission line must be opened to correct some type of trouble, such as a shorted transformer mentioned above. The sectionalizing switches are opened and both the normal and standby units feed up to this "open" point. After the work is completed and the sectionalizing switches are re-closed it has been found that the two units will buck each other for about a second and one of the units will dropout. This might be considered a bonus as it was not required by the specifications and it does obviate the need for a man to be at the standby end of a section to manually cut that unit off the line.

SLEET AND ICE STORMS

In late January of this year we had a severe sleet and ice storm in Chicago and its western suburbs with electric power service disrupted all over the place. Power was out for over four days in many locations. The power company used extra help in their maintenance and construction forces plus importing crews, trucks, equipment, and material from other areas.

We lost the local 60 cps power at several CTC interlockings, at various automatic gate protected highway crossings and at one of the 100 cps locations. The standby 100 cps unit at the adjacent station picked up the ATC power and local storage batteries kept the CTC and crossing protection operation for a while. Our supervisor recognized that these batteries would not last too long, so he judiciously added the CTC stations and crossing protection to the various 100 cps transmission line sections keeping an eye on the current load. The added loads did create higher voltage drop on the transmission line and at the far end of one section he only had 400 volts, but he did "save the day" so to speak. As commercial power was restored over the area, the extra loads were removed from the 100 cps line.

We feel that the transition from 60 to 100 cps has been satisfactorily accomplished with little interruption to the ATC system. There has been no interference from 60 cps power sources. There have been a few bugs to work out with the manufacturer and some failures of component parts; these have probably been as close to a minimum as might be expected from any new system such as this. It now appears that maintenance can be held to semi-annual or annual cleaning of dust from the equipment with a vacuum cleaner.

Discussion: In reply to a question from **B. Freeman,** PRR, Mr. Bush said that a study revealed too great a cost to use local 60 cps power and tuned alternators. He said the cost would be far in excess of that to provide the 100 cps transmission line. In replay to a question from **J. R. DePriest,** SAL, Mr. Watkins remarked that thyristors can be practical for voltages up to 800 and up to 250 amp rms. Such a unit might cost $500 or more with integral heat sinks.

Concerning voltage regulation, Mr. Watkins said that with thyristors it is in the range of ±1%. Frequency stability is 1% in a standard range, and even as well as 0.1% can be achieved in the 2.5 to 3.0 kc range. To obtain a frequency stability of the order of, 0.1% might not be economically justified with the present state of the art of thyristors, Mr. Watkins said.

Mr. Bush commented that operation had proved satisfactory with standby units feeding the long sections. Short vs long feed sections had been considered in the planning of the 100 cps system, and they were able to reduce the number of power feed locations from 28 to 11. **RS&C**