UDC 621. 311. 1. 076. 7

FUJI SIMULTANEOUS TELECONTROL SYSTEM FOR POWER DISTRIBUTION AREA (MARU-MATIC)

Michio Kikuchi
Second Electric Power Engineering Dept.

1. PREFACE

The demand for automatic control and supervision of power distribution systems is increasing, and in step with this demand is the progress being made in the modernization of power distribution equipment. Automation is one of the most important means of modernizing power distribution systems, just as it was for power plants. One type of equipment required for automating power distribution systems will be described in the following article.

The main system in automating power generating facilities was the one-to-one control.

One of the outstanding characteristics of the power distribution network control described here is that the distribution network requires single line multiple control. This unique requirement will require an unusual control system for power distribution.

The main objectives of centralized control of distribution systems is to transmit electric power to the consumers with the least amount of loss, least number of maintenance persons, suitability of cost, and established reliability in power distribution.

The principal functions and application of this Simultaneous Telecontrol System are as follows:

(1) Simultaneous switching of measuring instruments such as watt-hour meters installed at 2-hour or 3-hour rate contract consumer or demand points.
(2) Simultaneous ON-OFF control of power supplies for water heaters and electric heating systems.
(3) Simultaneous ON-OFF control for street lighting systems.
(4) Simultaneous ON-OFF control for load switches.
(5) Simultaneous control and measurement for load controls.
(6) Simultaneous switching of transformer voltage taps on substation to particular transformers in order to better control voltage levels.
(7) Simultaneous switching and control of heat-accumulator type electric heating systems, ON-OFF control of electric furnaces.
(8) Simultaneous ON-OFF control of lighting systems for stairs or show windows.
(9) Simultaneous ON-OFF control of capacitors or auxiliary transformers in electric circuits.

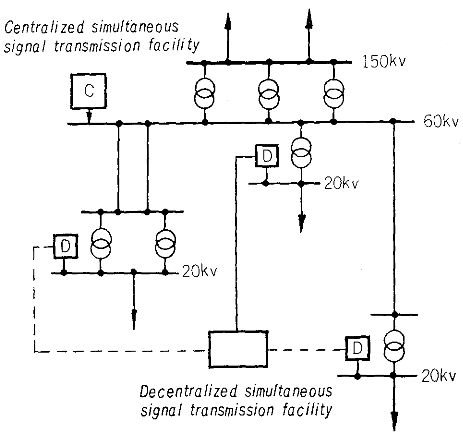


Fig. 1 **Maru-Matic network signal transmission**

In the simultaneous control method, a number of items may be simultaneously controlled. These items can be sequentially controlled in a one-to-one or single line multiple mode by sequentially controlling them in series.

However, in this case, the time interval of the sequential control between one item to be controlled and subsequent items must be in the range of between hundreds of ms to tens of seconds because of the reasons given later.

Special applications of sequential and simultaneous control are:

(1) Gate control, or sequential control providing a predetermined interval between "start", "excitation", "parallel" and "load" when automatically starting a hydraulic power plant in a remote area.
(2) Local control of an overall hydraulic power plant group control system which sequentially controls a group of hydraulic power plants located along a water system.
(3) Simultaneous switching of valves used for city water distribution systems, chemical plant or cooling water systems of thermal power plants.
(4) Simultaneous switching of valves and other controls in a gas supply system.
(5) Simultaneous control of alarms and or various types of traffic control signals for police and fire stations.

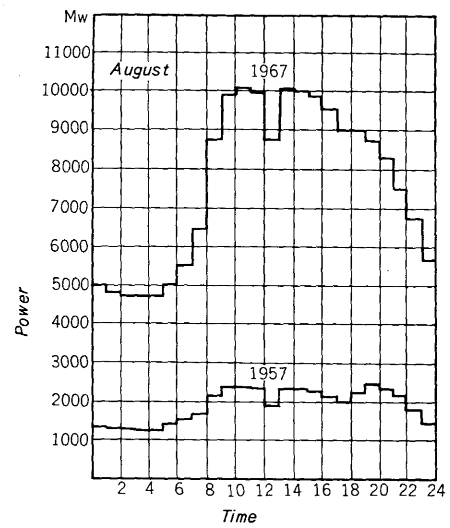


Fig. 2 Variation in load levels between day and night

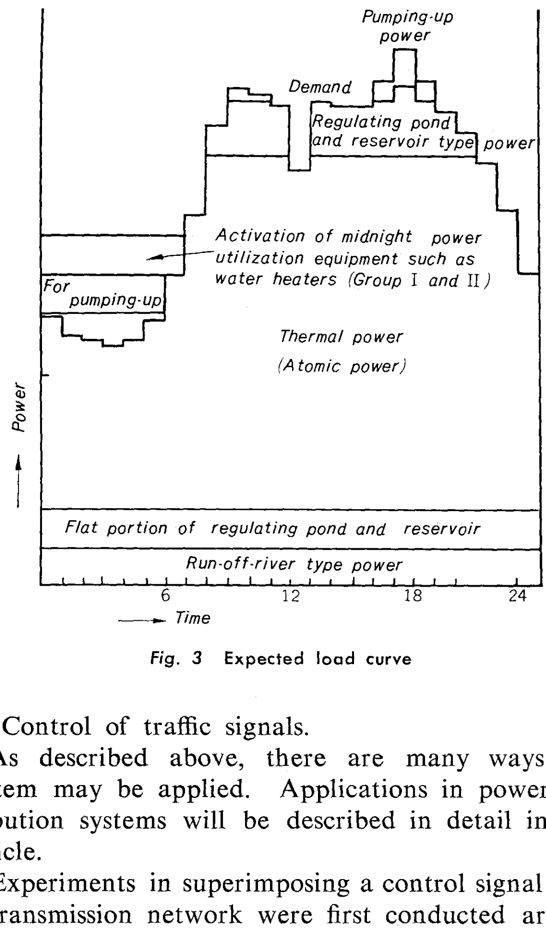


Fig. 3 Expected load curve

(6) Control of traffic signals.

As described above, there are many ways this system may be applied. Applications in power distribution systems will be described in detail in this article.

Experiments in superimposing a control signal onto a transmission network were first conducted around 1897.

Because the distribution network is located at the end of the power supply system, frequent load switching is necessary. This frequent switching in the distribution network causes problems as in the case of corresponding changes in impedance in the signal carrier systems. Another problem is the noise induced into the distribution system during load switching.

In solving the special problems peculiar to signal transmission through a distribution network, a method of constant ac signalling for a long period of time was developed as a means for discreminating the signals. The length of the signals actually employed in various types of systems at the present time is 230 ms, 460 ms, 500 ms or 1 seconds. Some systems utilize signals of longer length such as 18 seconds for example. When comparing these pulse lengths with several μ sec., the pulse length employed in the present communication carrier system or transmission line carrier system, the difference in pulse length is extreme, but such pulse lengths must be used because of the reasons given above.

This type of control system, which operates on principles different from the conventional power line carrier system and simultaneously controls a number of loads to satisfy the special requirements peculiar to the power distribution system, is the " Simultaneous Automatic Control System for Distribution Networks ". This is called " Rundsteuertechnik " in Germany and is equivalent to the " Round Control Technique " in England. This term means that the control signal is applied to the transmission point and from there propagted in all directions in a round pattern throughout the distribution network. The principles of control are well expressed by this term. Fuji Electric calls this system " Maru-Matic ". This system is called " Simultaneous Control " or " Maru-Matic " hereafter.

II. BASIC CONCEPTS OF SYSTEM CONFIGURATION

When considering the power distribution system electrically, one of the most outstanding characteristics is that various types of loads are connected and switched on and off at the demand ends. Some types of loads are always connected to a main line and current is therefore always flowing through the line. Therefore, an impedance is always connected to the power line. The parallel impedance referred to the power source side varies greatly since various types of appliances such as television sets, refrigerators, heaters, and motors are connected to the low voltage network. The switching on or off of these

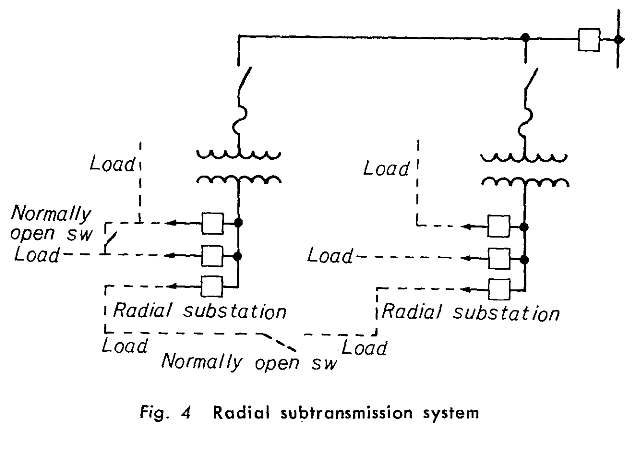


Fig. 4 Radial subtransmission system

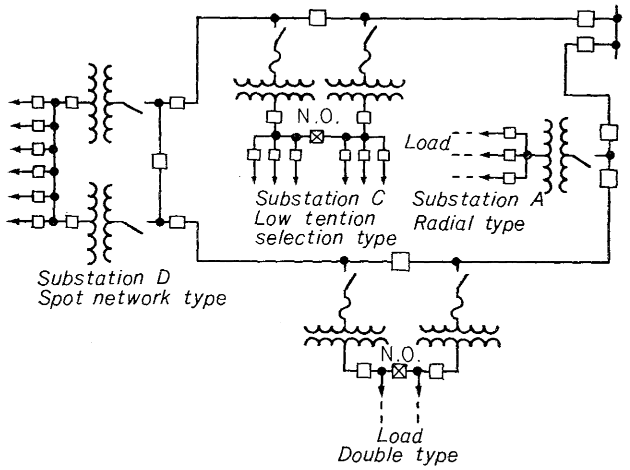


Fig. 5 **Loop subtransmission with variation types of substations serving a primary system**

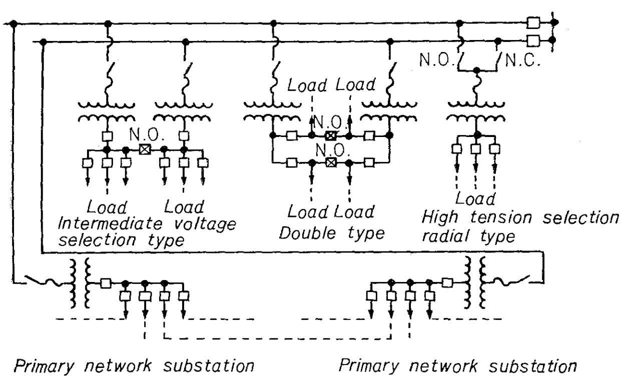


Fig. 6 **Multiple subtransmission with various types of substations serving a primary system**

appliances is controlled by the consumer's needs independent of the controller who wishes to control the power demand at the power source side of the distribution line. Thus, the impedance of low voltage commercial frequency networks varies at all times.

However, after passing through a low-to-intermediate voltage transformer ($1 \sim 30$ kv), a change of overall load conditions can be noticed to a certain degree. Impedance variations between day and night are evident. In the main line carrying higher voltages, variations in impedance can be more easily analyzed and checked since transformers connected to the main line have considerably higher impedance.

Application of communication carrier waves to the electric power line was originated many years ago especially with respect to power transmission lines since the latter provided a high degree of isolation between lines or between lines and the ground.

However, application of communication carrier waves to distribution networks is very difficult because of various reasons previously described. Therefore, the same techniques used for applying carrier waves to transmission lines cannot be used for dis-

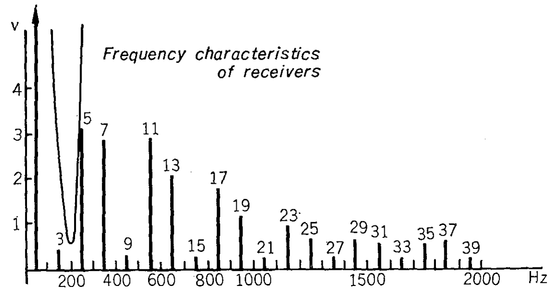


Fig. 7 **Results of noise measurements in distribution networks**

tribution networks.

Another problem in applying a control system to distribution networks is that the control system itself must match the distribution network arrangement.

A special circuit for the control signal is the best solution for the transmission of the control signal. However, if a signal is transmitted through the distribution network, it cannot be transmitted through an open point in the line unless a special coupling device is installed. The necessity of controlling and monitoring the distribution system in the future is apparent and the solving of these problems economically is extremely important.

Selection of either a distribution system or an independent signal transmission line for monitoring and control of the power distribution system along with the economic studies of the system, is one of the key factors in planning overall system arrangement.

In Europe, dc pulse application to low voltage distribution lines, multiple frequency assignment methods, and various other methods have been studied and tested for many years in the development of practical distribution line carrier systems. However, the only method found to be practical economically and technically was pulse interval type command transmission methods employing single frequencies.

Three features contained in the Maru-Matic make this system more practical and economical.

(1) The signal for the distribution line carrier system can be carried through and distributed by the power line.
(2) This system can also be used in the direct transmission method in which the signal is directly applied to an exclusive signal line instead of using the carrier method.
(3) By applying the signal to a communication line together with other signals, communication line carrier methods can also be achieved.

III. SYSTEM CONFIGURATION

The general arrangement of this system is shown in *Fig. 8*. As shown in *Fig. 8*, simultaneous control signals are applied to a 110 kv system with apparatuses connected to 415/240 v network, representing full control. When operating the simultaneous tele-

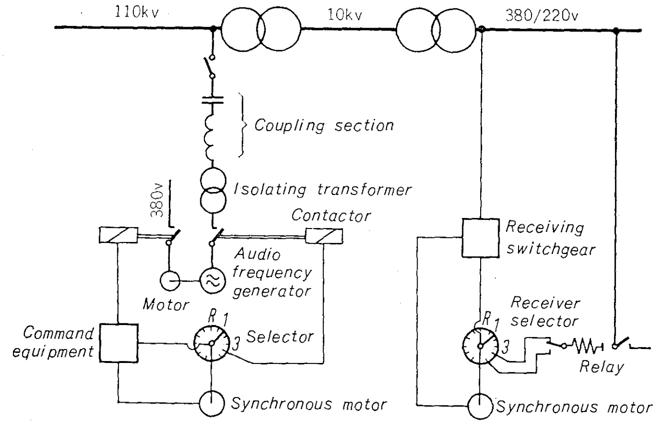


Fig. 8 General arrangement of simultaneous telecontrol system

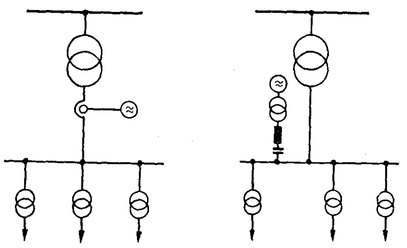


Fig. 9 (a) Series coupling type

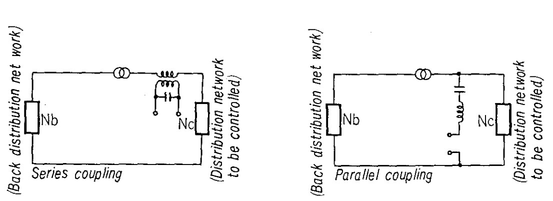
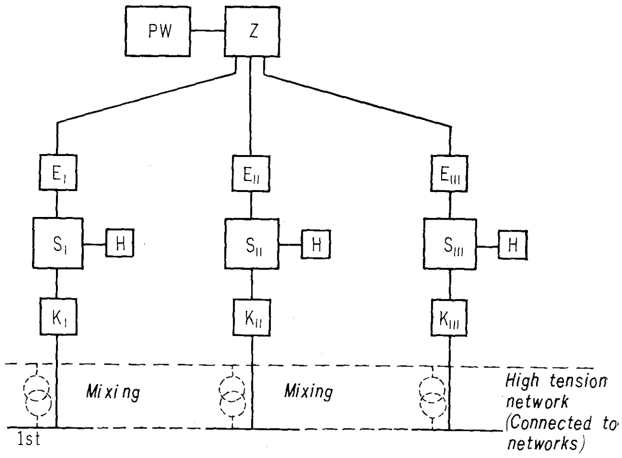


Fig. 9 (b) Parallel coupling type



Z: Central signal station (connected to networks)
PW: Program setter
E: Receiver
S: Audio frequency
H: Manually operated transmitter
K: Coupling device

Fig. 10 Remote control (schematic diagram)

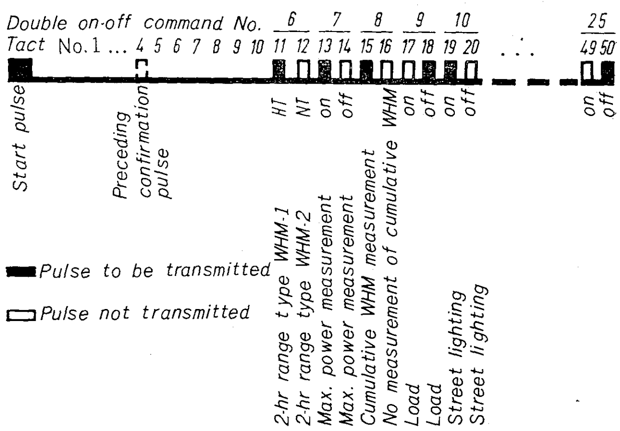


Fig. 11 An example of pulse arrangement

control, the motor or stationary type frequency converter which generates audio frequency power is started first. The operation of the synchronous motor shown at the lower left in the figure should be started in accordance with the synchronous speed corresponding to the commercial frequency of the distribution network to be telecontrolled. Synchronous motors are also installed at the receiving side and are always operated at the synchronous speed corresponding to the commercial frequency of the power distribution network. Both discs of the transmitting selector and the receiving selector shown in the figure rotate at the same speed. If the commercial frequency of the power distribution network rises, both transmitting and receiving discs simultaneously start to rotate at a faster speed and both discs slow down as the frequency drops. Thus, both discs are synchronously operated. This type of operation is called " the simultaneous operating system ". After obtaining this " simultaneous operating system " the signal is then applied to the system.

The two types of signal transmission methods shown in *Fig. 9* can be used to apply a simulteneous control signal to the power distribution system.

1) Series coupling type

The signal is sent to the network through CT connected in series with the network.

2) Parallel coupling type

The signal is sent the network through a coupling capacitor and other components connected in parallel with the network.

When audio frequency power has been generated by the frequency converter the system may be operated. The system is controlled following a predetermined program as illustrated below.

The pulse arrangement of the system is shown in *Fig. 11*. As shown in the figure, Tact No. 1 to Tact No. 50 is provided in this pulse arrangement of the system. The disc driven by the synchronous motor as a part of the simultaneous operating system described before completes one turn after it progresses from Tact No. 1 to Tact No. 50.

When starting the system, the contactor at the output of the audio frequency generator is closed for a predetermined period of time. The starting audio frequency pulse thus produced is then superimposed on the commercial power line. The power plant has an extremely small output therefore the audio frequency is connected for several hundred ms to the electric power distribution system which is of commercial frequency and is carrying power sent from hydraulic, thermal and atomic power plants. The energy generated by the audio frequency when applied, is carried through the distribution system whose impedance varies drastically and power is switched frequently. Some of its energy is consumed in domestic appliances and the remainder in the " simultaneous control signal receiver ".

The audio frequency start signal is applied to the simultaneous control signal receiver for a predetermined period of time and the control lever of the receiver is mechanically interlocked to the disc operating in conjunction with the simultaneous operating system. The control lever rotates with the disc. The disc then progressively ticks off the Tact numbers in synchronization with the remainder of the system.

When the normal distribution carrier method is employed, one or more preceding confirmation pulses are produced to confirm that the operation has been started by the signal transmitted from the central control center. This procedure is equivalent to loop checking in conventional data transmission techniques, and is very important. After performing this confirmation, the control command pulse is applied to the system at a predetermined Tact No. position, then the receivers operated simultaneously by a predetermined program.

When the programed operation is complete, operation of the transmitting equipment at the central control center is stopped, and only the synchronous motor at the receiver side of the system continues to rotate with the disc while the lever is disengaged, awaiting subsequent restart of the simultaneous operating system.

The advantages of an operation as described above are listed below.

1) If timers and auxiliary mechanical clocks are installed at several thousand are more demand points, such as presently seen in the water heating system in Japan, and the synchronous frequency of these mechanisms vary considerably over a long period of time, the mechanisms will stop. The stopping of these mechanisms causes a great deal of trouble in that they are must be reset. This system eliminates the need for simultaneous readjustment of the large number of demand points.

2) The expensive clocks and timer mechanisms installed at large power demand points require periodic adjustment and pin replacement. This system eliminates this problem and expense completely.

3) Similar advantages are obtained with this system when used with street lighting systems.

4) Direct sending and carrier wave communications are achieved utilizing the power line.

5) Since the discs of the simultaneous operating system are rotated by synchronous motors at all time, only a small amount of starting energy is required during system start so that the synchronizing operation is performed in a more reliable manner. Also, automatic running or reverse running is not required for the motor, thus the equipment is more simplified. Line noise can be checked easily and false starts are eliminated.

IV. TRANSMITTING PLAN AND CODING METHOD

As illustrated in *Table 1*, this system was originally developed by French manufacturers and presently more than 500,000 signal receivers are being used in France. As clearly shown in the table, various manufacturers in European countries such as West Germany, Switzerland and Austria have also manufactured receivers, transmitters, block devices and other related system equipment.

It should be understood that variations in the pulse code methods are due to special conditions imposed on the distribution line carrier system as described before and that the system itself has been regarded as established in the engineering field. Overall standardization is now being conducted in European countries.

The reason for the sudden development of this system in Europe rather than USA is that European countries have been utilizing thermal power plants for generating electric power for many years. As electric consumers the world over rely more on the thermal and atomic power plants in the years to come, the importance of this system will be more apparent.

This system with its excellent load switching capabilities during low demand periods and its many other applications is certain to gain recognition in the near future (*Fig. 2* and *Fig. 3*).

EdF of France established the signal frequency of 175 Hz for all regions in 1950. Standards for the transmitter and receiver were also established. In West Germany, power company " RWE " supplying power to the northern regions has established 217 Hz and 492 Hz along with all standards. Also, 480 Hz was established by Hamburg Power Co., 1350 Hz by Köln Power Co. of West Germany, 200 Hz by OECL of Switzerland, 300 Hz by MEB of England, and 175 Hz by Danubia of Austria.

Dependent upon the high or low signal frequency used, the following result should be obtained. If 175 Hz to 210 Hz is employed, a device such as a choke coil or closed circuit to block the load (such as a capacitor which passes high frequency) from the audio frequency will not be required. However, if the signal frequency becomes higher about 250 Hz, installation of a blocking device is necessary to distribute the signal to the assigned area. Especially in asynchronous motor circuit having a power factor

Table 1 The Development of Signal Carrier System in Power Distribution Networks

Year	Company	Signal	Country	* Coding Method	* Transmitter	Max. No. of Signal
1897	Brown Routin	DC bzw. 25～50 Hz	France	MF	M	2
1902	Turpin	RF	France	MF	M	2
1916	Duddell	Dc pulse	England	IF	M	
1920	Bethenod u. Genkin	100～500 Hz	France	IF	M	2
1925	Société Action à Dist.	500～700 Hz	France	IF	M	2
1928	CdC Actadis	400～1000 Hz	France	IF	M	12
1930	Brillié	750～1500 Hz	France	IF (mod.)	M	48
1931	Durepaire-Perlat	DC	France	IF (mod.)	M	5
1933	Telenerg Siemens	280～600 Hz	Germany	MF	M	10
1939	CdC Actadis	370～1000 Hz	Switzerland	MF	M	13
1940	Transkommando AEG	50 Hz	Germany	ID	M	2
1946	Landis & Gyr	475～725 Hz	Switzerland	II	M	50
1947 ～	Zellweger Uster	1350 Hz (1000～2000) Hz	Switzerland	II	M	22
1950	Brown Boveri	1000～1800 Hz	Switzerland	ID	M	20
	Sauter	1050 Hz	Switzerland	ID	M	100
1948	Metropolitan Vickers	510～900 Hz	England	ID	M	2
				II	M	8
1949	CdC Pulsadis	780 Hz	France	—	—	40
1948 ～	General Electric	720 Hz	USA	ID	M	2
1950				+II	M	8
	Seymour	60 Hz+240 Hz	USA	HW	M	2
	Line Material	3000 Hz	USA	ID	M	2
				+II	M	6
1954	Ghielmetti	700～2000 Hz	Switzerland	II	M	34
1954	Stw. Innsbruck	—	—	MF	—	—
	Standard Telefon	1200～2400 Hz	Austria	MF	M	20
	Uher	—	—	MF	RV	—
1955	CdC Pulsadis	175 Hz	France	II	M	40
1956	CdC Danubia Pulsadis	175 Hz	Austria	II	RV	40
1958	OBAC Pulsadis	157 Hz	Germany	II	WRQ	40
1959	CdC Danubia Pulsadis	175 Hz	Austria	II	WRTr	40
1965	CdC	175 Hz	France	II	WRTs	40

Note: *MF: Multiple frequency; IF: Number of pulses; ID: Pulse length; II: Pulse interval; HW: Half-wave; M: Machine; RV: Vacuum tube amplifier; WRQ: Mercury tube oscillator; WRTr: Thyratron oscillator; WRTs: Thyristor oscillator

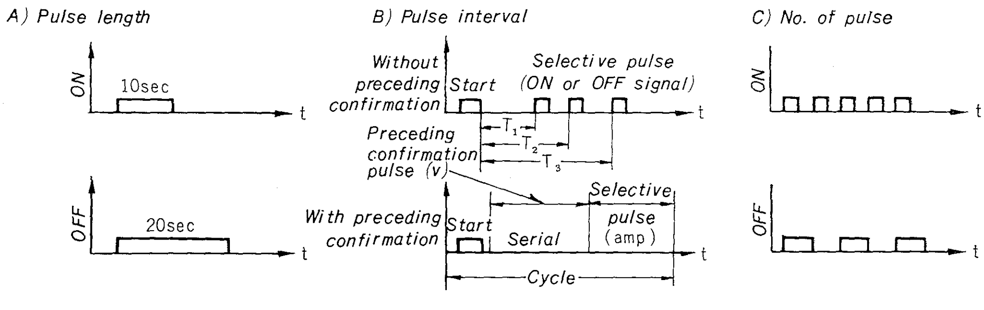


Table 1 (a)

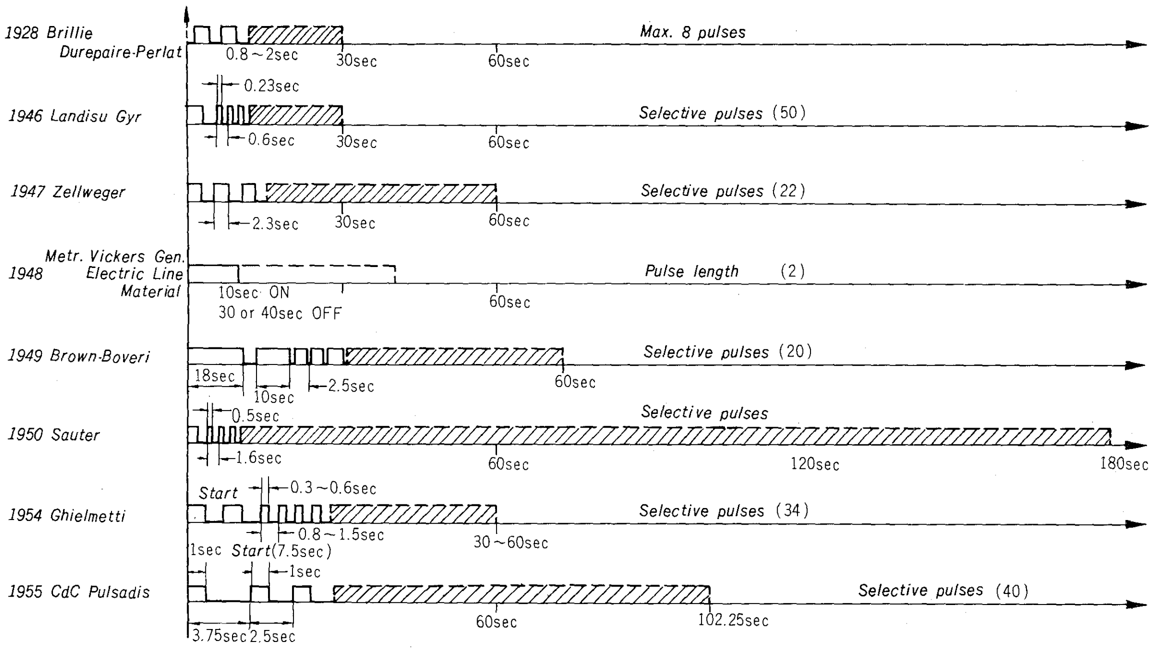


Table 1 (b)

compensating circuit, this circuit itself acts as a resonance tuning circuit for frequencies between 175 Hz to 210 Hz so that the audio frequency energy is effectively utilized. In this frequency band, 175 Hz, 190 Hz, 210 Hz and 217 Hz are recommended for 50 Hz power distribution networks. However, 200 Hz should be avoided since it is an even harmonic of 50 Hz frequency. This is necessary because a single-direction rectifier is employed in television receiver sets and it produces even harmonics. Also, even harmonics having comparatively short duration generated in the process circuit of the power distribution network sometimes interfere with the signal so that any signal having a frequency too close to the harmonics should be avoided. Selection of a higher frequency will have no cost reduction effect and may in addition add problems with resonance. When comparatively high frequencies are used, unstable receiving levels are experienced this is often due to a capacitor even if a blocking device has been installed. By increasing the frequency, the impedance governed by the leakage impedance of a transformer can be increased accordingly.

Another problem to be taken into consideration in selecting the signal frequency is "inductive interference" to television sets, radios, amplifiers, etc. which are connected to the power distribution line being planned and "signal leakage" to adjacent systems. These problems have been studied and tested in Switzerland and Austria in various ways. Results of these studies show that interference to communication facilities is increased as the signal frequency becomes higher. Mr. Meister, chief of engineering for PTT Co. of Switzerland developed the Meister curve shown in *Fig. 12*.

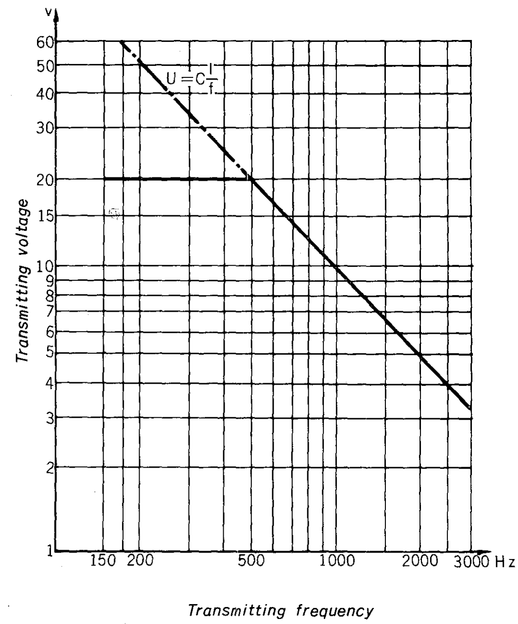


Fig. 12 Meister curve

This curve indicates the relationship between maximum allowable level and audio frequency in the form of a threshold curve. This maximum allowable level should be used as the threshold level never to be exceeded even if resonance occurs in the power distribution network.

In addition to the interference described above, caution should be taken to prevent "leakage" to the adjacent systems. With proper selection of signal frequency, signal sending methods and transmitting level, leakage to adjacent systems can be held to a minimum and installation of expensive leakage-preventing devices eliminated. It is a common practice to apply two signals having opposite phases to each other, to the two systems positioned in parallel to prevent leakage.

Several factors should be taken into consideration in choosing the best suited pulse code method for the simultaneous telecontrol system. It must be feasible economically as well as technically. The most important factor it should possess, however, is ease and convenience in handling with universal flexibility.

For economic feasibility and universal convenience, Fuji Electric has selected the pulse code method illustrated in *Fig. 16*. The standard start pulse has a pulse duration of 460 ms. The marker pulse duration is 110 ms, space duration is 467 ms, total of 50 pulses is provided in single rotation which takes approximately 30 seconds. This code method is the same short transmitting width method already in use in Europe as indicated in *Table 1* (*b*). As described, the signal can be more easily discerned if signal transmitting width is longer taking into consideration the characteristics of the power distribution network. However, shorter width is more desirable for control purposes. All operating errors must be strictly avoided so 110 ms is considered to be the best at this time. To assure maximum operating reliability, the preceding confirmation pulse is provided and will be described later. Reliability confirmation of the system can be performed by this pulse. When this code method is employed, a total of three outputs are available from each receiver. By using this method, the various types of simultaneous control described below can be performed.

(1) Simple application

With the exception of the start pulse, a total of 50 pulses are utilized when the preceding confirmation pulse is not used. Therefore, 50 different types of simultaneous telecontrols can be performed by one simultaneous-telecontrol group. When the double command method which utilizes ON-command and OFF-command as a set is employed, a maximum of 25 different selective commands can be executed. Also, since three outputs are available per each receiver, three controls of 25 to 50 selective commands are possible per each receiver.

(2) Combined use

Combined use does not mean combining several receivers for use. It should be noted that three outputs are available at each receiver. When three output contacts are connected in series, both " a " and " b " contacts can be provided to the three output relays. Therefore, " a " contact operation is provided by giving the signal pulse to the operating position of No. 1 and No. 2 relays and " b " contact operation is provided by giving the signal pulse to the operating position of No. 3 relay. Thus, relays Nos. 1, 2 and 3 are connected in series, one control command can be sent by applying pulse only to No. 1 and No. 2 but not to No. 3.

(3) Special combinations

By combining several receivers, separating signal pulses to certain groups or combining both, various types of modifications can be considered but they will not be discussed here.

In a radial pattern power distribution system, it is feasible to switch independently the 1 to 30 kv class loop type switches from the control center.

V. CONSTRUCTION OF RECEIVERS

1. Construction of Operation

The simultaneous telecontrol signal receiver employs the pulse interval method which controls by discerning various types of pulses by the time interval from the start pulse. The audio frequency impulse sent from the control center to a low voltage power distribution network is selected by the band filter at the input circuit, amplified by silicon-transistorized amplifiers and used to operate the audio frequency relay.

When the start pulse arrives, the audio frequency relay is activated and the electromagnetic coil in combination with the switch arm is excited. The switch arm is then pushed against the disc so that the disc teeth and switch arm teeth are interlocked starting the switch arm. After the start pulse has ended, the switch arm, in synchronization with the disc, enters the U shaped guide in the decoder case. If a false pulse is applied instead of the start pulse, the switch arm end cannot be entered into the U-shaped groove of the decoder. If a pulse length is shorter than the start pulse length, the switch arm returns to its original position immediately after (approx. 1/1000 sec or less) the false pulse disappears, thus preventing false operation.

2. General Specifications of Simultaneous Telecontrol Signal Receivers

Audio frequency: 8% band width
Approx. 180 Hz to 500 Hz, (higher frequency is available upon request)

Challenge voltage: 0.7% of rated voltage

Rated voltage: 105 v, 210 v, 415 v, 50/60 Hz (other specifications available upon request)

Transmitting impulse:
50 command signals, each having approx. 110 ms duration can be produced independently when start pulse has 460 ms duration and continuous transmitting program time is approximately 30 seconds. Different start pulse duration is available upon request.

Connecting assembly:
1 to 3 single-pole " c " contact

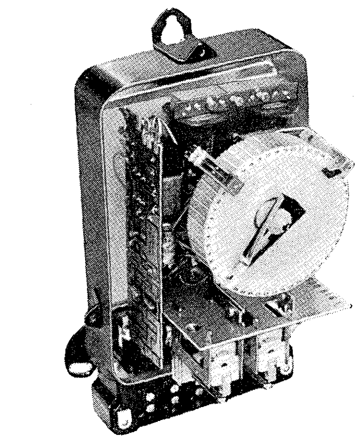


Fig. 13 Maru-Matic receiver

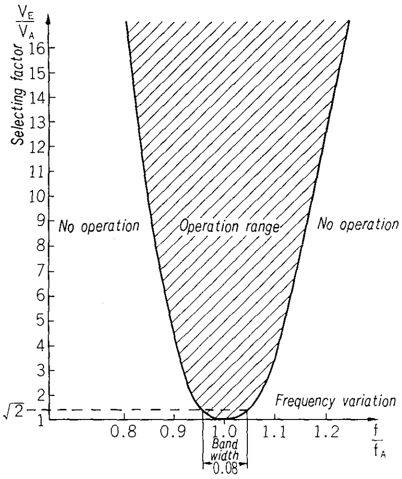


Fig. 14 Audio frequency band-pass filter characteristics

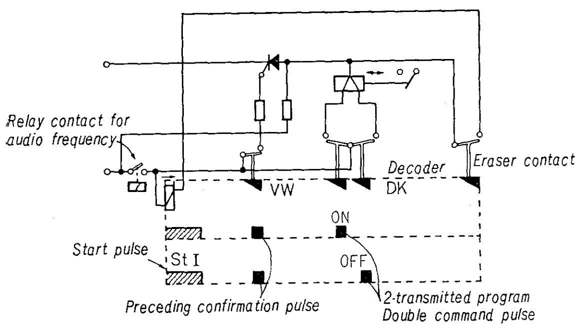


Fig. 15 Example of preceding confirmation pulse arrangements relative to ON-OFF double command

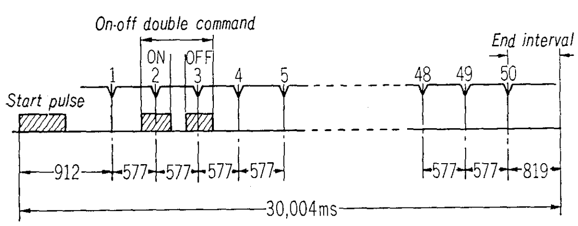


Fig. 16 Standard arrangement of transmitting pulse (for 50 Hz system)

	(210 v, 16 amp, cos $\varphi = 1.0$ for example), one 3-pole " a " contact, one single-pole " e " contact, or one 3-pole "a" contact.
Double command :	Corresponds to one switching assembly
Preceding confirmation device :	1 or 2 independent preceding confirmation circuits can be built in.
Case :	Steel
Welght :	Approx. 2.1 kg

3. Methods of Preventing False Operation

The methods of preventing false operation are described below. They are employed at the receiver side in order to increase reliability of the system. The equipment required for preventing false operation is not always installed in all receivers but is installed whenever necessary depending upon particular characteristics of each system. The equipment installed in the receiver is of simple construction.

1) Start pulse duration and false pulse detection

The start pulse is of predetermined pulse length. Thus, a false pulse (noise pulse) can be detected.

When a pulse having duration shorter than that of a normal start pulse enters the circuit, its difference is found in relation to time required for engaging the switch arm to disc casing at the decoder as previously described. Thus, a false pulse can be detected and eliminated.

However, if a pulse having duration longer than that of a start pulse enters the circuit, it cannot be checked in the above manner. Therefore, if a pulse is longer than a normal pulse by more than approximately 460 ms, the command relay is cut off by the operation of protecting device. The unit returns to its original condition (start) after one revolution by the operation of the eraser relay.

2) Combined preceding confirmation method

This method combines the preceding confirmation pulses and transmits them twice or more to the receiver in series so that the start command is confirmed in relation to the time interval. In actual arrangement, a series of thyristors are excited at different times at short intervals by using preceding confirmation pulse contacts. The command relay is then activated.

Upon completion of one rotation of the receiving cycle, the circuit outlined above is reset at the last position. This operation is the same as that described in 1) " Detection of false pulse ".

3) Reversed preceding confimation method

The normal preceding confirmation method was described before. This reverse method operates in such a manner that, after a false pulse is detected, the monitoring contact *P* activates the monitoring relay. The command relay operating circuit is disconnected and only correct pulse commands are

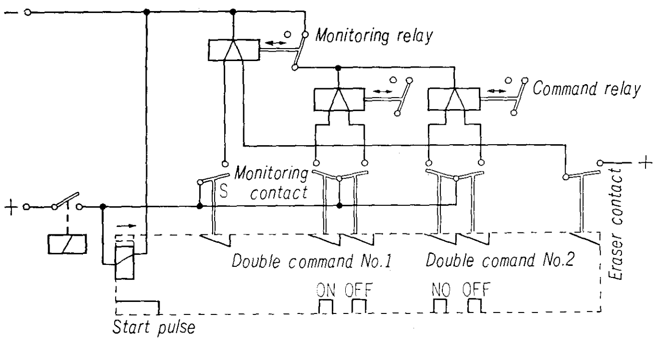


Fig. 17 Method of detecting false pulse

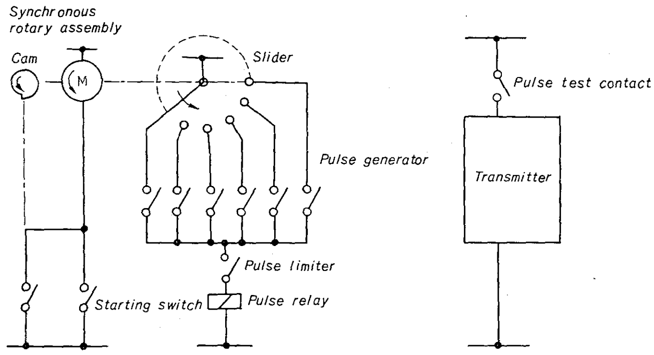


Fig. 18 Pulse code generator

allowed to enter after normal receiving conditions are established. After the command relay operating circuit is cut off, command is no longer executed. After the transmitting program has completed one cycle, the erasing contact is operated and the monitoring relay is reset.

4) Mixed method

Both detection of false pulse and reversed preceding confirmation methods are combined in this method to provide highly reliable control against interference pulses. Two monitoring relays are connected in parallel and command pulses are properly checked to provide predetermined operation only when the following two conditions are satisfied:

1. Start pulse has proper standard length.
2. There is no interference pulse after arrival of the start pulse.

4. Other Specifications

1) Perfect operation is assured within 80 to 110% rated voltage range.

2) Safety precautions are taken in all types of weather conditions. Normal operation under damp conditions in completely sealed area is assured. Normal operation is assured if mean yearly humidity is less than 75%, 95% humidity will not damage the device up to 30 days. Unless sudden temperature changes occur within a day, temperature variation of approx. 20° will not affect the device. Allowable ambient temperature range is between −5°C and +45°C.

3) Dielectric strength: 2000 v at 50/60 Hz.

VI. CONSTRUCTION OF TRANSMITTER ASSEMBLY

Various requirements for the transmitter are described below:

(1) The transmitter voltage level should not be unnecessarily high since various problems such as induction or interference to other systems may be created by the high voltage. Also, since transmitting voltage levels vary due to changes in load at the low voltage side of the power distribution system, the voltage level must be regulated. At the same time, the system must be planned and controlled in such a manner that the applied signals are all transmitted to all points with proper level sufficient to drive the receivers being maintained.

(2) Signal frequency can not be allowed to change in respect to change of power frequency of the system. Also, motor speed changes due to changes of commercial power loads should not affect the signal frequency. The changes must be within the selectivity characteristics of the signal frequency of the receiver.

(3) Since the synchronous motor is employed for measurement at the receiver side. The time interval of the pulse code must be matched to the frequency of the commercial power line before the pulse is applied.

(4) The system itself must have impedance and other circuit values matched to the distribution system to be economical.

There are two signal transmission methods:

(1) Parallel transmission

(2) Series transmission

The signal applied to the power distribution system is distributed to various points through various types of impedance devices before it reaches to the signal receivers.

When considering the distribution of the signal applied by the parallel transmission method, a part of a signal applied from U_T is distributed to high voltage power distribution networks and the rest to low voltage power distribution networks. In this case, the signal is distributed in inverse proportion as given by the following equations.

(a) $Z_{TH}+Z_H$

(b) $Z_L+Z_{TN}+Z_N$

The same principle is applicable to the series transmission method but, in this case, all impedance elements except Z_K are connected in series to the signal system. If signal current flow is J_N, voltage U_T is

$$E_V=J_N(Z_{TH}+Z_H)$$
$$E_N=J_N(Z_L+Z_{TH}+Z_N)$$

E_N is potential at the network side and acts effectively at receiver side, and E_V is the signal voltage component wasted and can be called voltage loss. Leakage reactance of the transformers and impedance

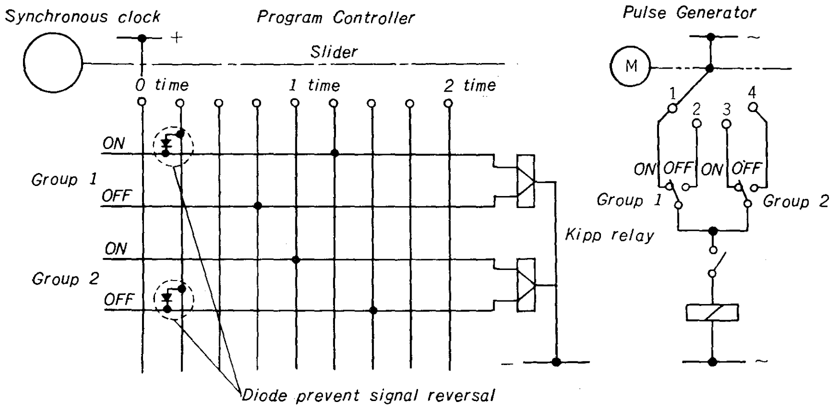
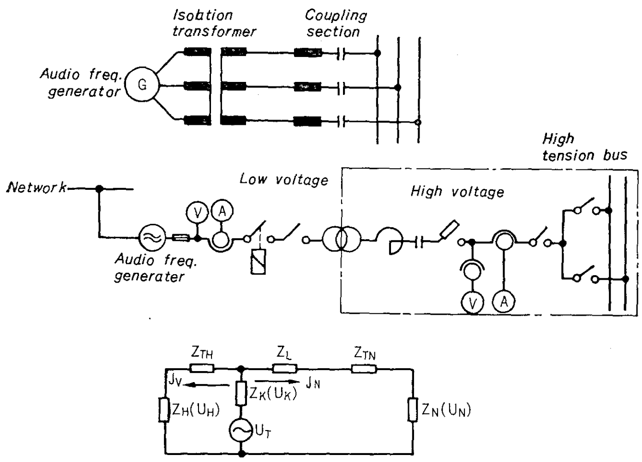
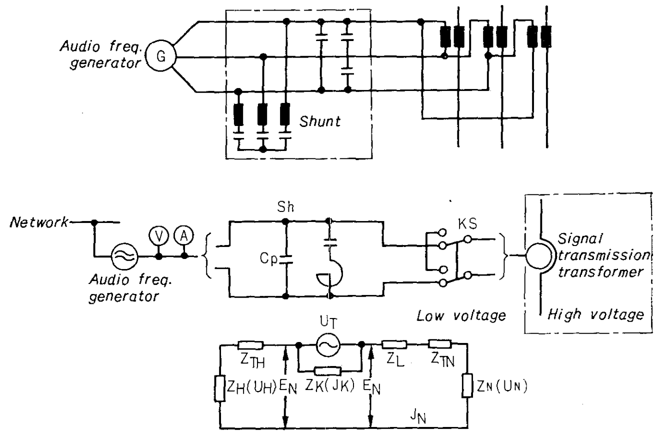


Fig. 19 Program controller



U_T : Signal voltage J_N : System current J_V : Loss current
Voltage drop
U_K : Coupling section U_N : Simultaneous telecontrol system
U_H : High tension system
Impedance
Z_H : High tension system Z_{TH} : High tension transformer
Z_K : Coupling section Z_L : Intermediate voltage conductor
Z_{TN} : Low voltage transformer Z_N : Low voltage system

Fig. 20 Parallel signal transmission



U_T : Signal voltage E_N : Network voltage E_V : Loss voltage
Voltage drop
U_H : High tension system U_N : Simlutaneous telecontrol system
Current
J_K : Shunt loss current J_N : System current
Impedance
Z_H : High tension system Z_{TH} : High tension transformer
Z_K : Coupling section Z_N : Low voltage system
Z_L : Intermediate voltage conductor Z_{TN} : Low voltage transformer

Fig. 21 Series signal transmission

of the high voltage system usually have the tendency to become higher as the frequency becomes higher. It can be assumed that this tendency is proportional to the frequency. Impedance group $Z_L+Z_{TN}+Z_N$ at the low voltage side usually becomes lower as a whole as the frequency becomes higher. It may be easily understood by considering various facts described above. The parallel sending method is more advantageous since this method does not require a large output because the voltage loss component is less when the signal frequency is comparatively high. When the signal frequency is comparatively low, the series sending method is more advantageous because the voltage loss is less.

In making a basic engineering decision in selecting either parallel transmission or series transmission, the impedance of the signal frequency being considered should be carefully studied.

The parallel transmission method is recommended if equation shown below is satisfied.

$$Z_{TH}+Z_H \geqq Z_L+Z_{TN}+Z_N$$

The series transmission method is recommended if equation shown below is satisfied.

$$Z_{TH}+Z_H \leqq Z_L+Z_{TN}+Z_N$$

When applying the simultaneous telecontrol system to extremely large power distribution systems, it becomes necessary to apply the signal from various points since the signal cannot be distributed evenly throughout the system if it is applied only at one point of the system. When the signal is to be applied to an extremely long distribution line, the fact that the signal voltage to be applied will become extremely high must be taken in consideration and the problem of induction interference previously mentioned must also be solved. When applying signals from various points in the system, the phase of the signals at the various points must be synchronized. Otherwise, a zero-phase-sequence component is generated and undesirable results obtained. For this reason, it may be necessary to simultaneously transmit the signals from the master station to the slave stations through a telephone line, microwave system or shortwave system.

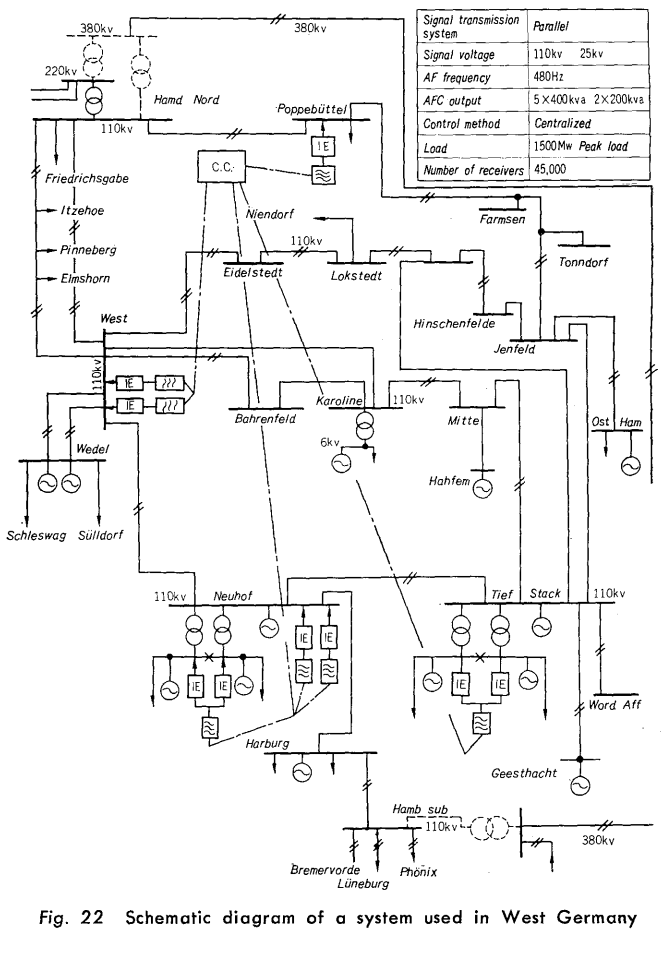
It is also necessary to install manual transmitting equipment at the transmitting station of each district in order to maintain system operation when trouble occurs in the remote control system. When the phase difference becomes extremely large, the circulating current flowing through the compensating winding of the synchronous motor increases and an unstable district or zone is produced, and the receiving level at this district drops below the sensitivity of the receiver. In parallel signal transmission, signal leakage to the higher order system is not governed by changes in the low voltage side load. However, in series signal transmission, signal leakage to the high tension system varies in proportion to the load current of the distribution power network to be controlled and the residual signal level changes accordingly. Comparing both methods, it may be said that parallel signal transmission is a voltage distribution type and series signal transmission is a current distribution type. However the receiver itself is operated by a voltage. The concept of overall system planning can be generally seen from the above description. Actual planning method of the transmitter will be discussed below.

The transmitter must provide a stable signal frequency and its voltage and phase must be adjustable. In the case of parallel signal transmission, a selective filter which shows a high impedance and resonates at 50 Hz or 60 Hz must be connected in series with the line between the signal voltage generating source and the distribution system in order to prevent entry of 50 Hz or 60 Hz power into the signal voltage generating source and the signal frequency is superimposed on the commercial frequency power system. On the other hand, in series signal transmission, the signal is superimposed on the corresponding power distribution system through the transformer in the form of a current. In this case, 50 or 60 Hz power is transferred to the secondary side through the current transformer and the signal frequency is sent out through the current transformer in such a manner that no voltage drop occurs in the power distribution system.

Generally, the transmitter consists of a pulse code generator equipped with a program controller and a signal frequency generator. The program controller completes one cycle every 24 hours and automatically starts the simultaneous telecontrol operation when the preset time elapses. Basically, the program controller has a horizontal axis having a dial hour ranging from 0 to 24 hours and vertical axis having the items to be controlled such as ON-OFF of hot water heaters, ON-OFF of street lights, etc. Pins are inserted into the hour points when the system is to become operative. By sequentially applying a voltage to each intersection of the vertical axis (electrically conductive) and horizontal time axis, a voltage is extracted if there is a pin at a particular intersection at a predetermined time and a voltage command for the particular operation is sent out at the predetermined time. This command, which represents the item to be controlled, sends the predetermined pulse code to the power distribution system. The pulse code generator has a slider which is rotated one cycle in 30 seconds by means of a synchronous motor. During this 30 seconds a maximum of 50 pulse codes, starting with the start pulse, are generated at predetermined time intervals. The time intervals at both the transmitting side and receiving side are synchronized since both sliders are driven by synchronous motors synchronized to the same power distribution system. The signal pulse is transmitted at the predetermined position by turning a switch installed below the rotating slider on or off in accordance with the predetermined code.

The operation described above can be performed more simply when electronic computers also used for other purposes are available at the control center and district transmitting station.

The signal frequency generator will now be described. As is widely known, the semiconductors of stationary type signal frequency generators widely used in recent years are easily damaged if the permissible operating temperature is exceeded. Therefore, a protective device to limit the current is provided in the current circuit and the terminal voltage is automatically regulated. Automatic regulation of the voltage in the distribution network must be provided to limit the interference signal level since the terminal voltage becomes extremely high resulting in such problems



Signal transmission system	Parallel
Signal voltage	110kv 25kv
AF frequency	480Hz
AFC output	5×400kva 2×200kva
Control method	Centralized
Load	1500Mw Peak load
Number of receivers	45,000

Fig. 22 Schematic diagram of a system used in West Germany

as induction and interference if a voltage regulator is not provided. It should also be noted that selection elements often wear out rapidly and their operating life reduced in some types of receivers when the receiving level becomes abnormally high. Stable operation may be obtained by providing a sufficient output allowance for the transmitter and installing a fuse to protect the transmitter. However from our experience this is not considered to be sufficient. The cost of the transmitter is governed by the size of the power distribution network, signal frequency and receiver sensitivity.

In addition to the stationary type transmitter, a rotary type transmitter is also feasible. The rotary type transmitter was primarily used in the early years of development in Europe. As previously described, the signal frequency should not be changed in response to system frequency variation. The synchronous generator for signal frequency generation must be driven by a proper driving mechanism whose speed can be controlled.

VII. TRANSMISSION SYSTEM PLAN AND ECONOMIC FEASIBILITY

The latest pattern of power demand indicates a gradual increase in the difference between day and night loads. The age of atomic power generation has begun and because of their characteristics, atomic power plants require that the load curve be as flat as possible. Nevertheless, the demand pattern at the load side shows a gradual increase in the difference between day and night loads. Therefore, it becomes desirable to fully utilize electric power during the night and simultaneous control of loads is indispensable.

When planning such a control system, it is necessary to plan the signal transmission method for load control in such a manner that the signals are applied to the load center of the power distribution system with the proper balance. Otherwise, various problems such as signal induction and interference to other systems and facilities may result and a large amount of expense required to correct these problems. Thus, proper overall system planning becomes necessary.

On the other hand, the cost of mass-produced receivers is low, but the cost per each receiving point is considerably high when the overall costs, including signal transmission equipment and installation work, are distributed over a small number of receiving points. However, as the number of receiving points increases, the cost required for the system becomes less than that of a conventional time switch system.

An actual example of the simultaneous control system employed by a power company in Hamburg, West Germany is illustrated in *Fig. 23.*

VIII. CONCLUSION

The above description of the simultaneous control system has dealt primarily with its application in power distribution systems. The audio frequency referred to in the above article is approximately 180 Hz to 500 Hz. In actual application, the frequency should be carefully studied since the use of 2000 Hz or 20 kHz, for example, may sometimes provide better results. However, the basic system arrangement for higher frequencies will not differ greatly from the system described above.

As described in this article, the system can be used for a number of applications and its operation differs slightly from the conventional method in which the contents of commands are transmitted in the form of combined digital codes and if necessary, the difference between the transmitted codes and received codes repeatedly checked for accurate control.

The basic principles of the simultaneous telecontrol system are about the same as those of the coded transmission method. However, as previously described, the time base for system communications is provided by synchronous motors combined with the power network.

As the next step in development, Fuji Electric is conducting research on a new system which will not require any synchronous motor.

Provision of a time base for communications between two remote points as described above, makes the simultaneous telecontrol system well suited to power distribution systems.

Our research on the system was started by combining many one-to-one control systems. The centralized control system ordered together with the hydraulic power plant facilities for the Kinugawa Hydro electric Poewr Station was designed and manufactured by us and completed in 1960.

The simultaneous control system for power distribution networks originated in Europe about 50 years ago and has been widely recognized as one of the established engineering fields. The most important features of this engineering is not only the excellence of components such as the transmitter and receiver but also the brilliant achievements made in system arrangement...software engineering. Examining the history of its development made major contriubutions to the development of the system possible by those who worked as software engineers capable of coordinating with component engineering.

As automation, mechanization and correction for differences between day and night power demands become more necessary, the simultaneous telecontrol system will become more important as a fundamental technique for solving these problems.

Ten years after our first achievement in the control system, we have planned the simultaneous telecontrol system with special coding and introduced this system to meet the urgent need for modernizing of power distribution systems.