AUTOMATIC CONTROL OF MODERN HYDRO POWER STATIONS IN INDIA

A DISSERTATION
submitted in partial fulfilment of
the requirements for the award of the degree
of
MASTER OF ENGINEERING
in
WATER RESOURCES DEVELOPMENT

By

S. V. TAMSE

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
UNIVERSITY OF ROORKEE
ROORKEE (INDIA)
April. 1976

CONTENTS

O.D. THAPAR
B.Sc.(Hons.), B.Sc.(Engg.),
F.I.E. (INDIA)
[illegible]

[illegible]
TRAINING CENTRE
UNIVERSITY OF ROORKEE
ROORKEE, U.P., INDIA

CERTIFICATE

Certified that the dissertation entitled "Automatic Control of Modern Hydro Power Stations in India" which is being submitted by Shri Shripad Vishnu Tanse in partial fulfilment for the award of Degree of Master of Engineering in Water Resources Development of the University of Roorkee is a record of the candidate's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is to further certify that he has worked for a period of over six months for the preparation of this dissertation from October 1975 to April 1976, spending all this period in residence at Roorkee University.

O. D. Thapar
2.4.1976

PLACE: ROORKEE
DATED: 2.4.1976

(O.D. THAPAR)

ACKNOWLEDGEMENT

I wish to record my deep sense of gratitude to Shri O.D. Thapar, Professor Hydro Electric (Designs), Water Resources Development Training Centre, At University of Roorkee, Roorkee, for his valuable guidance and encouragement at every stage of preparation of this dissertation.

Samse

(S.V. SAMSE)

SYNOPSIS

A review of prevailing practices for the control of various types of Hydro Electric Stations and their elements has been made so as to arrive at possible optimum control for modern hydro stations. The control of unit operations from the unit control board and from the central control room and their merits and demerits are discussed in Chapter II. In Chapter III, some typical control schemes of the conventional hydro electric stations, automatic control system of Bhakra Right Power Plant and proposed manual push button starting from the central control room of Dehar Power Plant are discussed. Importance of the pumped storage plants in the interconnected system and various methods of starting the pump are discussed in Chapter IV. Some recent developments in the control of large stations, the provision of equipment for converting to remote control, special considerations involved for the control of peaking plants, and modifications required in control scheme so as to reduce starting time are discussed in Chapter V. The increasing importance of the remote supervisory control and different types of telemetering are discussed in Chapter VI. Finally, conclusions as regard the application of methods of control and adoption of control scheme in modern hydro electric stations in India are made.

CHAPTER I

INTRODUCTION

The main control features for a power plant include the control circuits, control devices, indication, instrumentation, protection and annunciation at the main control board and at the unit control board. These features are necessary to provide operators with the facilities required for the control and supervision of the station's major equipment. In the design of these features consideration must be given to the size and importance of the station with respect to other stations in the power system, location of the main control room with respect to the equipments to be controlled and all other station features which influence the control system. The control system of a power station plays an important role in the station's rendering reliable service; this function should be kept in mind in the design of all control features.

Hydroelectric stations are particularly well suited to automatic control because of the relative simplicity of control of both the prime-mover and the stored hydraulic energy which drives it. These plants may be used for short periods as peaking stations when extra generating capacity is needed or as base load station for long periods when an abundance of water for generating power is available.

In Chapter II are discussed the types of hydro power developments, elements to be controlled, methods of control and control of unit operation. The elements to be controlled in hydro power stations are intake gates, main inlet valve, turbine, governor, the lubrication system, the excitation of the generator, main circuit breakers. Each of these elements has a particular function in the over all operation. The intake gate and main inlet valve render the plant in-operative and conserve water during shutdown period of the plant. The turbine gates under the control of the governor admit water in the runner in proportion to the load requirements of the turbine. The lubrication system establishes a lubricating film on the bearings during starting and maintain it during operation, and circulate the lubricant so that it can be cooled. The voltage regulator control the excitation of the generator in keeping with the voltage requirements and demand for reactive power output of the generator. The generator field circuit breaker provides a means of field interruptions during faults and thereby minimises damage to the generator and the other equipments. The generator line circuit breaker serves to connect the generator to the system after the generator has been started. It also disconnects the generator from the system prior to shutdown or following an electrical faults.

In Chapter II are also discussed the various methods of control. USBR practice broadly classifies the control under three main headings- manual, automatic and supervisory depending on the method of operation. In the manual control each operation is performed or initiated manually whereas in automatic control a sequence of operations are performed automatically but the initiation of the sequence of operations may be performed manually or automatically. Supervisory control means the control of a equipment from a remote point when the distance between the controlling point and the equipment to be controlled is so great as to make direct wire connections impracticable or unduly expensive. In English practice fully automatic control means a single starting impulse starts the unit and synchronise and load the unit automatically. Further in semi-automatic type of control the unit is brought upto ready to synchronise condition by the initiation of the sequence of operations by manual starting impulse but the synchronisation and loading are done manually.

Also discussed in Chapter II are the control of the unit operation. Unit can be started from the unit control board located near the unit but synchronisation and loading are performed from the central control room. Unit can also be started, synchronised and loaded from the central control room in the centralised control system. Their advantages and disadvantages are discussed.

Chapter III describes control schemes of starting, synchronising, loading and stopping from a central control room. Starting of the unit is proposed by means of a sequence master controller switch installed on the control panel of each unit. The master controller switch in the first step of its sequence is proposed to open main inlet valve and start unit auxiliaries. In the second step, the turbine is started and field breaker is closed. In the third step the paralleling of the unit manually is proposed. In the last step the loading of the unit to a preset value is proposed. Master controller switch in a similar way is used for controlled station shutdown. A scheme for starting, synchronising and loading automatically on receipt of single starting impulse is also discussed. A control scheme for automatic accelerated starting of the pre-selected unit on system frequency drop is shown and explained.

In Chapter IV are described the control of the pumped storage plants. Various starting methods of pumping plants and their merits and demerits are discussed. The purpose of a pumped storage hydro installation is to store energy during off peak periods to be used for generation during peak demand periods. The main purposes which a pumped storage scheme could fulfil in an interconnected system are the coverage of peak load in generating operation and immediately available reserve in cases of break down of other units in the system. In this chapter also discussed are the semi-synchronous starting of the Grand Coulee pumping plant and reduced voltage starting of the Muddy Run pumped storage plants.

In Chapter V some recent developments relating to the control of the hydro power plant and modifications in the control scheme to reduce the starting time of the peaking hydro plant and also to reduce change over time of the pumped storage plant from pumping mode to generating mode are discussed. Also discussed are the recent trend in braking system to reduce maintenance on the stator. Peaking and pumped storage plants are subjected to frequent start run-stop cycle. This causes the brake lining to wear more quickly. The debris released from the brake linings are carried out into the stator housing by the ventilating air. These deposit on the windings and thus prevent effective transfer of heat from the winding to the cooling air. To overcome this problem dynamic braking is now used. This is discussed in the Chapter.

Chapter VI discusses the importance of the supervisory remote control, types of telemetry and the data to be transmitted from the generating station to the central controlling station at a remote point. Remote control equipment is often employed in fully automatic controlled hydro-electric stations. Economic considerations usually dictate the use of the supervisory control equipment. Supervisory control equipment can be operated over a single pair of telephone wires or a power line carrier channel. The importance of analogue telemetry and digital telemetry and their merits and demerits are also discussed. An application of the supervisory remote control equipment using microwave communication system as a secondary channel to TVA's Raccoon Mountain pumped storage plants is discussed.

In the last Chapter, critical examination of various schemes and their application to hydro-electric stations in India are discussed. The use of supervisory and computer control in India is further discussed and concluded that non-availability of indigenous equipment for the purpose and there being no dearth of operating personnel, this type of control is not suitable. A centralised control with operators at only one level has been preferred for large hydro-electric stations in India because this type of control is more reliable, economical and can be easily converted to remote control scheme in future.

CHAPTER II

[illegible]

2.1 [illegible]

2.1.1 Hydro power development and layout of works will depend primarily on site conditions, as to how best the source can be exploited so that cost of generation per unit of electricity is minimum. With long distance and inter grid transmission, limit of generation at any site has not remained a significant factor. Some typical types of hydro power developments are indicated below as the layout and location of the plant influences the selection of type and method of control.

2.1.2 Run of the River Schemes or Diversion Schemes

This type of development aims at utilising the instantaneous discharges of the stream. So the discharge remain restricted to day to day natural yield from the catchment; characteristics of which will depend on the hydrological features. Now a days a slight variant of this type of development is generally used. In this type the entire yield for the day is stored, known as diurnal storage at the diversion headworks and released only for a few hours during peak period. This type of development has been prompted by the special feature of hydro-generation that it is very quickly adaptable to load variations.

The main features of this type of development is conservation and utilisation of available drop in the

the [illegible]. This head is conserved by guiding a flow through a well designed channel or conduit so that minimum possible head is consumed in the flow and the rest of the available head is utilised for power generation. Two types of layout may generally be possible (i) power house located just at the diversion works, (ii) power house located away from the diversion works.

2.1.3 Storage Schemes: In such schemes annual yield from the catchment is stored in full or partially and then released according to some plan for utilisation of storage. This may be for single purpose such as power development or may be for multi-purpose which may include irrigation, flood control, etc.. Therefore, design of storage works and releases from the reservoir will be governed by the intended uses of the stored water. If the scheme is only for power development, then the best use of the water will be by releasing it according to the power demand. If the power project forms a part of the large grid, then the storage is utilised for meeting the peak demands. Such stations could be usefully assigned with the duty of frequency regulation of the system.

In a storage scheme the total head to be exploited may be built up by raising the water level locally by dam across the stream. In any storage scheme reservoir operation will obviously involve progressive fall in reservoir level, and, therefore, gross head from any datum will be varying. The proportion of variation to the gross head will depend on the range of operation and the maximum operative gross head. In case of storage schemes two broad types of layouts may generally be possible,

(i) Power house located just downstream of the dam ,

(ii) Power house located away from the dam.

Power house located just downstream of the dam is a more common type of development. Various works involved in such cases will generally consist of (i) Dam and suitable spillway arrangement, (ii) Power house with usual appurtenant works, (iii) Pressure conduit system and intake works, and (iv) Tail race. In case drop available in the terrain is also proposed to be exploited, then power house will have to be located away from the reservoir. In this case water conductor system will be entirely different and consists of channel conduit combination system with suitable intake works. At the powerhouse location surge tank may generally be necessary and also other controlling and regulating devices close to the machines.

2.1.4 <u>Pumped storage Schemes</u>: It is a special type of hydro storage development. More commonly it is combined with conventional type of storage development. Under this type of development, there has to be another reservoir downstream and close to the main reservoir. From the main reservoir releases are made mostly during peak power demand period. During slack power demand period water from the lower reservoir is pumped into the upper reservoir. Basis of the economy of such a development is that during off-peak demand period there is little marketable value of the surplus power available in the grid and its use is made for pumping. The water so pumped is subsequently utilized for power generation during peak demand period when its marketable value is high. Pumping normally consumes more energy than it generates. Therefore, this type of development is economically justifiable only if surplus energy at off-peak demand period is cheaply available.

Civil works involved in this case are also same as in storage power schemes plus the lower reservoir with suitable intake arrangement for pumping water through the machine.

2.1.5 Tidal Power Stations. On account of increasing power demand everywhere, more and more attention is being directed towards hitherto unconventional sources of energy. In the field of hydro, tidal power is one such source which has received attention only recently. Characteristics of tidal power resources are quite peculiar. Such developments can be feasible only where tidal fluctuations are considerable. Tidal range or amplitude is given by the difference between high tidal level and subsequent low tide level. There can be several arrangements possible for the development of tidal power. Control of such power plants is not discussed in this dissertation.

2.1.6 Penstock Arrangements. In determining the number of penstocks for any particular installation, various factors have to be considered and should be decided on the basis of thorough economic analysis of different alternatives giving due consideration to the conditions of turbine regulation. The general practice is to provide one penstock for a unit. This is particularly applied for developments utilizing greater discharges under relatively low head. The recent trend is to use a single penstock to feed several units, particularly in case of high head developments. In India, most of the high head installations have used single penstock to feed two units. This necessitates the use of Y-piece at the turbine end of the penstock. To control the water entry to the turbine, a main inlet valve near the unit must be provided in each case in addition to the portal valve. The closing of the main inlet valve in emergency could be initiated by an appropriate devices. Therefore portal valves could be made to close upon rupture of penstocks. When water conductor length to head ratio is greater than five, a surge tank may have to be provided at the end of the tunnel or close to the power house for better speed regulation of the turbine and also to restrict water pressure-rise to the steel lined section of the penstock. In power houses located at the toe of earth dam, good site for surge tank may not be available and a provision of pressure relief valve near the unit may become essential for reducing the pressure rise in the penstock. In such cases water saving type relief valves are installed. Relief valve is opened automatically when load is thrown out and as the wicket gates close relief valve also closes. Such valves, however, do not improve load picking ability of the unit.

2.2 EQUIPMENT TO BE CONTROLLED

2.2.1 Although machines differ widely in physical appearance, there are comparatively few basic types of turbine and main controls described below are common to all.

2.2.2 Main Water Supply to Turbine Casing. The means for cutting off the water supply to the turbine casing are required to avoid wasteful leakage when the unit is shut-down and to permit access for maintenance of the connecting penstocks. Penstock gates or even simple stop-logs at the intakes and inlet valves adjacent to the turbines are adequate for this purpose. Inlet valve may be omitted at low head stations. The intake has a motor or hand lifted, gravity lowered gate, preferably with an automatic release operated by an excess flow device if a burst occurs in a pipe line. When a tunnel and a pipeline connect the reservoir to the turbines, an additional control valve may be provided at the junction of the tunnel and the pipe line if the latter is long, and either this valve or the intake gate should be arranged for remote closure in an emergency.

Main inlet valves at the turbines are either butterfly valve type or spherical type depending upon the head at the turbine inlet. All types of valve incorporate arrangements for slow filling of turbine casings by crack opening or by special bypasses. Main inlet valves are opened either by water servomotor (in case of high heads) or by oil-servomotor. The opening motion of the main inlet valve is preferably interlocked so as to open the valve only when balanced water head pressure is established on both sides of the valve. The main inlet valve and the intake gate are final safeguards against turbine or pipeline disasters respectively, and the shutdown control must be absolutely reliable.

2.2.3 Runner Water Admission and Relief. The admission of water to the runner in accordance with load demands is controlled by needle adjusted nozzles in impulse turbines and by guide vanes in reaction turbines, both forms of control employ oil-servo mechanisms. Rapid fluctuations of flow may cause disastrous water hammer fractures, hence, closures should be gradual and without shock. In impulse turbines, deflector plates take the jet off the runner instantaneously, the jet being cut off gradually afterwards. In reaction turbines having long intake passages, relief valves with rapid opening and slow closing characteristics operate hydraulically as the guide vanes close. In stations having short intake passages however, the relief valve are omitted. In Kaplan machines the runner blades are of variable pitch and are adjusted simultaneously with the guide vanes by means a oil servo-motor within the runner hub.

2.2.4 Governor Servo System: To meet the intermittent oil demands of the servomotors, each turbine has its own oil/air reservoir fed by oil pumps with an automatic unloader valve. The initial air charge may be provided by a separate compressor, but the subsequent air leakage must be compensated for by an automatic air compressor controlled by the sump-level. The oil pressure receiver which is partially filled contains enough energy stored in the pressure oil so as to ensure full closure of the nozzle or guide vanes: in an emergency. The servomotor oil admission is controlled by the governor. The main servomotor operates, through direct mechanical linkage, the deflector plates and pilot valves of the nozzle servomotor of impulse turbines, or guide vanes and pilot valves of the relief valve servomotor of reaction turbines. Frequent load fluctuations entail continuous pumping which may over heat the oil, and governor instability sometimes results. Water cooling coils are therefore sometimes provided in the oil sump.

2.2.5 Governor Drive and Speed Setting: The permanent magnet generator (PMG) attached to the generator shaft supplies the electric power to drive a synchronous motor that drives the rotating portion of the speed sensitive device of mechanical hydraulic governor. In case of electrohydraulic governors, the [illegible] supply is given to the speed sensing mechanism. Governors are designed to regulate the speed and thereby the loading on the unit within a desired range by increasing or decreasing the amount of water supplied to the turbine runner. Turbines capable of full output at minimum head can often seriously overload their generators at maximum head. Governors are, therefore, usually fitted with load limiters which are sometimes remotely controlled. The load limiter adjustment usually extends down to zero and thus affords a means for remote stopping and starting at a safe and controlled rate.

2.2.6 Lubrication System: The lubrication system includes the facilities required for lubricating both the turbine and generator. In most cases, the generator lubrication system is self-contained and, therefore, does not require auxiliary pumps. However, large machines may have bearing lift pumps for use during starting. Some high speed generators use pumps for circulating the lubricant after the machine is running. In the former, heat exchangers are mounted inside the bearing housing and into the oil sump, and cooling water is circulated through these heat exchangers. In the latter, oil coolers are mounted outside the generator housing. Oil is circulated through these oil coolers by circulating oil pumps. Automatic control scheme must consider the operating requirements of the lubrication system during starting, running and shutdown.

2.2.7 Generator Cooling System: Generator cooling involves air circulation by rotor fans. Generators are usually ventilated on the closed circuit system in which the same air is continually recirculated and passes through water cooling units. The water supply for both oil and air coolers can readily be drawn from the turbine casing, through reducing valves and strainers, so that it flows automatically when the main inlet valve opens. When water head exceed 400 ft, however, it is more economical to pump from the tail race/draft tube. Each turbine may then have its own pump, generally with one standby common to all units.

2.2.8 Braking and Jacking System: Braking assists big machines to minimise bearing wear by restricting protracted slow running before stopping. Impulse turbines have separate reverse acting jets controlled by independent oil servo-motors. When remotely controlled these jets must be cut-off when the machine has stopped to prevent counter rotation occurring. The heavier vertical machines require more powerful brakes in the form of oil jacks under the generator rotor which press friction pads against a special rim, the pressure being applied through air/oil reservoir. The same brakes are employed as jacks for lifting the rotor, (the pressure being supplied by a high pressure oil pump and suitable valves), for withdrawing the thrust pads and to assist in other dismantling operations. In addition, jacks are sometimes used to lift the rotor before starting in order to flood the thrust bearing pads.

2.2.9 Excitation System. The conventional type of excitation system consists of a direct shaft mounted D.C. exciter

The main field may be controlled by pilot exciter or directly by motor driven amplidyne. The modern direct acting automatic voltage regulator may consist of a voltage resonance circuit, one or two stage magnetic amplifiers and a high sensitivity motor driven amplidyne which controls the field of the main exciter. The function of the regulator is to adjust the generator excitation automatically in response to deviations in terminal voltage detected by voltage sensitive circuit. Suitable amplification is provided by amplifier to ensure that the voltage is held within close limits for any load from zero to full load. Hand control of the generator excitation for starting and for emergency purposes (i.e. AVR is out of service) is by means of the conventional hand or motor operated rheostat in the field circuit of the amplidyne. No rheostat is provided in the main exciter field circuit, the amplidyne output terminals being directly connected to the field of the main exciter through the field breaker. Adequate protection is provided to remove the regulator from the service in the event of incorrect operation. Under this condition the excitation control is automatically returned to hand control.

Besides the terminal voltage control, the excitation system controls the reactive power flow from the machine. This adjustment is made possible by the fact that a change in the field current of a generator connected to a system does not change its load but does change its power factor.

A compounding circuit of quadrature injection type is included in the voltage regulator to stabilise reactive KVA loading of the generator when operating in parallel with other units. A line drop compensation is provided by feeding a bias signal into each voltage regulator and thus altering the terminal voltage of each machine as a function of the load-flow in the transmission line.

When transient stability is critical, thyristor controlled static excitation system is sometimes used. This is highly sensitive and fast acting excitation system. Usually feedback damping signals and other control measures have to be employed so as to ensure stability in post-fault period and obviate higher than necessary dynamic over voltages.

The field circuit breaker and discharge resistances are mounted in a separate cubicle and placed by the side of AVR panel. Field breaker serves to interrupt the field during faults. In case of rapid rough synchronising as described in chapter III, the generator breaker has to be closed first and has to be followed by rapid closing of field circuit breaker.

2.2.10 **Main Breaker control:** The rest of the generators are unit connected that is the generators are directly connected to their transformers without any intervening switchgear and the generator transformer leads are connected to the busbars through the high voltage circuit breaker. This most general form of connection will be discussed for the purpose of the control. The generator line circuit breaker serves to connect the generator to the system after the generating unit has been started, voltage built up and synchronized to the system. It also disconnects the generator during normal shutdown. However, the opening of the circuit breaker during emergency stopping is initiated by electrical and mechanical protection operation and by overspeed device. The necessary control for this purpose is to be provided.

2.2.11 Miscellaneous Equipment: Generators for use in humid climates frequently have internal heaters for preventing moisture condensation after shutting down and for avoiding deterioration of the insulation and iron laminations. Some leakage through the cover gland generally occurs with vertical turbines (especially at low head stations without inlet valve). This requires ejectors or level controlled motor driven pumps. Gravity drainage of the turbine cover via hollow fixed vanes to the draft tube or to the station sump, is sometimes possible for vertical reaction turbines. Horizontal set stations can generally drain leakage water to the tail race if the suction head is positive, but the depth of the spiral casing of vertical set stations necessitates sump with level controlled drainage pumps. Embedded pipe work systems are often employed for vertical sets to connect draft tube and relief valves to a common sump so that all water may be removed and access for maintenance is permitted after the insertion of of draft tube stoplogs.

2.3 CONTROL SCHEMES

2.3.1. A great variety of control schemes have been evolved for starting and stopping the units. These schemes range from fully manual where every operation is performed by mechanical devices, to fully automatic in which closure of one electrical circuit results in the starting of unit auxiliaries, opening of turbine gates, synchronizing and loading of the unit and similarly normal stopping is achieved by another switch which reduces the load, switches off the circuit breaker, shuts down the turbine and stops all auxiliaries.

According to the [illegible] committee (27), control schemes are classified as manual, automatic, and supervisory depending on the method of operation. In a manual control scheme each operation is performed or initiated manually. In automatic control scheme, a sequence of operations is performed automatically but initiation of the operation may be performed manually or automatically by contact making relays. In supervisory control the equipment is controlled from a remote point when the distance between the controlling point and the equipment to be controlled is so great as to make direct wire impracticable or unduly expensive. However, [illegible] committee (28) broadly classifies the control schemes under the following categories.

2.3.2 Manual Control: Thereby each step in the chain of the starting, synchronizing, loading and stopping sequence is selected and performed in turn by hand whether mechanically or by push buttons.

2.3.3 Cottage Attended Control: Whereby units are started, synchronised and stopped manually and are left to run on load automatically with supervision only by means of an alarm bell at the attendant's cottage.

2.3.4 Semi-automatic Control: Whereby from a single manual starting impulse a unit may be brought to the ready to synchronise condition by the automatic selection, performance, and proving of a sequence of controls. Likewise a similar stopping impulse completely shut-down the unit. Synchronising and loading remain manual functions from the local and remote control points. The term does not embrace any supervisory control equipment which may be interposed in the case of long distance remote control.

2.3.5 Fully Automatic Control: Whereby means are provided for running up, automatically synchronising and loading the units a predetermined quantity on a receipt of a single starting impulse. Subsequent manual variations of loading and excitation may be provided as a remote control function. The corresponding stopping impulse will cause the load to be reduced, the unit to be disconnected from the busbars and the turbine to be shutdown completely. Again supervisory control equipment is not included in the scope of the term.

2.3.6 Supervisory Control: Whereby telephone type apparatus employing the selection of control facilities and the coded transmission intelligence is used for starting, stopping, switch closing or opening and other functions initiated from a remote point, together with indications of successful operation of voltage and load and of the condition of alarm conditions at the remote control point. The equipment will be ancillary to either semi-automatic or fully automatic unit control.

2.3.7 Light current direct control: Whereby apparatus of a similar nature to and performing the same functions as supervisory control equipment is used, but coded signals are not employed. Each function is performed over separate pilot wires usually of the size of telephone cables.

2.4 CONTROL OF UNIT OPERATION

2.4.1 Depending upon the method of control and location of control points, the control of unit operation may further be discussed under the following main headings.

2.4.2 Manual (mechanical or push button) control: In this type of control, unit auxiliaries are started manually or by electrical push buttons mounted locally. The successful operation of auxiliaries is indicated by lamps mounted at the equipment or verified by visual inspection. Any abnormal operation of these auxiliaries during running is displayed by an alarm fitted locally. Necessary electrical interlocks in the starting circuit of the turbine may be included. The turbine itself is started from the governor panel. An operator of the panel adjusts the speed of the turbine and the excitation to bring the unit to ready to synchronise condition. Then he transfers the unit to control room for synchronising and loading. Once the unit is synchronised, the adjustments of load and excitation are being carried out by the control room operator. When a unit is taken out of service, the control room operator first unload the unit and then trips the main circuit breaker. The stopping the unit and its auxiliaries is performed by the operators at the machine.

This type of control is simple but require large number of operating personnel at various floors of the power house. This method of control may therefore be economical only if services of the operating personnel are cheaply and readily available. Smaller lengths of control cables and lesser number of control relays are required. But the operation of the unit auxiliaries by going to them is time consuming. Further in this method more reliance has to be placed on the ability, competence and integrity of a number of operators. Moreover, such schemes are difficult to modify for converting the controls to remote/automatic control type.

2.4.3 Control of Unit From Unit Control Panel:

Sometimes the controls of auxiliaries and the unit are brought to a centrally located control board. This board is called unit Control Board (UCB). In such type of stations, valves in cooling water, pressure oil and air supply circuits are normally motor operated. Cables are run from various motor starters to the UCD for start/stop operations. An operator at the UCD starts the unit auxiliaries Their successful operation is indicated by lamp mounted on the UCD just above the control switch. The necessary interlocks are included in the turbine starting circuit. Operator then starts turbine and brings it to speed-no-load position by adjusting the speed and excitation. Then he transfers the unit to the central control room for synchronising and loading.

This type of control involves cable connections between UCD and various auxiliaries. The scheme enables single operator to supervise the unit and its auxiliaries from UCD. However, separate operators are required at the control room. This scheme is favoured specially for power stations having large number of units because the cost of cables for taking all controls to the central control room would be high. Generator, transformer and busduct protective relay panels may be mounted near the UCD and only alarm indications may be taken to the central control room. Line and busbar protective relay panels may be mounted behind the control panels in the control room if the cable lengths involved between switchyard equipment and the control room are small. If the distance is greater, these panels are mounted in a separate switch room at the switch yard and only necessary controls and indications are brought to the central control room.

This type of unit control still requires co-ordination of operators at two levels - one at the UCD and the other at the central room. However at later date the scheme could easily be modified for converting it for remote/automatic control.

2.4.4. Control of Unit from Central Control Room. In this type of control, the controls of the auxiliaries and the unit are brought to a desk/panel in the control room. This involves taking all cables from the unit and its auxiliaries to the central control room. Hence this scheme is normally recommended for stations having smaller number of units. The scheme enables operators at the central control desk to supervise and control the unit from a single controlling point. There is no problem of coordination among the operators as the responsibility of starting auxiliaries, turbines and their control rested on a single operator in the central room. All alarms and indications are brought to a common annunciator board in the control room. The protective relay panels of generator, transformer and breakers may be located near the unit in the machine hall and only indications may be brought to the common annunciator board. Feeder and line protective relay panel locations depend upon the distance between switchyard and the control room and arrangement may be as explained above.

The unit control from the central control room may be by sequence controller switch as in Dehar Plant(12) or it may be fully automatic as in [illegible] Right Bank (20). In the former, control switch puts the unit in operation by performing the four sequence stages, that is, opening the inlet valve and starting unit auxiliaries, opening turbine gates, parallel and loading. The sequence control switch in the reverse order stops the turbine. In the latter, a single starting impulse energises a master start relay which starts unit auxiliaries, opens turbine gates parallel and load the unit to a predetermined value. These two schemes are discussed in greater detail in Chapter III.

2.5 GROUP CONTROL CENTRE

2.5.1 Where topography favours, the development of a river system in several steps forms an independent group for storage and generation purposes. The generation at several such steps may often be controlled at one point which has been designated as group control centre (2). The group control centre may be defined as consisting of administrative, operational and maintenance centre for the control of components streching throughout the developed river system. The group output is often collected at one major high voltage substation, from where it passes enbloc to the primary transmission system. Operation of this sub-station forms an integral part of the group control duties. For routine operation it is more economical to use supervisory remote control at the group control centre than to staff individual stations. The nature of group control load dispatching duties depends on whether the group comprises a self-contained generation consumption system or it forms part of some major system. In both cases the centre has to determine the allocation of load between its members to achieve the requisite demand most economically.

2.5.2. Electrical Information Required at the Centre:

The group control centre requires an indication of each machine load from which the centre derives automatically the total load on each power station and hence the total load on the group. When the reactive power flow is to be supervised in the system, it may be necessary to add reactive power metering. A single diagram showing all the switches and machines is essential, preferably with automatic indication. Busbar voltage readings are necessary for the main collecting point substation and for any individual power station from which direct information is given. Instruments for frequency indication and for recording the time error may also be provided at the centre.

2.5.3. Hydraulic Information Required: The primary quantities are reservoir levels and tail-race levels. These should be recorded and as well as indicated since the centre often has the statutory obligations which demand continuous supervision of certain river levels. These records enable storage capacity to be converted into equivalent stored energy. Tail level readings indicate the presence of imminent or actual spilling conditions, it is desirable to add visual warning when such discharges begin. It is also desirable to record the duration and the magnitude of spill for deduct-unit calculation. The movement of float controlled flood gates or flood device from stream may initiate alarm. It is common to establish rain gauges at representative points in the catchment area and to secure readings of rainfall automatically over telemetry equipment. From these readings the amount of runoff is assessed and rise in stream level is calculated.

2.6 SYNCHRONISING

2.6.1 Before connecting a generator in parallel with the other machines it is necessary to ensure that the incoming machine and the running system have the same frequencies and voltages and are in phase. The methods employed in hydro power stations are described below.

2.6.2 Manual Synchronising. In this method incandescent lamps are connected across the respective phases of the incoming and running voltage buses. Voltage of the incoming machine is matched with the system voltage by manually adjusting the excitation of the machine. The frequency and the phase angle difference are indicated by lamps. Lamps will flicker with a frequency equal to the difference between the frequencies of incoming machine and the running system. When two voltages are equal and the frequencies are same, there may still be a phase difference between the voltages which is indicated by the lamps glowing steadily. The adjustment of speed of incoming machine brings the two voltages in phase. When the phase and frequencies are matched the lamps will extinguish. This is the indication of the synchronism of the machine with the system. The breaker is then closed manually.

The main disadvantage of the automatic synchroniser is if the system is disturbed, i.e., the frequency of the system is falling due to the tripping of certain generators or due to the sudden addition of large loads, it may then take very long time to synchronise the unit with the system. Sometimes it may not be even possible to synchronise the machine. Under such conditions the manual synchronising method is used.

2.6.b <u>Self Synchronising</u>: In this method the generator circuit breaker is closed after the unit has accelerated to approximately 95 percent of the rated speed. Field is then applied immediately after the generator breaker is closed. Earlier, this method of connecting the unit to the system was recommended for smaller units as compared to the system size for it causes disturbance in the system. However, this method has been employed now a days to large units for raising the falling frequency of the system. The provision of such type of synchronising is made in the Bhakra Right Power plant. The details of the scheme are described in the Chapter III.

This method is employed when the generation is required to be added to hold the falling system frequency. The method has got great advantage as the voltage and its phase of the incoming machine need not be matched with the system frequency before closing the generator circuit breaker. The scheme for large units employ frequency difference relay to automatically close the circuit breaker when the difference in frequencies is within the predetermined value.

2.7 AUTOMATIC REGULATION OF A GENERATING UNIT

2.7.1 The principal duty of an automatic regulation of a generating set is to maintain its rotational speed and the frequency within predetermined limits when the unit is operating alone or in parallel with the other units. Automatic regulation also assumes duties linked with the economic distribution of the load between the units as well as with frequency regulation. The modern governor which is one of the important components, is not only able to maintain continuously the rotational speed of the unit within predetermined limits but can also regulate the operation of the plant and of the system. Operation of a generating set at a constant speed is necessary in order to maintain the system frequency (one of the basic qualitative parameters of the system) at varying loads on the system. This requirement can be satisfied only when the generator load is always equal to the power developed by the turbine. Any change in the generator load must thus be accompanied by a corresponding change in the power developed in the turbine. Head and turbine efficiency are constant at any given instant; any change in the power delivered by the turbine is thus possible only through a corresponding variation of the turbine discharge. This is effected by the governor acting on the turbine gates, runner blades, and other regulating members of the turbine.

The turbine governors must be able to maintain a uniform rotational speed of the generating set at all operating conditions. However, the actual speed of the turbine deviates from the rated speed within certain limits. The relationship between the rotational speed of the generating set and load is called static governor characteristic. The limits of the deviation of the rotational speed from zero load to full load is called speed droop. The magnitude of the speed droop is the ratio of the difference between the rotational speeds of the generating set at zero load and full load to the average rotational speed. This usually varies between zero and five percent. Hydro-mechanical and electro hydraulic governors are designed for automatic speed regulation and control of turbines and for regulation of active power delivered by one or groups (in case of electrohydraulic governors) of generating sets. Governors may be divided into two groups according to the manner in which the speed regulation process is stabilized. In one group governors respond only to deviations of the rotational speed from a predetermined value; and in the other group governors respond to speed deviations and accelerations. The latter type is discussed further below.

2.7.2 Speed and Acceleration-Sensitive Regulation:

Speed sensitive regulation involves a response of the flyballs to changes in the rotational speed. Because of the inertia of mechanical system and flyballs, the governor does not respond immediately when the generator load is varied suddenly. There is a certain time lag(or delay) between the actual load change and the governor response. This delay is eliminated in modern regulating systems through the use of governors responding not only to changes in the rotational speed, but also to accelerations during load variations. The acceleration instantaneously assumes a maximum value at the beginning of the regulation process, whereas the change in speed is still almost zero at this instant. The governor responds to the maximum acceleration and starts opening the turbine gates to a significant extent before the change in the rotational speed of the generating and flywheel attains the value necessary for initiating the corresponding opening of the gates. The principal advantage of such a governor is that an abrupt variation of the load causes a far smaller temporary change in the rotational speed of the generating unit than the speed sensitive regulation alone.

2.0 [illegible]

2.0.1 Once the unit is started and synchronised with the system, the operating personnel in the control room have to perform or supervise the following four important functions of the unit.

1. Load- frequency control
2. Reactive power and voltage control.
3. Hydraulic control
4. Supervision of alarm and protective equipment

Functions of the above four are discussed below

2.0.2 Load Frequency Control: In an isolated system consisting of a generator and load, the varying demand of the load can be satisfied entirely by the governor action. The governor of the unit is set to maintain the frequency at

50 Hz by setting the speed droop indicator to zero. The machine speed will be maintained exactly at 50 Hz with varying load demands provided the amount of load is not greater than the units ability to carry it.

When a unit is operating in a large interconnected system it is not, and is indeed virtually, impossible to set all governors to respond isochronously to maintain constant frequency. In such cases unit speed droop is set at 3 to 5 percent depending on the system's load sharing requirement. A governor set on 5 percent speed droop will cause its generator to accept 100 percent of its capacity when there is a frequency drop of five percent. Depending on its regulating ability, unit can be adjusted to help maintain system frequency which is the exact indication of the balance between supply and demand. The operator in the control room, on receipt of orders from the central load despatch office, adjusts the speed level of the unit to assist the system to maintain frequency at 50 Hz. In the case of units fitted with automatic load-frequency control device, the speed level is adjusted from the load despatch office itself.

2.8.3 Reactive Power and Voltage Control: When the unit is serving isolated load, its terminal voltage is held to a scheduled value by means of continuously acting automatic voltage regulator. The reactive power requirements of the load connected to it are adjusted by excitation control called power factor control. When unit is connected to a large powers system, i.e., to an infinite bus, the voltage and frequency of the bus and hence of the generator terminal are held under control and bus voltage is not affected by changes in the excitation of the generator. Once the generator is paralleled with the system, it assumes the system voltage and any change in its excitation results only in changing its kilovar loading and its power factor. Generally the unit is operated at rated kilovar load. The maximum and minimum excitation applied to the generator is dependent upon the reactive power capability of the unit. On the high side, the limitation is field and armature overheating, and on the low side the limitation is stability and leading power factor.

2.8.4 Hydraulic Controls Associated with each hydro-electric station there will be a number of hydraulic items to be brought to the power station control room. These items may be selected from the following (24).

1. Primary storage level indication and gate control.
2. Tailrace level indication
3. Secondary storage level indication and gate control
4. Flood control including spillway gate operation, position indication, discharge and alarm.
5. Intake gate control and indication, and indication of head loss through screens.
6. River control and discharge indication for statutory obligations to other users such as fishery authorities, chemical works, water supply authorities.
7. Irrigation water release and discharge indication.

8. Surge tank water level indication.

Spillway gates may be operated locally by hand or motor control, remotely by supervisory or direct control of motor winches, or automatically. When automatic operation occurs, it is desirable to give an alarm at the attended point, and preferably to record the duration of the flood discharge. Many dams and intake works have sufficient information and control facilities to warrant supervisory control equipment. The necessary pilot cables must be taken from a route not affected by flood any time.

2.3.5 Supervision of Alarm and protective equipment.

The object of an alarm equipment in any power station is two fold. Firstly, it enables the duty staff to determine quickly the nature of the incident faults. Secondly, to record transitory fault occurrences for subsequent analytical investigation. For mechanical troubles, the number of displays is a matter of opinion and cost. But it is pertinent to display not only those conditions which cause shutdown but also various non-trip conditions. In the operator's room these may be further classified as 'urgent' and 'Non-urgent' to help operators realise the urgency of the action needed. Generators are provided with minimum necessary protection against electrical and mechanical faults. Relays have flag indicators to indicate their operation. The operator's attention is drawn by an audible alarm on the alarm panel and by flashing light. Operators must on occurrence of trouble or fault attend to it and maintain a record of the nature of the trouble and instruct maintenance staff to carry out the repair early.

2.9 SYNCHRONOUS CONDENSER OPERATION

Hydro power stations are normally situated far away from the load centre, and are connected to the latter by long transmission lines. At light loads the voltage on of the generating end bus rises due to the line charging current. If the loads are connected to the generator bus it is essential to maintain the bus voltage to normal value to prevent the damage to the consumer's equipment. In such cases to maintain the voltage to a normal value the following methods (24) are adopted.

1. Switching on shunt reactors at a strategic points in the transmission line.
2. Operating special synchronous condensers at the main load terminal stations.
3. Running some of the idle hydro generators as synchronous condensers at load end.
4. Disconnecting one of the two transmission lines.

The use of hydro generators as synchronous condensers does not involve major modifications in the control scheme, as we know, any synchronous generator when under excited consumes reactive power. This power it takes from the system and thus it controls the voltage rise. For synchronous condenser operation, unit is started as normal generator and synchronised with the bus. Then wicket gates are closed and compressed air is admitted to the runner chamber in reaction turbines. Compressed air depresses the tail water and thus reduces the water friction of turbine runner. Machine takes more power from the system if its runner is allowed to churn water. In condenser operation, however, runner seals must be supplied with water during dry running.

Synchronous condenser operation of water turbines is sometimes used as a source of spinning reserve. To change the operation to generating mode, refilling of spiral casing and then opening the main inlet valve takes considerable time in case of reaction turbines. So to lessen the change over time, spiral casing is allowed to remain full of water during synchronous condenser operation and control scheme is designed to enable to open the turbine gates, then the valve is opened about 50 percent. With this procedure, unit can be made to take load from spinning operation in about 25 seconds.

CHAPTER III

CONTROL OF CONVENTIONAL HYDRO POWER PLANTS

3.1 GENERAL

The control scheme of any hydro generating unit must be designed to perform the following functions either manually or automatically.

1. The starting of the unit auxiliaries and the turbine must be possible by a single starting impulse or by a sequence control switch.
2. Each operation in the sequence of starting must be carried out only after the preceding operation has been performed.
3. The sequence of operations connected with the successive movements of several devices be ensured through proper interlocking.
4. Synchronising, loading and regulation of the unit must be possible from the central control room.
5. Normal shutdown of the unit must cause unloading and disconnecting of the unit from the system, initiate the closing of the turbine gates and application of brakes at an appropriate speed.
6. Emergency shutdown of the unit through the automatic fault detecting devices must cause immediate disconnection of the unit from the system and shutdown of the unit.
7. All abnormal conditions which do not require immediate disconnection of the unit from the

system must be arranged to give a warning to the operators.

Some schemes which incorporate the above mentioned points are discussed in this Chapter. The schemes recommended by Brown & Dorr(1) and Frost & Brittlebank (2) are described to compare them with actual schemes of Dehar, Bhakra Right Power Plant and Churchill Fall Plant.

3.2 STARTING BY SELF-SYNCHRONIZING METHOD

3.2.1. In this method of starting the generator circuit is closed after the unit has been accelerated to approximately 95 percent of the rated speed. Field is applied immediately after the generator circuit breaker is closed. The method is employed only on units which constitute a relatively small percentage of the total system capacity because with this method a considerable amount of synchronizing power is exchanged with other units in the system. A typical scheme recommended by Brown & Dorr(1) is shown in Figure 3-1 and described below.

3.2.2 Starting: With reference to Figure 3.1, the 1 "Start" can be a contact on a local push button or a contact operated by supervisory control equipment. If the lockout relays 86G and 86T are reset, the machine speed contact 14 closed, the generator field breaker 41 open, and if the protective contacts connected across the coil of master relay 4 are open, the master relay 4 picks up and seals itself. It will remain picked up unless short circuited by the 1 "Stop" contact and any one of the protective devices connected causes the coil of 4 to be deenergized by either of the lockout relays 86B or 86E. A make contact of relay 4 sets up a circuit to all the devices operated in the starting sequence. Relay 88W is operated immediately after 4 picks up to start operation of the bearing oil pumps. Incomplete sequence time relay 48 is likewise energized immediately. Adequate bearing oil pressure closes contacts 63D and 63H is picked up. A contact of relay 63H energizes the governor starting solenoid 65S, and the turbine gates start to open under the control of the governor.

When the generator has reached 95 percent speed, contact 13Y closes which completes a circuit to the closing relay of the generator circuit breaker 52. Closing of the generator circuit breaker completes a circuit to the closing relay of the field circuit breaker 41. Thus, the generator is connected to the system at slightly less than the synchronous speed, and its field is applied immediately thereafter. The field breaker contact deenergizes the incomplete sequence relay. After the unit is connected to the system, the load can be adjusted by means of speeder motor or it can be arranged to take load automatically.

3.2.3 Stopping: The 1 'Stop' contact can be a contact on a local pushbutton or a contact operated by supervisory equipment. When 1 'Stop' contact is closed it short circuits relay 4 and causes its release. When relay 4 deenergizes, it de-energizes the governor solenoid 65S and the bearing oil pump motor relay 63QX. A time delay circuit continues the oil pump motor operation for a definite period of time after the release of relay 63QX. Release of the governor solenoid causes the turbine gates to start to close. When the gates reach no-load position, gate contact 33WX closes; closing of this contact completes a circuit which sequentially trips the generator circuit breaker and the field breaker. Thus the generator is disconnected from the system with no disturbance as the load has been dropped gradually before the generator circuit breaker was opened. The turbine gates continue to move until they reach the fully closed position. When the gates are closed completely, gate interlock 33G operates brake relay 20 provided contacts 14, 4 and 52 are closed. Relay 20 causes the unit brakes to be applied for a definite period of time assuring that the machine is brought to a stop.

3.3 STARTING BY AUTOMATIC SYNCHRONIZING METHOD

3.3.1 In this method the generator is connected to the system only after the magnitude, frequency and phase of the voltages of the incoming unit are matched with the running system. The control scheme recommended by Brown & Dorr (1) is shown in Figure 3.2 and is described below.

3.3.2 Starting: It will be noted from Figure 3.2 that the circuit for energizing relay 4 is the same as shown in Figure 3.1 except that it is unnecessary to check the position of the field circuit breaker 41 before starting. The operation upto the energizing of relay 63QX is the same as for self-synchronizing. When relay 63F picks up the governor starting solenoid 65S is energized, automatic synchronizing and speed matching auxiliary relay 25X is energized and the generator field circuit breaker 41 is closed. Thus the turbine gates start to open under the control of the governor, the generator field current builds up as the exciter comes up to speed, and the speed matching and the automatic synchronizing equipment is energized. As the generator comes up to speed, the speed matching equipment functions to match the generator frequency with the line frequency and the voltage regulator adjusts the field current for line voltage. When the instantaneous frequency difference and the phase angle difference are satisfactory for proper synchronizing contact 25 is closed to energize the generator circuit breaker closing circuit. Closing of the generator breaker de-energizes relay 25X and thus the automatic synchronizing and speed matching equipment out of service. The incomplete sequence relay is de-energized when the generator reaches 95 percent speed. The synchronizing time is adjustable. Where it is required that the generator energize a dead bus, the contact of relay 25 in the foregoing description must be paralleled by a contact of a dead bus must be relay in series with a synchronous speed contact.

3.3.2 Stopping: The normal shutdown by operation of the '1 Stop' contact is exactly same as the described in section 3.2.3.

3.4 [illegible]

3.4.1 In semi-automatic control contact system one [illegible] starting impulse starts unit auxiliaries and opens turbine gates and thus bring the unit ready to synchronise condition. Synchronising and loading are remained to be performed manually. In automatic control system a provision is made to start the unit to synchronise and to take the load automatically on receipt of starting impulse. The system suggested by Frost & Brittlebank (2) is shown in Figure 3.3 and description of the scheme is as follows.

3.42 Starting Sequence: With reference to Figure 3.3, the starting impulse energises a master control relay which remains latched in whilst the machine is starting and running. This relay starts the standby lubricating and governor oil pumps and at the same time initiates the opening of the main inlet valve and starts a timing relay for an excessive starting time alarm. Pressure switches and flow relays on the oil systems and limit switches on the main inlet valve prove that the first stage is complete and initiate the guide vanes (or nozzle) opening circuit for the second stage. The essential auxiliaries commence running as the machine gathers speed and by virtue of pressure switches on their delivery lines automatically shutdown the standby pump. The final stage involves the proof of delivery from the essential auxiliaries coupled with operation of a voltage relay energised by the pilot exciter or the permanent magnet generator when the machine is upto speed which simultaneously energises a final stage-signal relay and deenergises the excessive starting time relay. Failure in any part of the system will result in excessive starting time relay completing its operation, thereby transmitting a signal "failure to start" and de-energising the master control relay, thus returning the plant to its shutdown position. The final stage signal relay brings in the automatic synchronising equipment in fully automatic control schemes or transmits a signal "ready to synchronise" in semi-automatic ones. Loading and synchronising of semi-automatic unit is carried out in the usual manner. In both systems it is desirable that the field switch be left permanently closed, tripping only when the generator protection operates and after which it must be reclosed.

3.4.3 Stopping Sequence: On receipt of a "shutdown" impulse, the master control relay is tripped, thus energising the closing circuits for guide vanes (or needles) and main inlet valve. As the generator voltage falls the normal auxiliary pumps stop and the standby pumps commence working automatically. Brakes are applied when the speed falls 35 to 40 percent. A time delayed stopping relay releases the brakes and shuts down the standby pumps after the turbine has come to rest.

3.5 MANUAL PUSH BUTTON CONTROL

3.5.1 In this type of control units are started by sequence control switch which in its four stages starts auxiliaries, opens turbine gates, synchronises the unit with the system and load the unit. The control system proposed for Dehar Power Plant (12) is discussed below.

3.5.2 Salient Features of the Project: Tehri power plant located at the end of the [illegible] envisages installation of four units of 165 MW each in the first stage and two more units of same capacity in the second stage of development. The turbines are of vertical shaft 'Francis' type each rated at 2,30,000 H.P., 300 r.p.m. at rated head of [illegible] metres. The generators are of semi-umbrella type and each rated at 165 MW, 0.95 power factor, 11 KV. Eighteen single phase transformers each of 60 MVA capacity are proposed to be installed on the upstream side of the machine hall. Twelve of these step up the generator voltage to 220 KV and remaining six will step up to 400 KV. 220 KV double circuit will connect Tehri plant with [illegible] substation about [illegible] km from the plant and the 400 KV circuit will connect the Tehri station with [illegible] substation about [illegible] km from the plant.

3.5.3 Control System: The units are proposed to be controlled from the main centralised control room located upstream of units three and four. The provision for starting and stopping of units from the unit control board placed near the generator is also proposed. Protective relay panels of generators, transformers, busbars and lines are proposed to be installed in the central control room.

3.5.4 Normal Unit Starting: The normal starting of the unit is proposed to be effected through a sequence master controller switch ([illegible]) as shown in Figure 3.4. The [illegible] in the first step of its operation energises auxiliary starts relays 45-AI and 45 MI. The contacts of these relays open main inlet valve and start governor and lubricating oil pump motors and also open cooling water valves in the generator air cooler and turbine gland cooling water supply circuit. The pressure and flow relay contacts in the delivery circuit of the auxiliary pump motors prepare the circuit for turbine gates opening. UCS in the second stage opens turbine gates upto rated speed no load position. Synchronising is proposed either by auto-synchronising equipment in the second stage of UCS or by manual synchronising in the third stage of UCS. Loading of the generating unit is proposed in the fourth stage of UCS. The necessary interlocks in each sequence of operations are shown in figure 3.4 and it is seen that each sequence can be started only after the preceding has been successfully completed.

3.5.5 Automatic Accelerated starting of Unit on Frequency.

Brief: It is proposed to incorporate for automatic accelerated start of a preselected unit whenever the system frequency drops below a pre-determined value. The under frequency relay 81-AX detects the drop in the system frequency (see figure 3.4) and energises auxiliary starting relay 45- AX. This initiates opening of turbine gates and simultaneously gives impulses for all auxiliaries through start relays 45-AI and 45 MI. Before a unit is set for under frequency start, the governor locks and turbine inlet valve are opened and other operations which are normally done are carried out. A signal and alarm is also proposed to be adjusted. The unit is then proposed to be manually synchronised and loaded. This method of semi-manual starting can also be resorted to in case of other emergencies.

3.5.6 Normal Unit Stopping: In the normal stopping scheme the [illegible] in the reverse direction is proposed to unload the unit in the first stage. In the second stage [illegible] disconnects the unit from the system and initiates closing of turbine gates and in the last step it stops all auxiliaries. The scheme for normal stopping and emergency stopping is shown in figure 3.5.

3.5.7 Unit Stopping on Emergency: Automatic protective devices are proposed to be provided to detect failures in normal operating conditions of the various equipments and ensure an immediate stop of the unit whenever necessary and actuate alarms. An emergency stopping occurs in the following cases:

1. Electrical protection operation.
2. Mechanical protection operation.
3. Turbine speed 115% and governor sluggish.
4. Turbine overspeed
5. Governor oil pressure low
6. Turbine gate pins shear then the unit on emergency stopping.

The control scheme for emergency stopping is shown in figure 3.5.

3.6 Automatic Starting: In this type of starting the control of unit from the central control room adopted for the Bhakra Right Power Plant (20) is discussed. The scheme for quick synchronising and automatic loading of the unit on under frequency start is discussed.

3.6.1 Salient features of the plant: Two power plants one on the Left Bank and the other on the Right Bank are located at the foot of the Bhakra Dam - one of the highest straight gravity dams. Left Bank power plant comprises five units each of 90 MW capacity and the Right Bank Power plant comprises five units of 120 MW capacity each. The turbines in the Right Power Plant are of Francis type each rated at 127 MW, 167.5 r.p.m. at rated head of 122 metres. Generators are of conventional type, each rated at 120 MW, at 0.9 p.f. and 11 KV. Transformers are located on the downstream side of the machine hall and each is rated at 135 MVA, 3 phase, 11/220 KV. The switchyard of the Right power plant is situated about 1 Km. from the plant. The two power plants are electrically connected at Ganguwal sub-station.

3.6.2 Arrangement of Control Equipments. The operation and control of the power plant is of centralised type and is controlled from the main control room situated on the down stream of the machine hall. The main control board consists of desk-panels and is equipped with the control switches for all the main components of the plant. Protective relay panels of the generators are mounted in the machine hall near the unit. Line and busbar protective relays are mounted in a separate switch room at the switchyard. Only controls and necessary indications are brought to the central control room. The automation scheme of the [illegible] power plant provides for the following:

1. Normal starting of the unit
2. Accelerated starting of the unit at frequency drop.
3. Normal automatic operation of the unit under load.
4. Normal stopping of the unit.
5. Emergency stopping of the unit under abnormal conditions.
6. Warning signals about abnormal operating conditions and troubles.

3.6.3 Unit Starting: A single starting impulse by control switch [illegible] mounted on the control desk, energises starting relays 1 Rel, 2 Rel and 3 Rel see Figure 3.6. The starting relays contacts initiate the starting of all essential auxiliaries and opening of cooling water valves in the various circuits. The contact of starting relay 1 Rel also opens gate limiter and initiates the opening of turbine gates upto speed no-load-position only after the successful operation of all auxiliaries. If the auto-synchronising equipment is switched in the synchronising and loading of the unit to a predetermined value are done automatically. Thus a single starting impulse brings the unit to a preset load.

3.6.4 Accelerated Starting of the Unit at Frequency Drop.

The provision for starting a pre-selected unit

108836

automatically is incorporated in the control scheme. Unit for automatic starting on frequency drop in the system is selected by the selector switch 21 FW see figure 3.6. Under frequency relay FY connected across the bus p.T. detects the drop in the frequency and is energised at a pre-set frequency drop. The contact of this relay energises relay 22 FW which in turn energises unit auxiliary start relays 1 PTA, 2 PTA and 3 PTA. These starting relays initiate turbine gate limiter opening and also open the turbine gates to a speed no load position. The frequency difference relay FDY senses frequency difference between the incoming turbine and the running system. When the frequency difference comes within the pre-set value, this energises the closing of the main circuit breaker. The generator field breaker is closed immediately after the generator breaker is closed, see figure 3.7.

3.6.5 Unit Stopping. Normal unit stopping is initiated by 'Stop' position of control switch 21 [illegible]. This energises normal stop relay 1 [illegible] which unload the unit and disconnect it from the system. Also it initiates turbine gate closing and applications of brakes at appropriate speed. The emergency stopping of unit is initiated by electrical and mechanical protective devices, overspeed device and gate shear pin break detecting device at the time of closing.

3.7 AUTOMATIC CONTROL SYSTEM OF CHURCHILL FALLS POWER PLANT

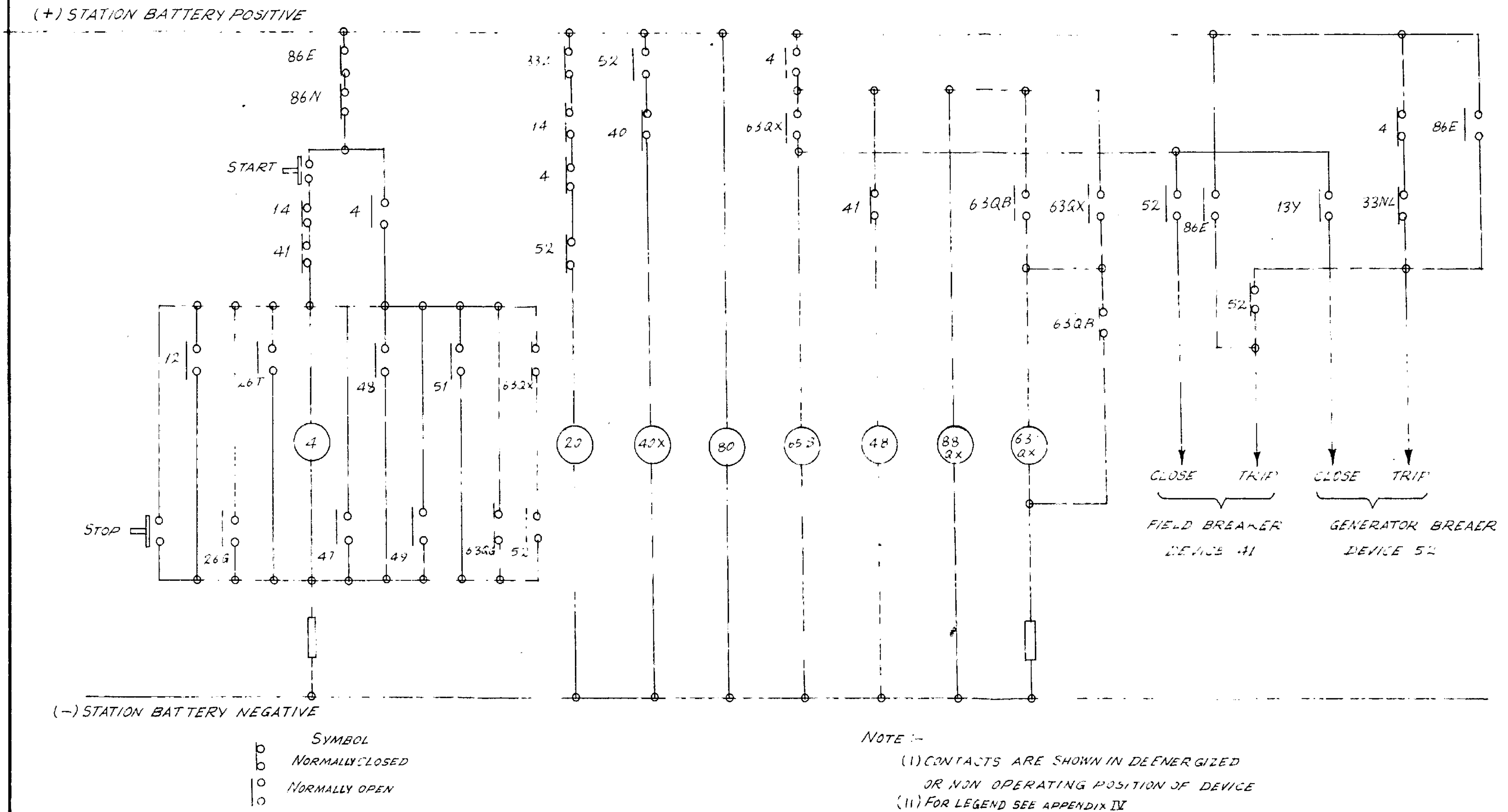
3.7.1 Salient Features: Churchill Falls power plant is having eleven units of 475 MW each. Units are housed in an underground cavity. The turbines are Francis type, rated at 6,40,000 HP at 200 r.p.m. under a net head of 313 meters. The generators are rated at 500 MVA, 0.95 power factor and 15 KV. Unit connected transformers rated at 500 MVA, 3 phase 15/240 KV are installed underground in a gallery just upstream of the machine hall. 240 KV oil filled cables connect these transformers to 240 KV bus at the switchyard. In the switch-yard six numbers 1000 MVA transformer banks, 240/735 KV are installed to transmit bulk power at 735 KV. The main control room is located in an administrative building at the switch-yard.

3.7.2 <u>Control System</u>: The control system is arranged to permit normal operation of the entire power complex from the control room using the following facilities(19).

1. A main control desk in the control room from which units can be started, synchronised and loaded automatically. The load on the unit can be controlled and normal switching operations can be performed from this desk.
2. A supervisory control desk for remote control of the outlying hydraulic equipment.
3. A recording instrument board.
4. Lamp type annunciators.
5. A console and automatic typewriters for data logging operators.
6. A large operator's desk on which telephones for communications are mounted.

3.7.3 Unit Starting: The complete sequence of normal starting is shown in Annexure I. Units are started from the control room. Complete controls for the units are also provided on the unit control boards near the generators. These facilities can be used to operate the machines locally during commissioning, testing and maintenance or in an emergency.

3.7.4 Unit Stopping: In normal stopping the unit is first unloaded and then disconnected from the system. Various activities involved during normal stopping are shown in Annexure II. The emergency trip and non lockout trip sequences are shown in Annexure III.

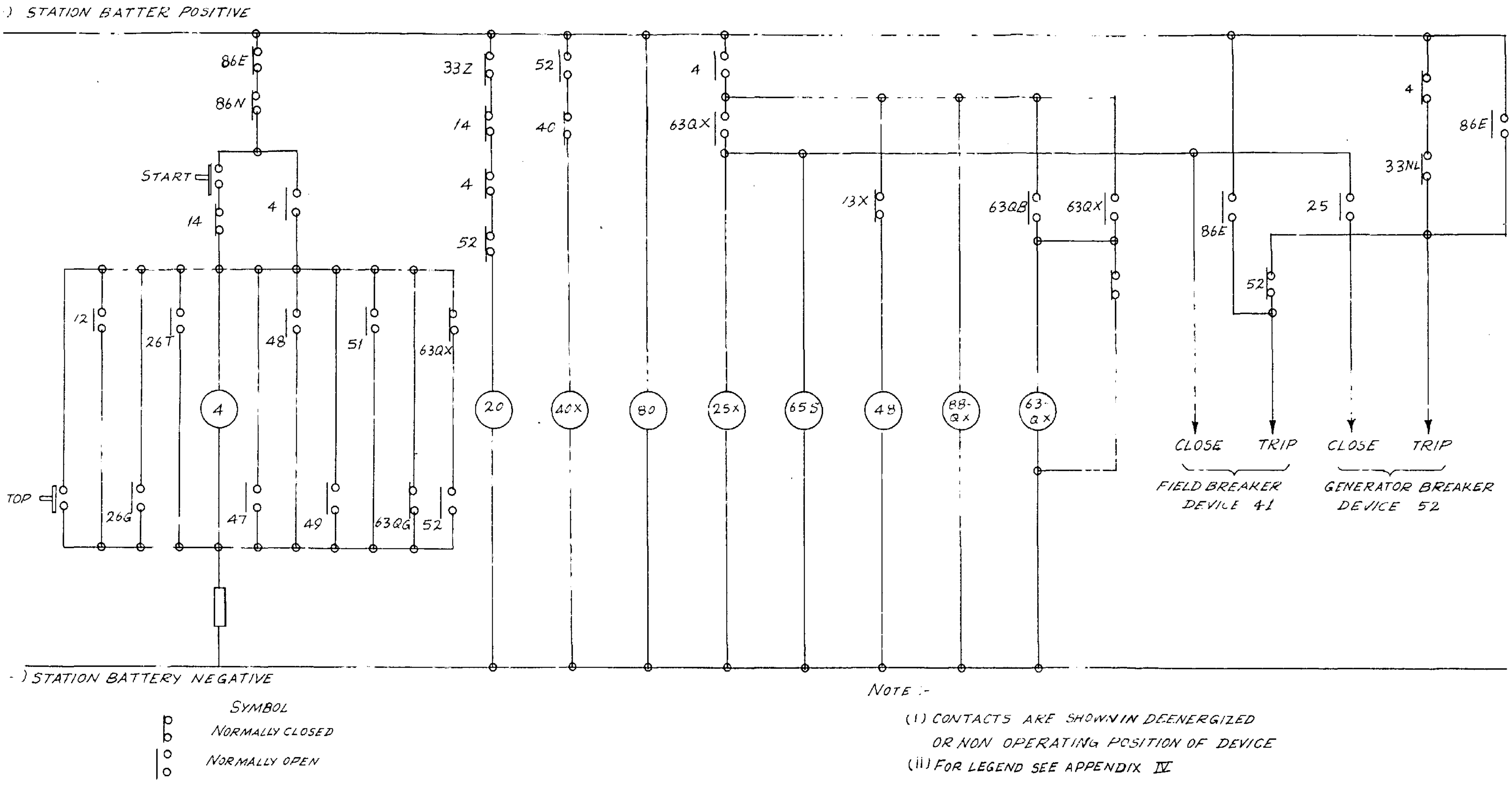


NOTE :-

(I) CONTACTS ARE SHOWN IN DEENERGIZED OR NON OPERATING POSITION OF DEVICE

(II) FOR LEGEND SEE APPENDIX IV

FIG. 3·1 TYPICAL SCHEMATIC DIAGRAM FOR SELF-STARTING METHOD



NOTE :-

(I) CONTACTS ARE SHOWN IN DEENERGIZED OR NON OPERATING POSITION OF DEVICE

(II) FOR LEGEND SEE APPENDIX IV

FIG. 3·2 TYPICAL SCHEMATIC DIAGRAM FOR AUTOMATIC SYNCHRONISING AND STARTING METHOD

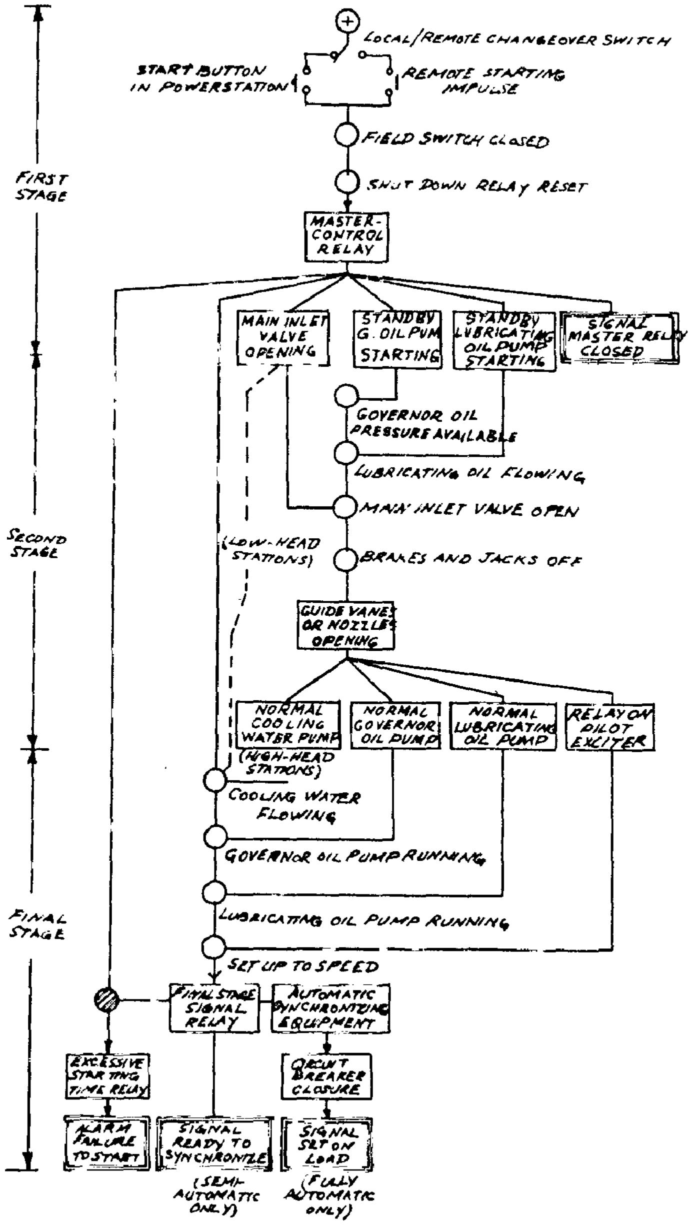


FIG. 3·3 SEQUENTIAL PARALLEL SCHEME FOR AUTOMATIC STARTING OF TURBINES

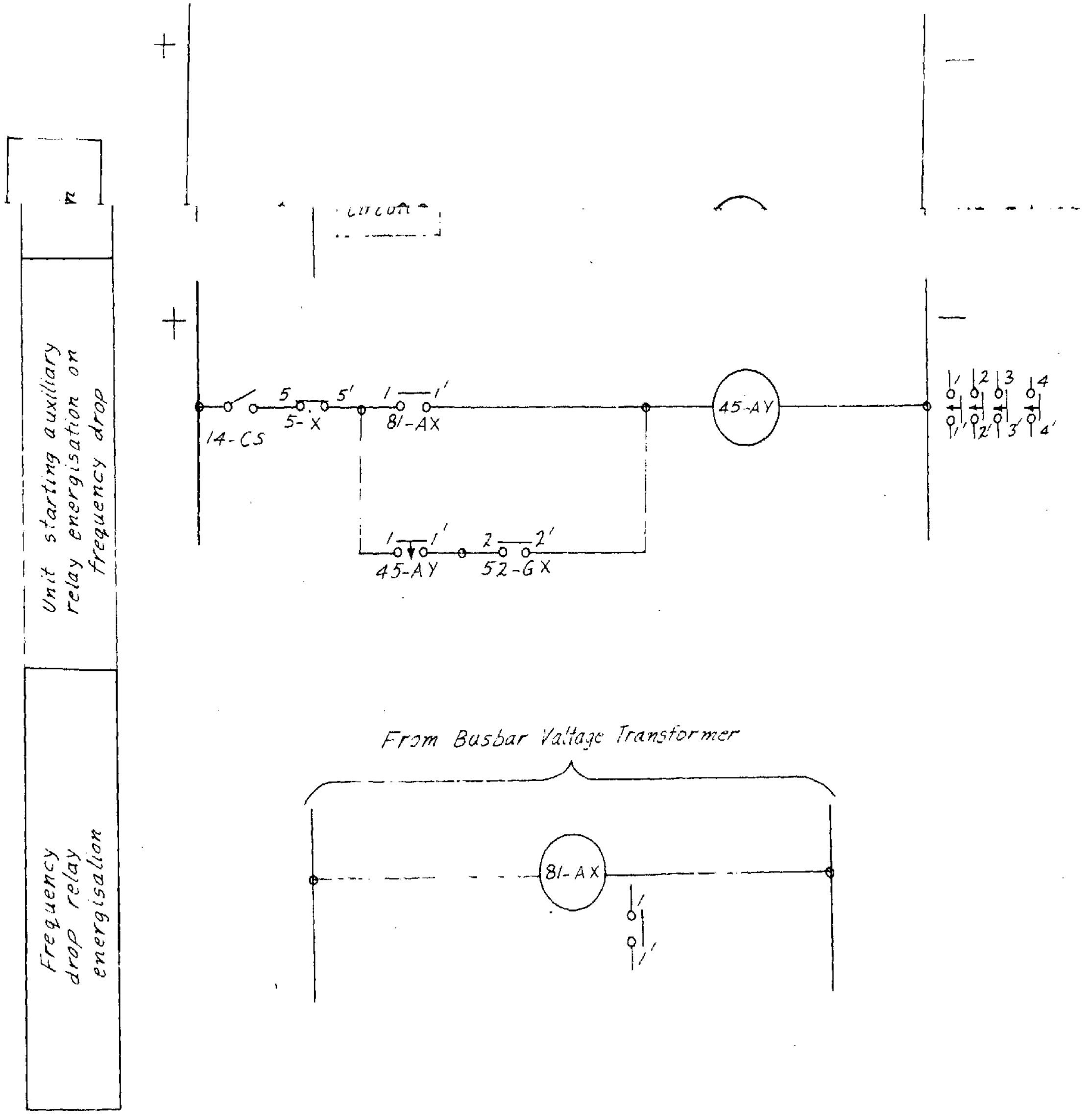
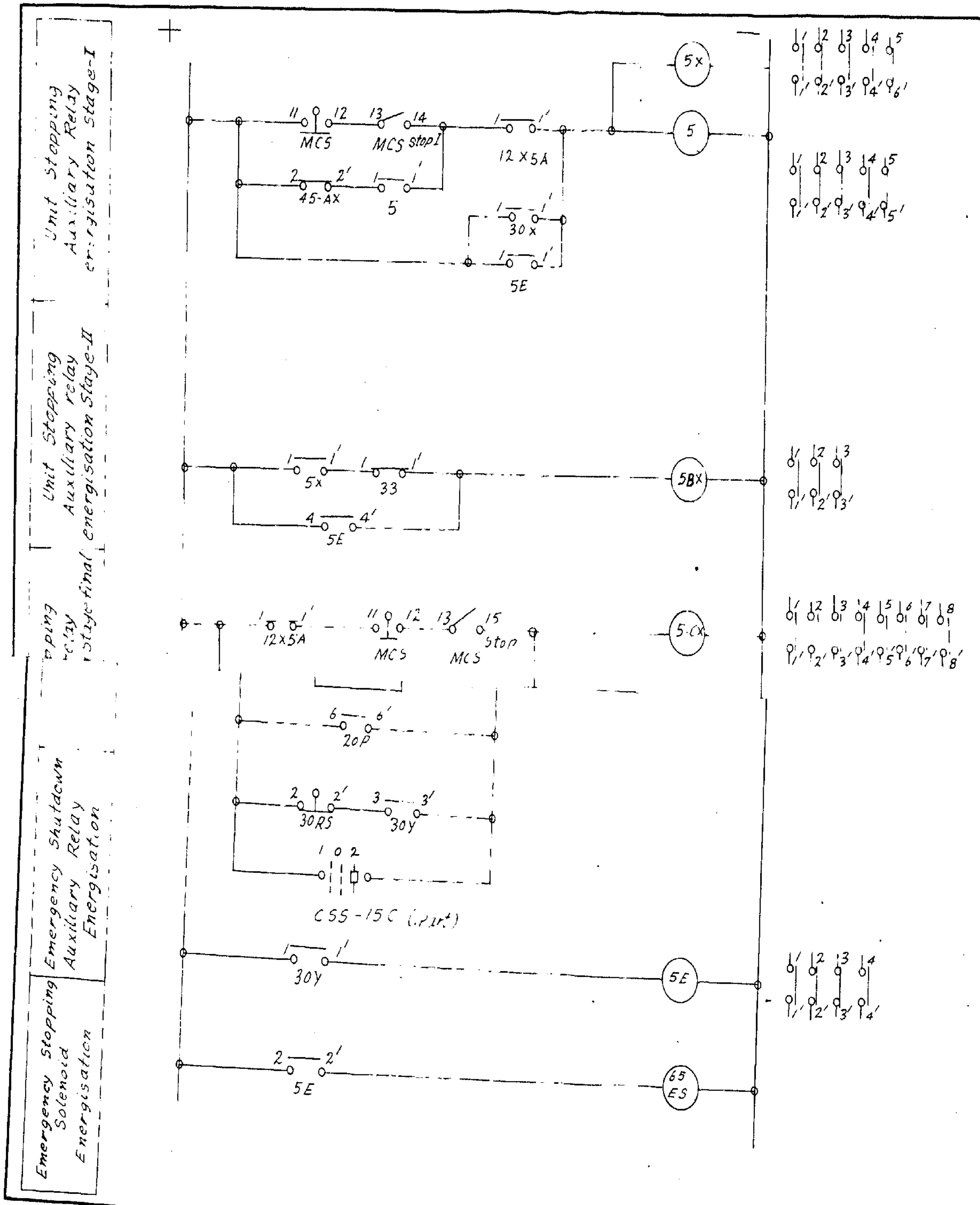


FIG. 3.4 UNIT STARTING FROM SEQUENCE MASTER CONTROLLER SWITCH AND ON SYSTEM FREQUENCY DROP DEHAR POWER PLANT



[illegible]

MCS — M[illegible]st[illegible] cam roller switch.

PBS — [illegible] button for immediate shutdown of the unit [illegible] control desk.

[illegible] — [illegible] button for [illegible] shutdown of the unit on [illegible] cubicle

[illegible] — Shutdown relay resetting push button on control panel.

5 — Shutdown relay

[illegible] — Shutdown relay auxiliary

[illegible] — [illegible] auxiliary stopping relays

[illegible] — Emergency shutdown relay

[illegible] — Controlled action shutdown relay

[illegible]Y — Immediate action shutdown relay

[illegible] — Emergency shutdown solenoid

[illegible]-1[illegible] — [illegible] isolating valve control selector and shutdown switch on [illegible] panel

[illegible]

[illegible] — [illegible]

FIG.3.5 UNIT STOPPING DEHAR POWER PLANT

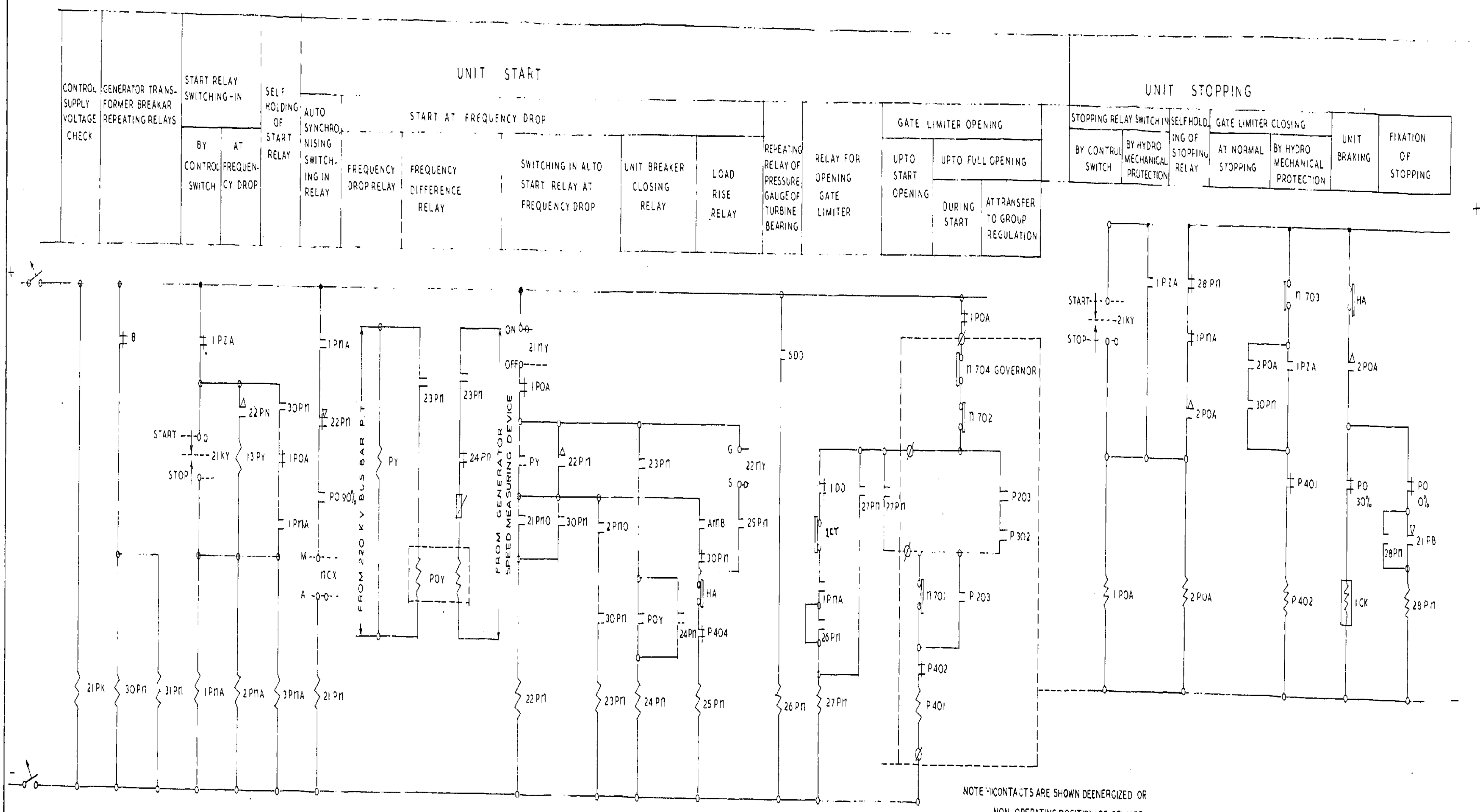


FIG. 3·6 UNIT STARTING AND STOPPING
(NORMAL & ON FREQUENCY DROP STARTING)

NOTE: i) CONTACTS ARE SHOWN DEENERGIZED OR NON OPERATING POSITION OF DEVICES

ii) FOR LEGEND SEE APPENDIX-V

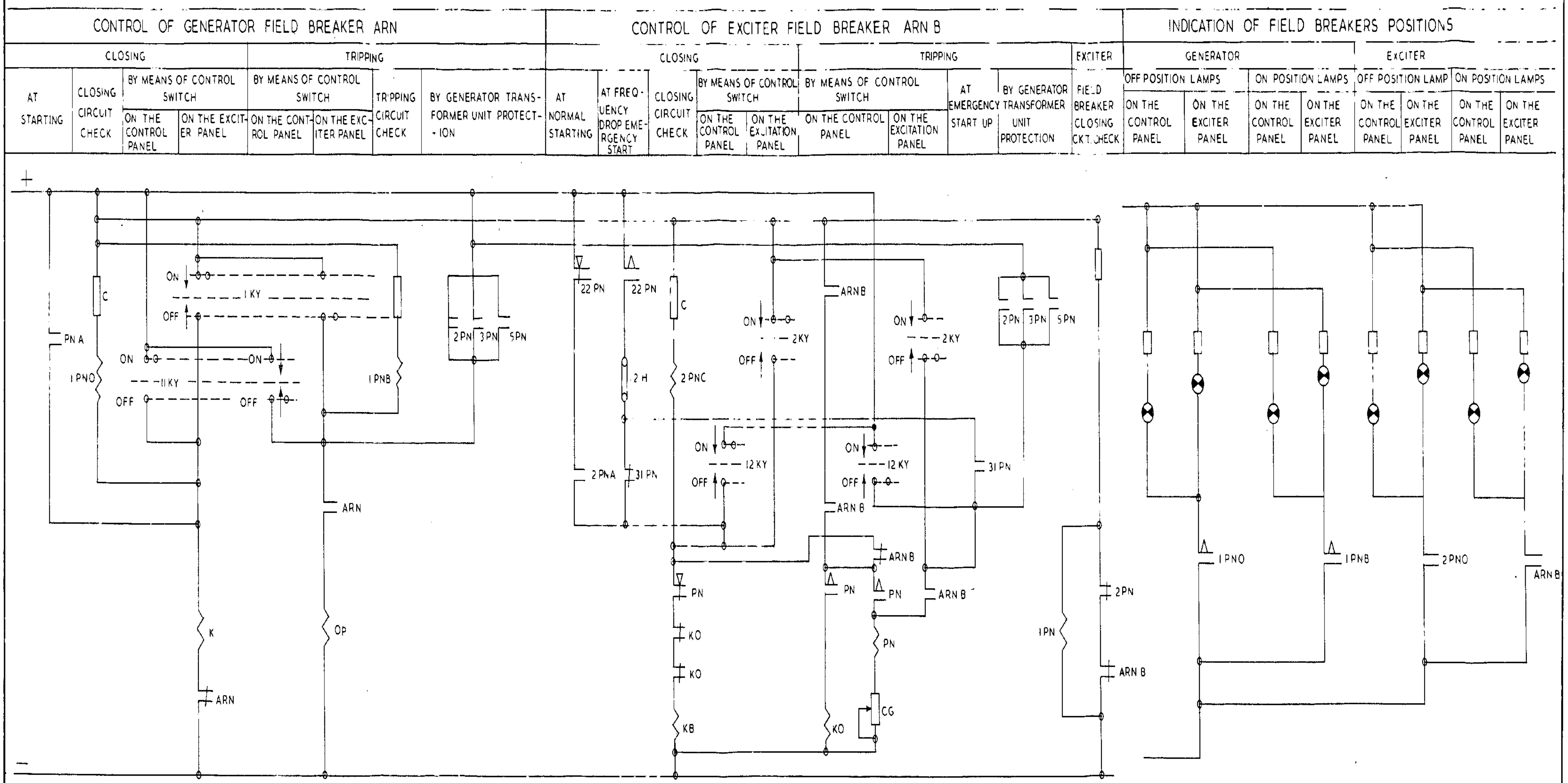


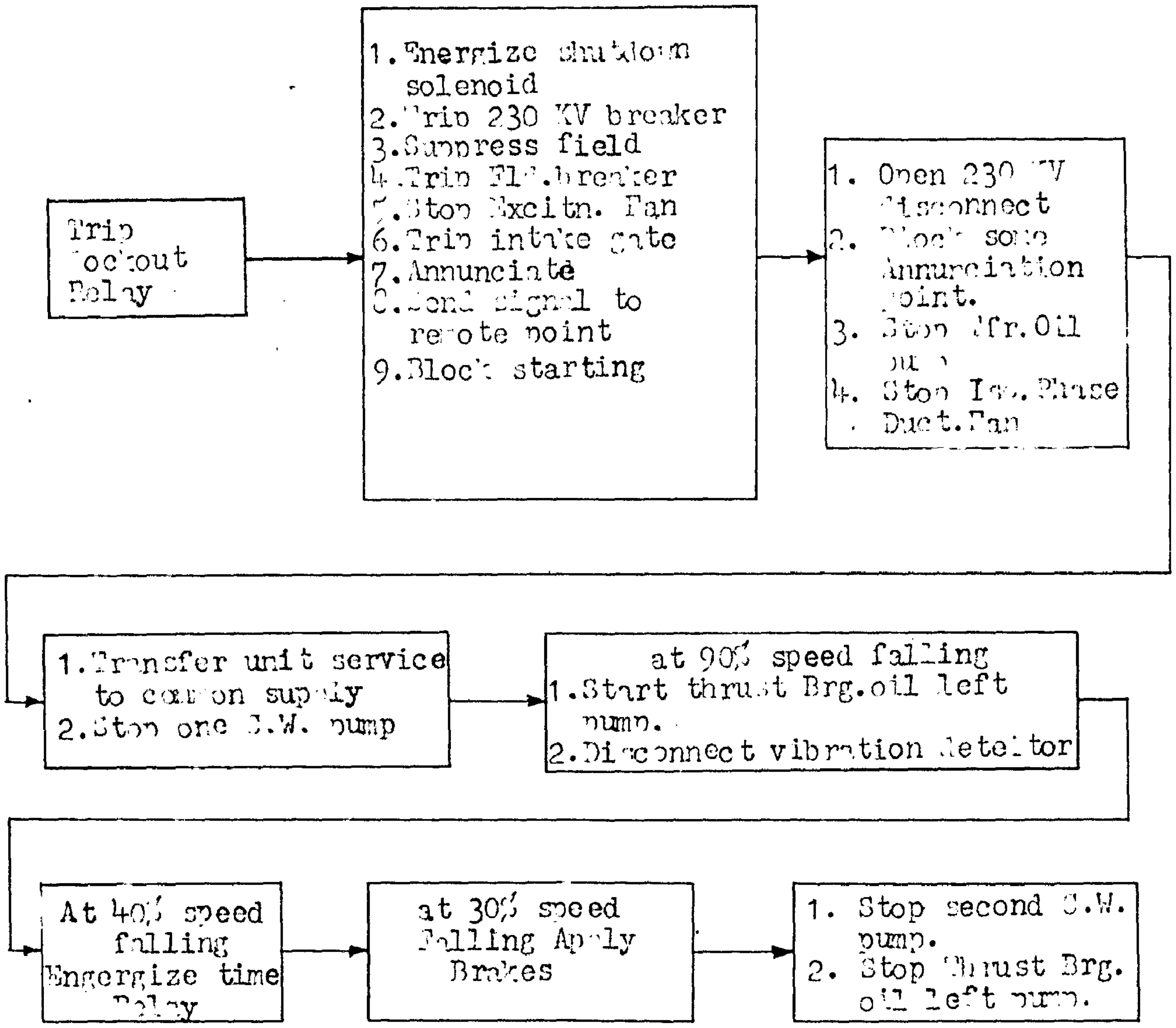
FIG. 3.7 CONTROL OF GENERATOR AND EXCITER FIELD BREAKERS - BHAKRA RIGHT POWER PLANT

NOTE - i) CONTACTS ARE SHOWN DEENERGIZED OR NON OPERATING POSITION OF DEVICES

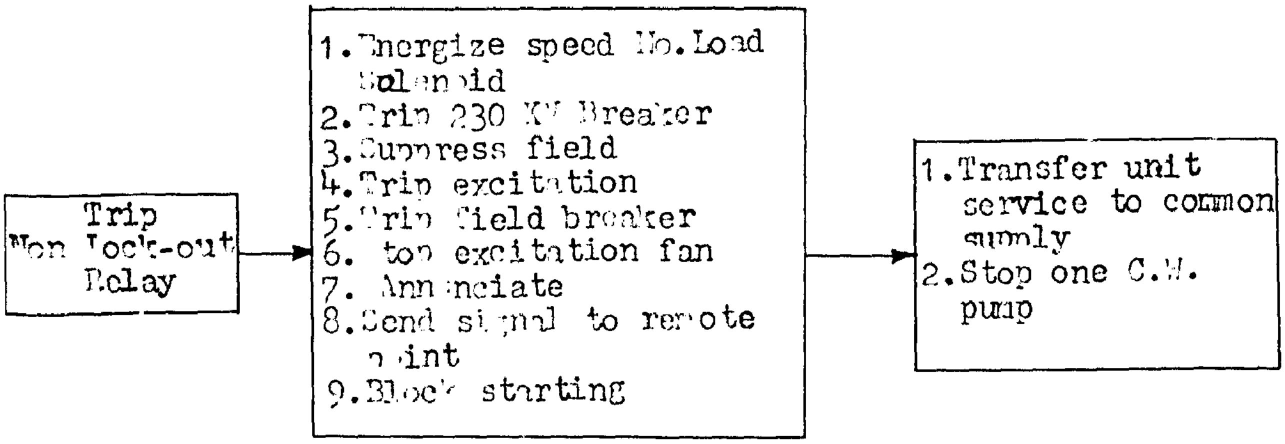
ii) FOR LEGEND SEE APPENDIX VI

ANNEXURE XII

LOCKOUT TRIP OR EMERGENCY TRIP



NON LOCK-OUT TRIP



APPENDIX XV

LEGEND

DEVICE	DESCRIPTION
1	Start-stop elements
4	Master start Relay
12	Generator overspeed contact (closes at 125 percent synchronous speed)
13 X	Generator speed contact (open at 95 percent speed and above)
13 Y	Generator speed contact (close at 95 percent speed and above)
14	Generator underspeed contact (closes at 50 percent speed and below)
20	Generator brake timing relay.
25	Automatic synchronizer equipment.
25 X	Auxiliary relay to energize device 25
26 G	Generator winding over temperature relay
26 T	Transformer winding over temperature relay
33 HL	Interlock closed from zero to no-load opening of the turbine gates.
33 [illegible]	Interlock closed at zero opening of turbine gates
40	Field failure relay
40 X	Auxiliary timing relay for device 40
41	Generator field circuit breaker
47	Single and reversed phase relay
48	Incomplete sequence timing relay

ITEM	DESCRIPTION
49	Generator thermal overload relay
51	Generator over current relay
52	Generator circuit breaker
63 G	Governor oil pressure relay
63 B	Bearing oil pressure relay
63 X	Auxiliary relay for device 63 B
27	Station Battery under voltage relay
86 I	Lock-out relay- immediate tripping of generator circuit breaker (electrichlly operated manually reset)
86 N	Lockout-relay - normal shut down (electrically operated manually shutdown)
88 [illegible]	Bearing oil pump motor relay.

ANNEXURE V

[illegible]

ITEM	DESCRIPTION
D	Auxiliary contact of circuit breaker
21 DX	Control Supply check relay
30 PT, 31 PT	Breaker position repeating relays
1 PTA, 2 PTA 3 PTA	Starting Relays
FDX	Frequency difference Relay
FX	Frequency drop Relay
RO 90%	Speed relay contact to pick up 90% of speed and above.
22 FU	Under frequency Auto Start relay
21 TX	Control switch for unit starting/stopping (Normal)
21 TX	Control selector switch for selecting unit to start at frequency drop
LDX	Auto/Manual control selector switch of synchronising.
2 PTD	Exciter breaker ([illegible]) position repeating relay
1 POA, 2 POA	Contacts of Shutdown Relay 1 POA & 2 POA
1 PZA	Shutdown relay
22 TX	Group/separate control selector switch
6 DD	Turbine bearing oil flow relay contact
1 DD	Contact of pressure gauge on braking system

ITEM	DESCRIPTION
1 GS	Contact of gate servomotor to break contact when gates are fully opened.
N 701	Gate opening limiter contact to remain closed upto speed no load.
N 702	Gate opening limiter contact to remain closed upto full gate opening.
N 703	Gate opening limiter contact to open when gates are fully closed.
N 704	Contact of Auto/manual operation of governor selector switch to remain closed when handle in automatic position.
N 705	To remain closed when regulator is on limiter
NA	Contact of gate apparatus to remain closed upto full gate opening.
21 TD	Contact of time delay relay 21 TD for function of stopping
D 401	Gate limiter motor raising coil
D 402	Gate limiter motor lowering coil.

APPENDIX V[illegible]

LEGEND

ITEM	DESCRIPTION
ANB	Generator field Breaker contacts
ANBD	Exciter Field Breaker Contacts
1 [illegible]	Control switch for manual closing/opening of ANB mounted on exciter panel
2 [illegible]	Control switch for manual closing/opening of ANBD mounted on exciter panel
11 [illegible]	Control switch for manual closing/opening of ANB on control panel in control room
12 [illegible]	Control switch for manual closing/opening of ANBD on GP control panel in control room
2 [illegible]	Contact of unit starting relay 2 [illegible]
[illegible]	Closing coil of ANB
C[illegible]	Opening coil of ANB
[illegible]	Closing coil of ANBD
[illegible]	Opening Coil of ANBD
1 [illegible], 1 [illegible]	D.C. Auxiliary Relays to indicate position of ANB
2 [illegible]	D.C. Auxiliary Relay to indicate position of ANBD
C	Ballast resistor
12 [illegible]	Link
2 PT, 3 PT, 5 PT	Contacts of protection relays to trip ANB & ANBD
31 [illegible]	Contacts unit breaker position repeating relay 31 [illegible]
22 [illegible]	Contact of auto-start relay 22 [illegible] Frequency Drop

CHAPTER IV

CONTROL OF PUMPED STORAGE HYDRO PLANTS

4.1 GENERAL

The purpose of pumped storage hydro installation is to store energy during off peak periods to be used for generation during peak demand periods. Water is pumped from a lower reservoir to an upper reservoir. Stored water is later used to generate electricity. Pumped storage plants also improve the system load factor. The installation of large base load nuclear and steam units has increased the demand for pumped storage due to its advantages of providing spinning reserve. Its ability to fill in the off peak load requirements improves the overall efficiency of the thermal generations in the system. The main purposes which a pumped storage station could fulfil, in an interconnected system are (5).

1. Coverage of peak load in generating operation.
2. Pumped storage and therefore increase in storage of night period energy.
3. Immediately available reserve in cases of break-down.

The machinery and equipment used in pumped storage power stations are classified as below (3).

1. Separate Type: The pump is separately installed from the turbine and generator, and the pump is also driven by a separate motor.

2. Tandem type: The pump, turbine and generator are placed on the same shaft, and the generator is used concurrently as a motor.

3. Reversible type: The reversible pump-turbine is connected directly to the generator motor.

Of these, the separate type installation costs are usually very high. In tandem type shaft becomes very long. Also change over to generating mode is very difficult. Reversible type installations are cheaper and are being increasingly used in the pumped storage schemes. In reversible type units there are three types of pump (7) depending on the head. They are:

		Head on site
Francis type	-	30 m - 500 m
Mixed flow type	-	10 m - 100 m
Axial flow type	-	3 m - 10 m

6.2 Control System: The control system of the pumped storage power station can be divided into two; (i) turbine operation and, (ii) pump operation. Since power generation or pumping is carried out depending on the load condition of the system, switching from one operation to the other must be carried in a very short time. The generation operation of the pump turbine is the same as that for ordinary turbines. As a special characteristic of the pump turbine, however, the starting gate opening and no-load gate opening change drastically through changes in head. Consequently, there is need for making it possible to automatically adjust-gate opening in line with the differences in water levels between the tailrace and the reservoir through the use of water level regulator. In a pumped storage power station when the turbine and pump are of the tandem type, the starting of the pump can be carried out by the turbine. In the case of reversible pump turbine, however, it must be started by a generator motor. For this purpose, a special type generator motor is necessary, but the pump turbine itself requires a water level depressing device in order to depress the water level of the upper part of the draft tube and permit the runner to rotate in the air. There are two ways of depressing the water level. One is to tighten the main inlet valve and to depress from inside the spiral case. The other is to leave the valve open, fully close the guide vanes and then depress the runner chamber water. The former method is used for comparatively small capacity ones. The latter method is used when the depression capacity is large and also where there is no main inlet valve. After the water level depression has been completed the pump turbines are started by one of the following methods(22).

6.2.1 Across-the-Line Start. The pumped storage unit is started with full voltage from the main transformer by closing the unit circuit breaker. The unit comes up to near full speed as an induction motor, at which time excitation is applied to bring the unit into synchronous operation. This method has the advantage of being the simplest, quickest and most economical; requiring only the addition of continuous [illegible]. It is limited to the smaller size units, since large units would have to be built with sufficient amortisseur winding capacity to eliminate the heat produced during start up. It also has a major disadvantage in that it causes extreme voltage dips on the transmission system.

5.2.2 Reduced Voltage Start: The unit is started at reduced voltage, either from a tap on the main transformer or through a series reactor in the start circuit, by closing a start circuit breaker. When the unit reaches full speed as an induction motor, excitation is applied to bring it into synchronous operation. Once operating as a synchronous motor, the running breaker is closed. Reducing the starting voltage reduces the voltage dip at start, but the starting time is increased in the process. A second voltage dip occurs when the transfer is made from the starting to the running breaker. Reduced voltage start is also limited to the smaller size units due to the same reasons i.e. amortisseur winding capability to eliminate heat.

5.2.3 Synchronous Start: The unit is started as a synchronous motor by another unit operating as a generator with both units initially at rest. The necessary switching is performed to connect the generating unit to the pumping unit. Static excitation or separate excitation system is required to provide full field at zero speed. The fields of both units are energized and the generator turbine gates are opened to a predetermined position. Both the generator and the motor accelerate together and at 95 percent speed the generating machine is placed on governor control. The units are then synchronized with the system. The last unit which acts as a generator must be provided with different starting method if all the units are to be used as pumps.

4.2.4 Reduced Frequency or Semi-Synchronous Start

This method is similar to the synchronous start except the pumping unit is started as an induction motor. The generator turbine gates are opened to a predetermined value. When the speed of the generator reaches approximately 60 to 80 percent, a starting breaker is closed tying the stators of the generating unit and the pumping unit together and closing the generator field breaker. Upon application of the field, the generator will decelerate while the motor accelerates. When motor reaches approximately generator speed, the motor field is applied to bring it into synchronism with the generator. The turbine gates are then opened at a predetermined rate. The generating unit is placed on the governor control and then synchronized to the system through the running breaker. As with synchronous start, at least one machine must be provided with different starting method if all units are to be used as pumps.

4.2.5 Wound Rotor Induction Motor Start: In this method, an induction motor is coupled to the generator motor shaft. The unit is brought up to speed by the induction motor. The speed matching and synchronizing relays automatically synchronize the machine with the system. This is the most flexible starting method but it is usually slower.

4.2.6 Reduced Winding Start. The unit is started as an induction motor by application of full voltage to only part of the parallel stator winding. This reduces the starting current and voltage dip. Machine impedance during starting is inversely proportional to, and starting torque directly proportional to, the amount of winding used. This method has the disadvantage of unbalanced heating and complex stator winding design.

4.2.7 Static Converter Start: This method is similar in principle to synchronous starting from another unit. The converter is used for getting variable frequency. The converter is a rectifier inverter set which takes power from an auxiliary source. Rated field current is applied at stand still to main motor from a separate excitation source. At low speed, the inverter frequency is controlled by devices which sense shaft position. At higher speeds the inverter frequency follows machine speed and the machine accelerates toward synchronism under current control.

In the following sections, semi-synchronous starting of Grand Coulee 65000 Hp pump motor (7) and reduced voltage starting of Muddy Run pumped storage plants (11) are described to explain the method of starting and stopping of pumped storage plants.

4.3 Control of 65000 Hp pumping Plant at Grand Coulee

4.3.1. General. The Grand Coulee power development on Columbia River in U.S.A. comprises (1) two power plants-one on the left bank and the other on the right bank; each comprises nine units of 108 MW each; (ii) a pumped storage plant having twelve units of 65000 Hp each; of which six were designed as pump turbine- the generators are rated at 50 MW each, (iii) the third power plant (future development) which will house twelve units of 600 MW each. When completed, the development will have about 10,000 MW installation. All power plants were originally planned for starting and stopping from respective power houses. Later, the control schemes have been modified and controls of all plants were brought to the central control point @ the left power plant. The scheme discussed below describes the control of pump units from local control point as well as from the centralized control point.

4.3.2 Pump Starting Method: The 65000 Hp motors were designed to be started by either synchronous or semi-synchronous method. A single line diagram for a generator and its associated pump is shown in figure 4.1. On synchronous start, both the generator (G-2) and the pump (P3) that is to be started are at rest. Their motor driven exciters are operating at rated speed. The power plant operators at the generator and pump unit control boards adjust the excitation controls to predetermined positions so that the required excitation will be applied when the main exciter field breakers are closed. With these adjustments completed and pump accessory equipment operating, the power plant operator at the unit control board then proceeds with the following.

1. The pump-motor main circuit breaker (7932) is closed.
2. The main exciter field breakers for the generator (unit L-2) and the pump-motor (P3) are closed.
3. The generator turbine gates are then opened and, as the generator starts to rotate, power is supplied to the pump motor. The pump motor rotates in synchronism with the generator.
4. The generator turbine gates are opened further to bring both the generator and the pump into normal operating speed.

For an induction start, the generator is removed from the 230 KV bus and the speed reduced to one-half normal speed. The generator main exciter field breaker is opened and the excitation rheostat is adjusted to a predetermined position that will provide a field current of 1100 amperes at 250 volts when the main exciter breaker is closed. When all the adjustments are completed and the conditions are ready for a pump start, the power plant operator at the generator control board closes, by remote control, first the pump motor breaker and then the generator main exciter field breaker. A starting current of approximately 500 amperes is supplied to the motor from the time the pump motor circuit breaker closes until the generator main exciter field breaker is closed. When the generator main exciter circuit field breaker is closed, the starting current gradually increases and reaches a maximum of 4000 [illegible] in 20 to 25 seconds, as the motor is accelerated as an induction motor. During this time, the speed of the motor decreases from half to one-fourth speed because of the electrical load [illegible] of starting the pump. If the speed of the generator drops one fourth, the operator at the generator control board manually adjusts the turbine gate limit to bring the generator back to a minimum operating speed about 25 percent. Synchronism between the generator and the pump motor is usually accomplished in 30 to 35 seconds. When synchronism is obtained, the pump motor field breaker is automatically closed by the motor field application control circuits. With the pump motor and generator in synchronism, the generator turbine gates are manually operated to open and bring the units up to normal operating speed in approximately one and one half minutes. With the pump and the generator at normal operating speed, the operator in the control room takes over control and synchronizes the pump with the system.

4.3.3 <u>Centralized Control</u>: With the centralized control system, the operation of the pump can be controlled by one power plant operator at the control console in the left power house main control room. The operator selects the pump to be started by placing the start-stop selecting switch (SSSS) for the pump in the start position, see Figure 4.2. This energizes master start relay, 4 A, if the circuit breaker and the siphon breaker valve in the discharge pipe for the pump are open. When the motor start relay, 41, is energized, it is sealed in through one of its contacts. Another contact on this relay energizes the TBHP relay which starts the thrust high pressure oil pump. Since the thrust bearing does not require an external lubrication source after the motor is started, the high pressure oil pump remains energized only until the speed of the motor reaches 90 percent of rated value. At this point the contact of the centrifugal device, 14, on the motor shaft is opened. This deenergizes an auxiliary relay, 14X, which in turn drops out the thrust bearing high pressure oil pump relay, TBHP. Another contact of the 41, energizes the relays for the cooling water control, CWC, the pump bearing lubricating pump, BLP, and the alarm cutoff, AC. It also energizes the alarm horn. The CWC relay energizes a motor-operated valve in the cooling water system to open the valve and supply cooling water to the motor stator and bearing coolers. The BLP relay starts both a.c. and d.c. motor driven pump bearing lubrication pumps. The d.c. motor driven pump operates until it is deenergized when the oil pressure increases above the minimum value required for lubrication. The alarm horn, located in the pump pit area, is energized to sound a warning to all personnel in the area that the pump is being readied for a start. The alarm is deenergized by the AC thermal relay after operating approximately 15 seconds.

Another contact on the master relay energizes the brake valve solenoid, BVR, and the exciter motor auxiliary, [illegible], relays. The energizing of these relays release the pump motor brakes and starts the motor driven exciter set for the pump unit by closing 6.9 KV supply breaker for the drive motor. With the pump auxiliaries operating and conditions normal, five interlocks in the ready lamp circuit will be closed. These interlocks indicate the following conditions.

1. The thrust bearing oil pump is supplying oil to the bearing at the required pressure.
2. The pump bearing oil pressure is at normal
3. The cooling water pressure is at normal.
4. The brake light relay, [illegible], is energized, indicating all brake shoes are in the released or down position.
5. The [illegible] relay is energized by the exciter voltage which is at the normal level.

When these five contacts are closed, the pump ready lamp is lit. This informs the operator that the selected pump is ready for a start.

4.3.4 Generator pre-start control: On the generator section of the control console desk there is a pump start selector switch, [illegible], which the operator uses to set up the controls for either pump one or pump two start. If he selects pump two start, 2A relay energizes, and if he selects pump one start, 2B relay energizes see fig. 4.3. The energization of either one of these two relays picks up a generator load reduction relay, GLR, which is interlocked through the pump motor air circuit breaker red-light relay contacts. This GLR relay applies a bias signal in the generator load control circuits which will reduce the unit load to zero. When the generator load reaches zero, a no load gate position, NLGP, contact closes. This event energizes a 52TX2 relay which trips the generator unit breaker, thus removing it from the 230 KV bus. When the generator breaker is tripped, the green light relay, 52 GLX, contact closes, and this energizes a 94 X 2 relay which in turn trips the generator field breaker. As the generator field breaker is tripped, one of its auxiliary contacts energizes the relay 65 WGX which drives the turbine wicket gate limit motor to close the wicket gates. Another relay, 65 WGX3, is energized at the same time. After a preset time period, this relay drops out 65WGX relay. This energizes 65WGX2 relay which in turn energizes the turbine wicket gate limit motor to drive it in the opening direction. At the half speed gate position, a cam switch, HSGP, opens to stop the wicket gates at the partially open position which will maintain the generator speed at 60 rpm.

After the speed reducing auxiliary control relays have functioned, the field adjustment circuits are then energized through the closed contacts of the deenergized 65WGX and 65WGX2 relays. The control relays RR, RRX, 70RR, and 70RL work in sequence to drive the main exciter field rheostat to the full resistance or zero position and then return it to the position desired for the selected pump one or pump two start.

4.3.5 Pump Start: After the prestart operations are completed and the normal operating conditions interlock contacts are closed, the generator ready lamp on the control console is energized. From this indication operator knows that the generator is at half speed, the generator thrust bearing high pressure lubrication pump is operating, and the main exciter rheostat is in the correct position for the selected pump start. With the ready lamps on the pump and the generator showing that every thing is adjusted for the start, the operator then proceeds with the final start action. The start is initiated by pressing the hold button for the pump and the generator. This for example energizes relay 3P (pump P-3 ready relay, Fig. 4.2) and relay 2G (generator G-2 pump. Start ready relay Fig. 4.3). Contacts on these two relays make up the circuit to the pump motor air circuit breaker closing relay, [illegible], as shown in Fig. 4.4. As the pump motor air circuit breaker closes, the red lamp relay is energized. This in turn closes the generator field breaker which supplies the field excitation to the generator. As the speed of the pump increases and comes into synchronism with the generator, the pump field breaker closes automatically. With the closing of the pump field breaker, the circuit to the turbine wicket gates limit motor raise relay 65MLR is energized intermittently through the 66W contact. This drives the turbine wicket gate limit motor in the opening direction in a series of short steps or pulses. These pulses increase the gate limit and allow the turbine wicket gates to open gradually. This action brings the generator into full operating speed where the turbine governor takes over the control to maintain the rated speed. The pulses to the wicket gate limit motor continue until they have driven the gate limit to the full open position.

As the pump water flows through the discharge pipe, it operates a float switch which energizes the siphon breaker valve controls. This closes the siphon breaker valve and initiate the application of vacuum to the vent section of the pipe. This reduces the total pump head by 20 feet. With the generator and pump operating at normal speed, the control console operator selects the automatic synchronizer to synchronize the generator-pump system to the 230 KV bus.

4.3.6 <u>Stopping Procedure</u>: The stopping of a pump unit is initiated by the control console operator moving the start stop selector-switch, [illegible], to the 'Stop' position. This energizes the master stop relay, 4D, plus an auxiliary relay [illegible] see Fig. 4.4. The 4D relay starts the thrust bearing high pressure oil pump. The [illegible] relay drops out the siphon breaker close relay, [illegible], which causes the siphon breaker valve to open. When the interlock contact on the thrust bearing high pressure oil pump is closed by oil pressure, the circuit is made up to a pump motor air circuit breaker trip relay. After the opening of the pump motor air circuit breaker, the pump comes to a complete stop. Through the contact of 4D relay, the pump auxiliaries are maintained and operated for five minutes after the pump has been completely stopped rotating. At this time the action of the time delay relay, D2, drops out the [illegible] relay. This deenergizes the auxiliary equipment relays and leaves the control system in a normal reset condition.

4.4 Control of Muddy Run Pumped Storage Plant.

4.4.1 General: Muddy Run pumped storage plant comprises eight generator motors each rated at 111 MVA at 0.9 p.f., 13.8 KV as generator and 134,000 HP as motor (11). Each unit is provided with motor operated switches for phase reversal. Station type air circuit breaker connects the unit to the 13 KV bus. Each pair of units connects to a 250 MVA, 13.8/230 KV transformer and to 230 KV bus through air circuit breaker. Power for starting the unit as motor is provided from 6.6 KV starting buses supplied from taps in the low voltage windings of two of the four main transformers as shown in figure 4.5. Two starting buses are not normally connected. Each unit connects to its respective 6.6 KV bus through a motor operated starting switch. Since the starting breaker can be common to all units, the starting switches of all units are interlocked so that only one can be connected to the starting bus at a time.

4.4.2 Control System: The plant is designed for normal operation as an unattended station with remote control and supervision. Selection of the control location can be made only at the station by positioning the control-selector switch on the unit control board in " MANUAL" "STATION-AUTO", OR "REMOTE AUTO". Manual is intended primarily for maintenance purposes. Four modes of operation are provided that is generate, pump, spin, and generate after spin.

4.4.3 **Start Operations** Prior to starting, the control selector switch at the plant must be placed in the local manual or remote automatic position to select the control location. Then the mode selector switch is turned on one of the four modes. In each of the modes three distinct initiating steps are involved.

Step 1: Selects the mode of operation which checks oil and air pressures, control switch positions, and starting readiness of the equipment. If the conditions are normal the auxiliaries ready to start lamp comes on.

Step 2: Starts selected auxiliaries and positions switches and devices in accordance with the mode of operation. The unit ready to run lamp lights when this is satisfied. The unit is now in standby i.e. ready to run but the rotor has not turned.

Step 3: Energizes the main start circuit which sequentially activates operators and devices to move the unit from standstill to rated speed. Successful completion of step 3 lights the in service lamp signifying that the unit is ready for voltage and load adjustments.

Each step must be completed in a given time or else shut down begins and start up control lock out. Annexure I & II show complete sequence of operations in three steps. In the following paragraphs only step 3 is discussed as most of the operations in steps 1 & 2 are common to all modes.

4.4.4 *Generate Control:* Positioning the function selector switch to run initiates step 3 of the generate mode. The cooling water pump starts, the unit water valve opens and water flows are established to the bearing, turbine packing box, and the air coolers of the generator. The wicket gates lock and brakes are removed, and the governor start solenoid is energized. This opens the wicket gates to speed no load position which brings the unit to almost rated speed. As the unit passes 75 percent speed, the high pressure oil lift pump shuts down. At 95 percent speed generator operation exciter field breaker closes. A speed matcher relay adjusts the speed of the unit to the system and a synchronizing relay closes the unit breaker. The station lights in service lamp and unit is ready for loading either manually or by automatic load frequency control equipment.

4.4.5 *Pump Control:* Step 3 of pump mode start up is initiated by positioning the function selector switch to run. The cooling water pump starts and establishes flow to all circuits as above. The unit brakes are released and starting switch closes the generator motor to the starting bus. The generator motor field series resistor shorting switch opens to insert additional resistance in the field circuit to increase motor starting motor. The upper and lower runner seal ring water valve opens to lubricate and cool the runner seals while the turbine is rotating in air. Air is admitted to the draft tube and depresses the water to a level below the turbine runner. At the same time runner band drain valve opens to drain the water trapped in the runner.

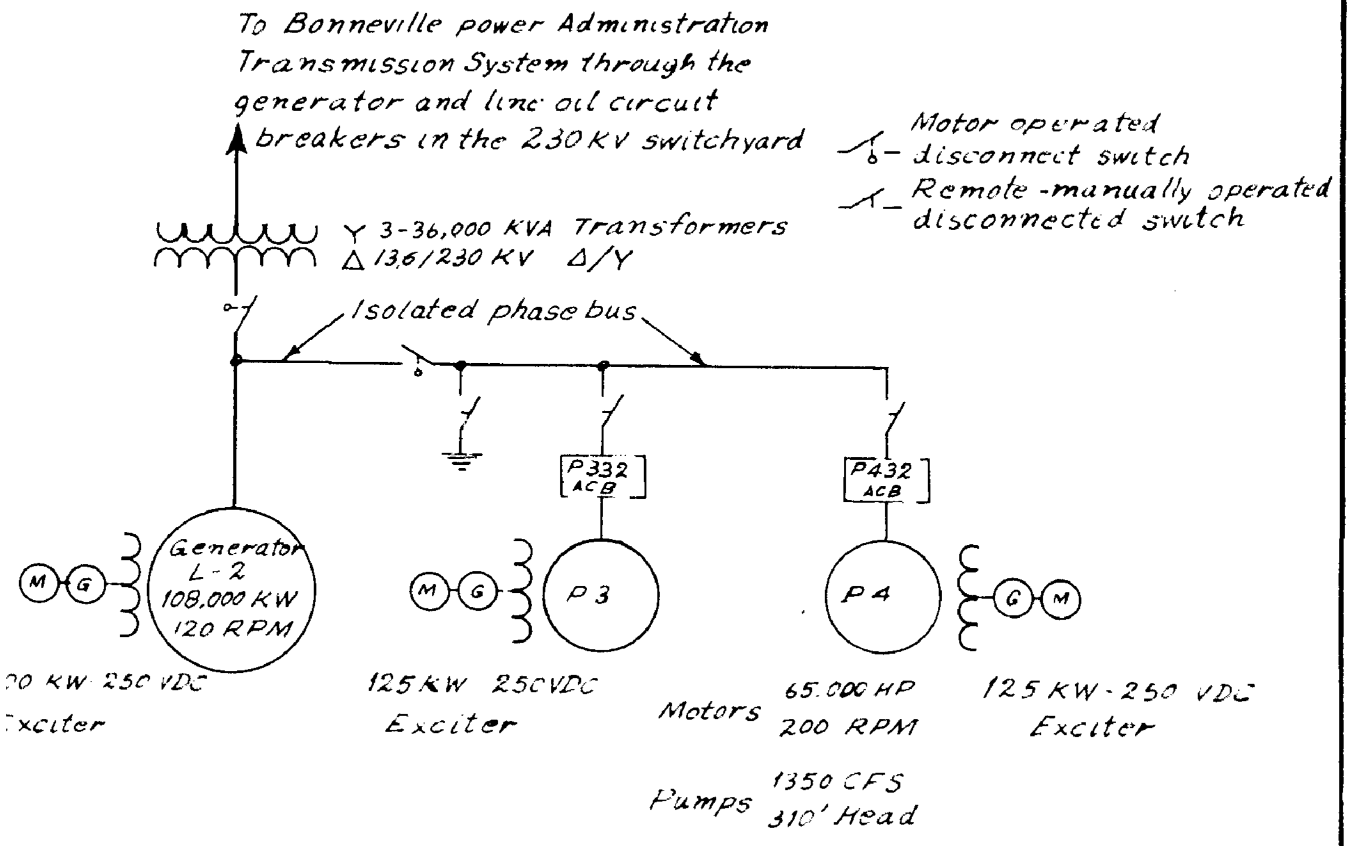
Completion of the foregoing closes the starting breaker, applying low voltage to the generator-motor. As the unit begins to rotate, the pump rotation relay verifies direction of rotation and an acceleration check occurs at 10 percent and 60 percent speed i.e. if these speeds are not attained in a preset time shutdown is initiated. At 75 percent speed the high pressure oil lift pump shut down, wicket gate lock is removed and the automatic lubrication system for the wicket gates is started. At approximately 100 percent speed the pump operation exciter field breaker closes and d.c. voltage is applied to the stabilizing field for field forcing. When excitation has built up the voltage regulator supply breaker closes and 1[illegible] seconds later the exciter control field breaker closes. The voltage regulator begins regulating to a d.c. base in the absence of a.c. reference. A motor synchronizing relay detects synchronous operation and initiates closing of the field series resistor shorting switch. With the resistor shorted, voltage regulator sensing transfers to a lower d.c. voltage base. When the motor synchronizing relay has operated, it started 15 seconds delay in the sequence to allow the machine to stabilize.

After the settle-down period, the starting breaker opens, disconnecting the stator from 6.6 KV starting bus. After a delay of approximately one second, which allows generator-motor to decelerate, the unit breaker closes connecting the stator to the 13 KV bus. Ten seconds later voltage regulator setting transfers from the d.c. base to the potential transformer terminals (a.c. base) on the generator-motor leads. Closing the circuit breaker initiates pump priming. The turbine bowl drain valve and depression valve close while the air release valve opens to vent depression air to the atmosphere, allowing water in the draft tube to fill the turbine runner cavity. Water pressure in the draft tube increases until the turbine blade tip pressure switch contacts close. These contacts close the depression air release valve and the exciter field rheostat to the full load position, and energize governor motor and complete opening solenoid. The wicket gates open to the pump position. The indication lamp lights to indicate that start up is completed and the voltage adjusting device may be operated for final adjustments.

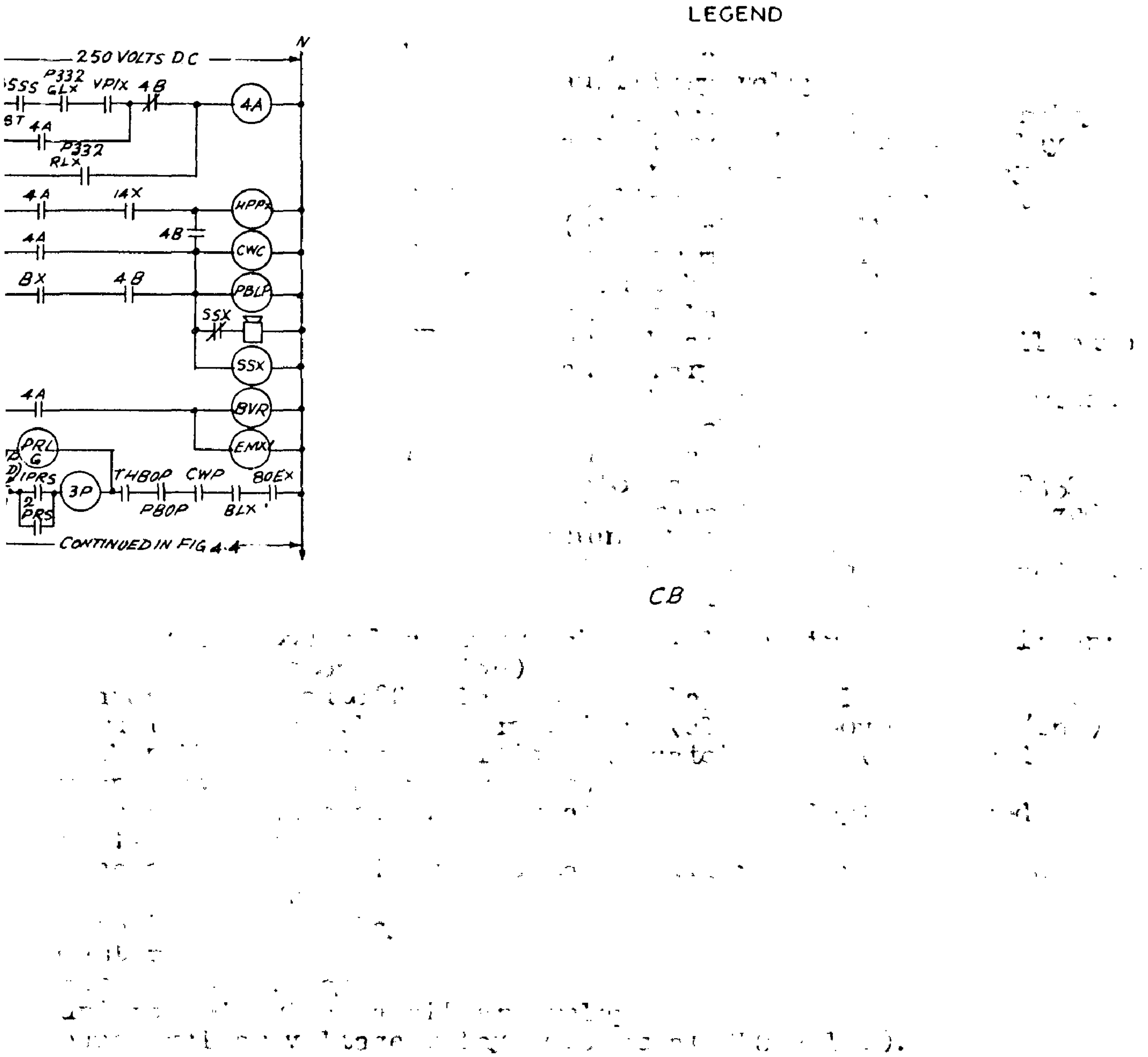
3.4.6 <u>Pump (Condenser) Operation:</u> (Step 1 of the automatic start up of pump sequence is the same for the generator mode to the point where the unit is synchronized with the system with the exception that the upper and lower runner seal ring water flow is established alongwith other cooling water flow. Closing the unit breaker energizes shutdown solenoid of the governor and thus closes wicket gates. The turbine head drain valve opens and the air system depresses the draft tube water below the runner. As the wicket gates are closing the turbine is rotating in water and unit draws approximately 25 to 30 percent of rated power as a motor. As the water is depressed rotating power drops to about 3 to 5 percent. When the start up is completed the in service lamp lights and the unit is ready for [illegible] adjustments.

4.4.7 Generate-after-pump Control: With the generator rotor operating in pump mode the unit may be transferred to generate mode without shutdown. The operator positions the mode selector switch from pump to generate after pump. The in service lamp goes out and the auxiliaries ready to start lamp lights. When the auxiliary start switch is operated, the exciter field breaker, the voltage adjusting device, and the governor speed adjuster move to preset positions. Auxiliary start must be completed in a preset time or the unit will be shutdown. With auxiliaries start completed, the auxiliary ready to start lamp goes out and unit ready to run lamp lights. Positioning the function selector switch to run initiates closing of the [illegible] [illegible] in valve and depression air valve. When the valves close the governor starting solenoid is energized and the wicket gates open to lightly load the generator. The run sequence must also be completed in a preset time or a shutdown occurs. When the unit ready to run lamp goes out and in service lamp lights, the unit is ready for voltage adjustment and loading.

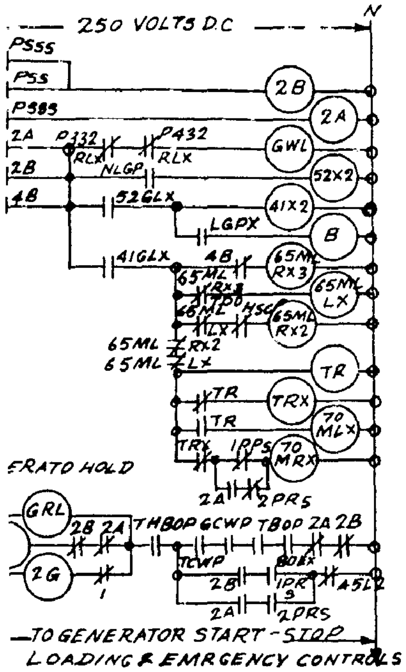
4.4.8 Stopping Control: Shut down of a unit in any mode of operation can be initiated by positioning the function selector switch to shutdown. This starts a controlled-action-shutdown, unloads the machine run the exciter rheostat to no-load position, trips the unit breaker, shutdown all unit auxiliary equipment and applies brakes at 40 percent speed. Trouble contacts of the type that indicate possible damage to equipment if the machine continues to run can also initiate a controlled action shutdown and lockout the controls against another start and sound an alarm. Immediate action shutdown can be initiated by operation of contacts signaling serious trouble requiring immediate shutdown. With this type of shutdown unit breaker trips without waiting for load reduction, auxiliaries are shutdown, brakes are applied at 40 percent speed, and the start up circuit is locked and an alarm sounds.



G. 4.1 SINGLE-LINE DIAGRAM OF GENERATOR L-2 AND ITS ASSOCIATED PUMPS, P-3 AND P-4, GRAND COULEE DAM.



4·2 SCHEMATIC OF CENTRALIZED POWER CONTROL FOR GRAND COULEE PUMPS–PUMP AUXILIARY SECTION (UNIT P-3 SHOWN.)



LEGEND

[illegible]

generator low [illegible] relay

generator [illegible] load [illegible]

[illegible]

low gate position auxiliary relay

no-load gate position relay

temperature [illegible] switch

motor circuit breaker for [illegible]

[illegible] (energized when [illegible])

motor circuit breaker [illegible] relay (energized when [illegible] is closed)

[illegible]

[illegible] thermal [illegible])

[illegible]

[illegible] relay

[illegible] breaker [illegible] relay (energized when [illegible] is open)

[illegible] generator [illegible]

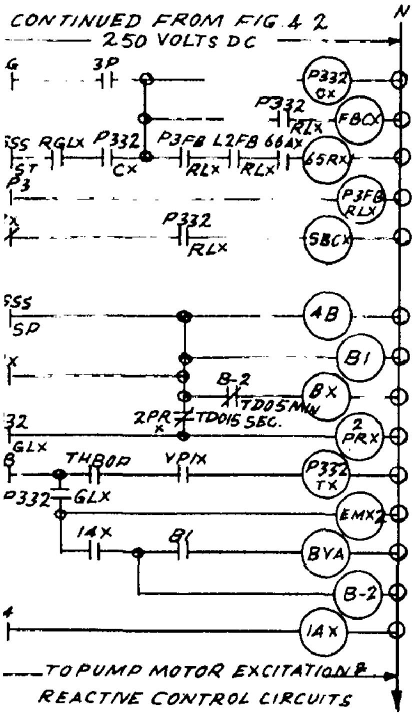
[illegible] relay (energized when [illegible] is open)

[illegible] relay-[illegible]

[illegible] control

[illegible] relay

SCHEMATIC OF GRAND COULEE DAM CENTRALIZED POWER CONTROL PART OF SCHEMATIC FOR A MAIN UNIT GENERATOR ASSOCIATED WITH A PUMPED UNIT



LEGEND

[illegible]

3 [illegible] red

[illegible]

[illegible] selector switch [illegible] in stop position [illegible] in open position [illegible] P-3 [illegible] limit motor [illegible] relay [illegible]

4 SCHEMATIC OF GRAND COULEE DAM CENTRALIZED POWER CONTROL PUMP UNIT START AND STOP SECTION.

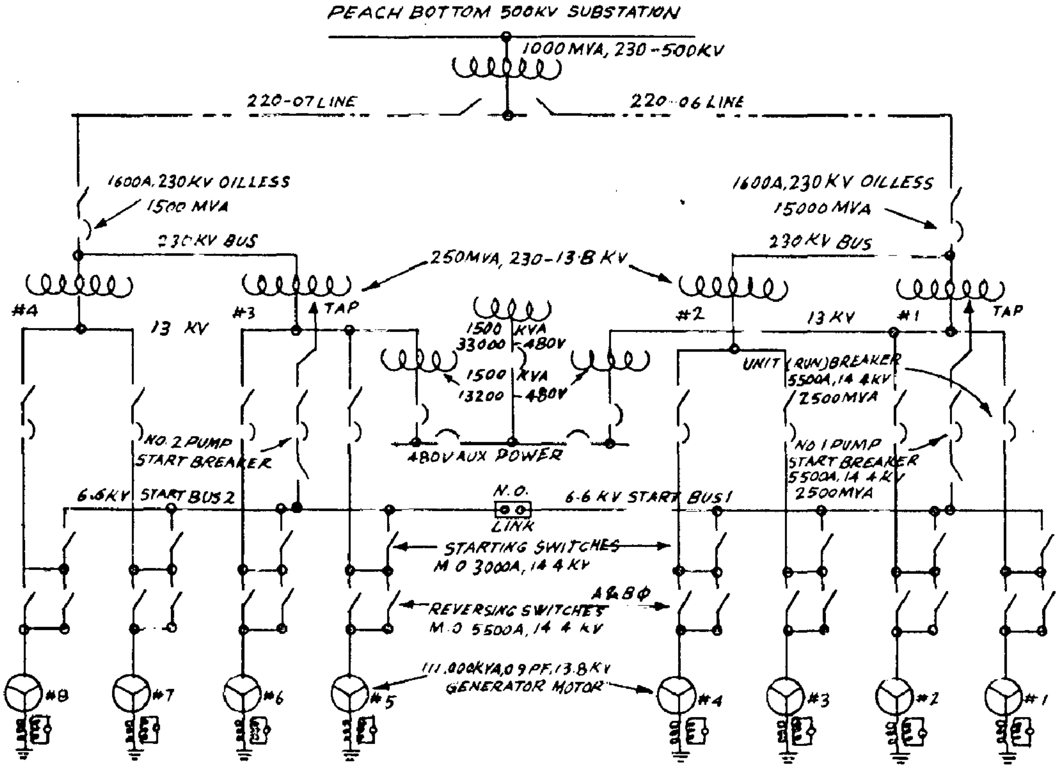
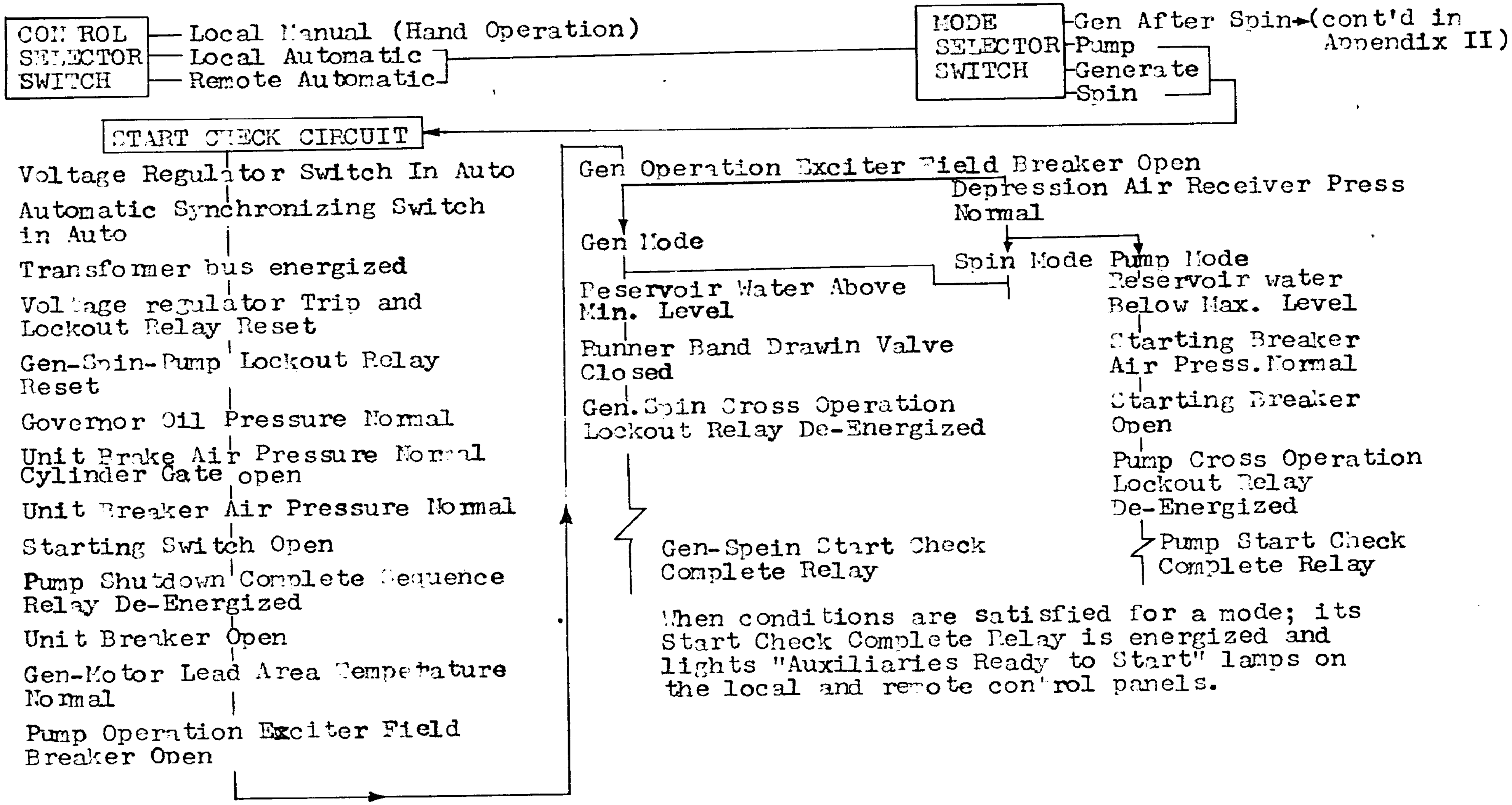


FIG. 4·5 MUDDY RUN STATION. SINGLE LINE DIAGRAM

APPENDIX I

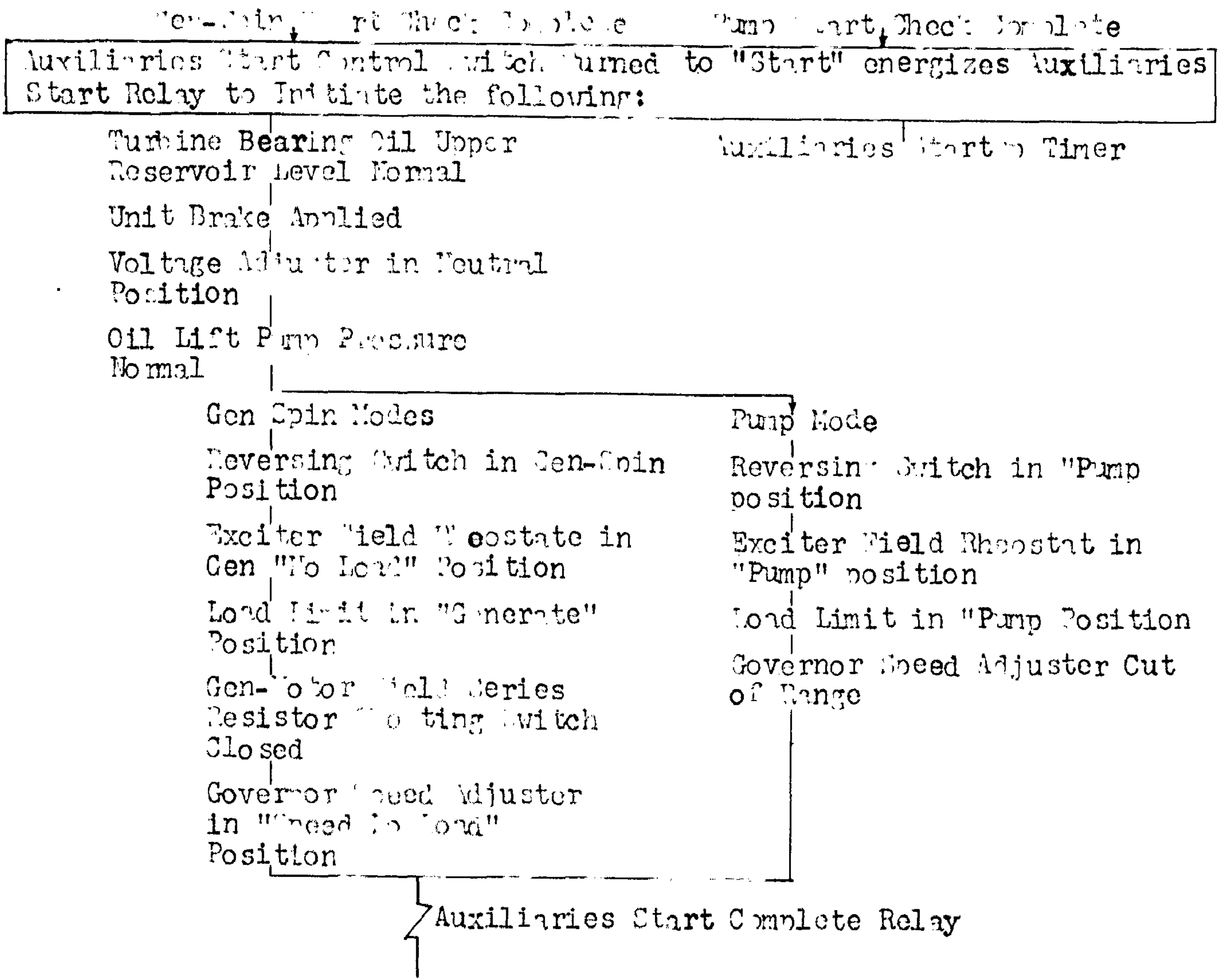
GENERATE-PUMP-SPIN (CONDENSER) START CHECK SEQUENCE- STEP 1



When conditions are satisfied for a mode; its Start Check Complete Relay is energized and lights "Auxiliaries Ready to Start" lamps on the local and remote control panels.

(cont'd)

[illegible] P 2



Gen-Spin, Start Check Complete

Pump Start, Check Complete

Auxiliaries Start Control Switch Turned to "Start" energizes Auxiliaries Start Relay to Initiate the following:

Turbine Bearing Oil Upper Reservoir Level Normal

Unit Brake Applied

Voltage Adjuster in Neutral Position

Oil Lift Pump Pressure Normal

Auxiliaries Starting Timer

Gen Spin Modes

Reversing Switch in Gen-Spin Position

Exciter Field Rheostat in Gen "No Load" Position

Load Limit in "Generate" Position

Gen-Motor Field Series Resistor Shorting Switch Closed

Governor Speed Adjuster in "Speed No Load" Position

Pump Mode

Reversing Switch in "Pump position

Exciter Field Rheostat in "Pump" position

Load Limit in "Pump Position

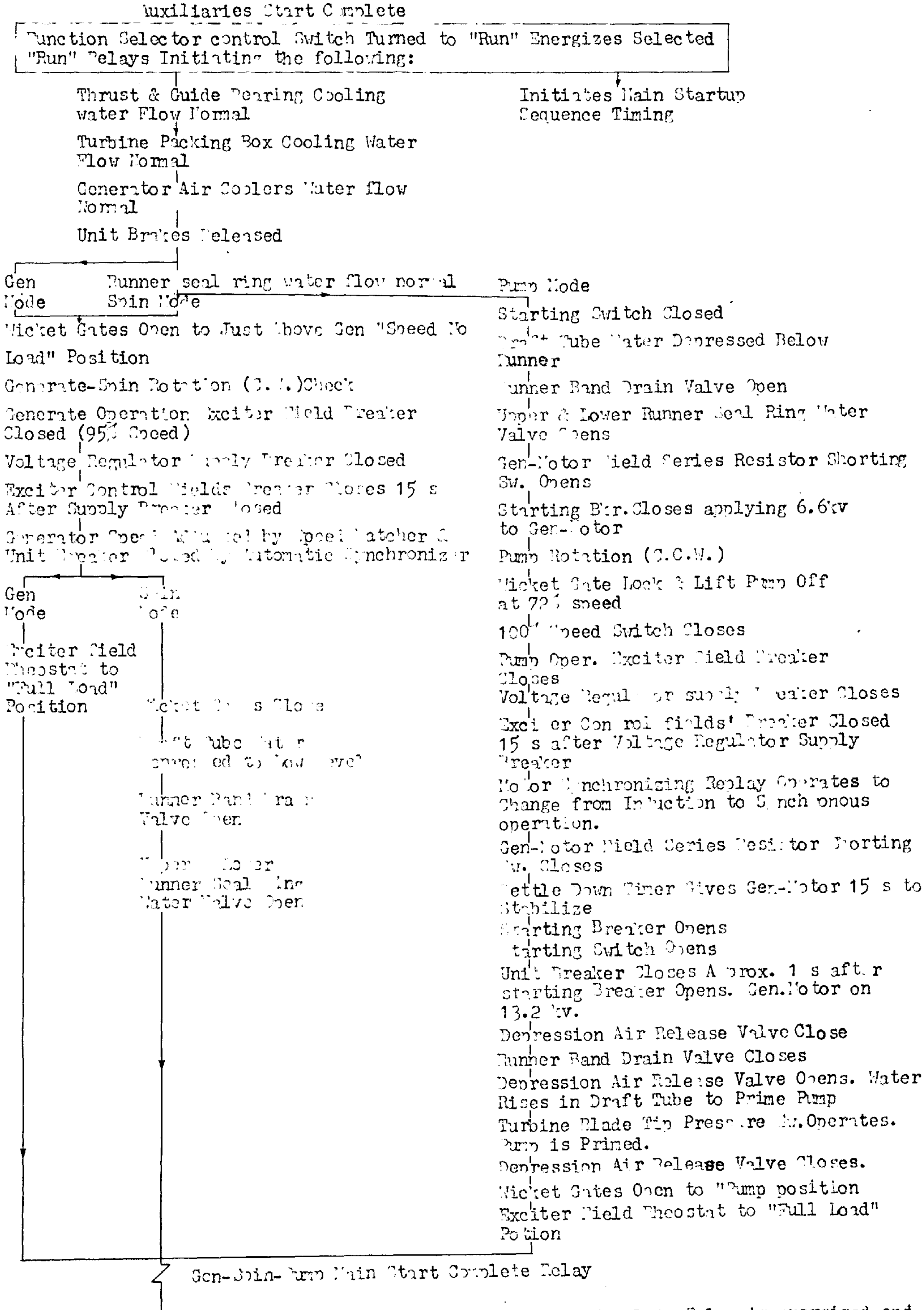
Governor Speed Adjuster Cut of Range

Auxiliaries Start Complete Relay

When conditions are satisfied for a mode, the Auxiliaries Start Complete Relay is energized, and lights the "Unit Ready to Run" lamp on the local and remote control panels.

(Cont.d)

GENERATE-PUMP-SPIN (CONDENSER) MAIN START-UP SEQUENCE- STEP 3



Auxiliaries Start Complete

Function Selector control Switch Turned to "Run" Energizes Selected "Run" Relays Initiating the following:

Thrust & Guide Bearing Cooling water Flow Normal

Turbine Packing Box Cooling Water Flow Normal

Generator Air Coolers Water flow Normal

Unit Brakes Released

Initiates Main Startup Sequence Timing

Gen Mode

Runner seal ring water flow normal

Spin Mode

Wicket Gates Open to Just Above Gen "Speed No Load" Position

Generate-Spin Rotation (C.W.)Check

Generate Operation Exciter Field Breaker Closed (95% Speed)

Voltage Regulator Supply Breaker Closed

Exciter Control Fields Breaker Closes 15 s After Supply Breaker Closed

Generator Speed Matched by Speed Matcher & Unit Breaker Closed by Automatic Synchronizer

Gen Mode

Exciter Field Rheostat to "Full Load" Position

Spin Mode

Wicket Gates Close

Draft Tube Water Depressed to Low Level

Runner Band Drain Valve Open

Upper & Lower Runner Seal Ring Water Valve Open

Pump Mode

Starting Switch Closed

Draft Tube Water Depressed Below Runner

Runner Band Drain Valve Open

Upper & Lower Runner Seal Ring Water Valve Opens

Gen-Motor Field Series Resistor Shorting Sw. Opens

Starting Bkr. Closes applying 6.6kv to Gen-Motor

Pump Rotation (C.C.W.)

Wicket Gate Lock & Lift Pump Off at 72% speed

100% Speed Switch Closes

Pump Oper. Exciter Field Breaker Closes

Voltage Regulator supply Breaker Closes

Exciter Control fields' Breaker Closed 15 s after Voltage Regulator Supply Breaker

Motor Synchronizing Replay Operates to Change from Induction to Synchronous operation.

Gen-Motor Field Series Resistor Shorting Sw. Closes

Settle Down Timer Gives Gen-Motor 15 s to Stabilize

Starting Breaker Opens

Starting Switch Opens

Unit Breaker Closes Approx. 1 s after starting Breaker Opens. Gen.Motor on 13.2 kv.

Depression Air Release Valve Close

Runner Band Drain Valve Closes

Depression Air Release Valve Opens. Water Rises in Draft Tube to Prime Pump

Turbine Blade Tip Pressure Sw. Operates. Pump is Primed.

Depression Air Release Valve Closes.

Wicket Gates Open to "Pump position

Exciter Field Rheostat to "Full Load" Position

Gen-Spin-Pump Main Start Complete Relay

When conditions are satisfied for a mode, its Main Start Complete Relay is energized and lights the "In Service" lamp on the local and remote control panels. Unit is now ready for loading as a generator and/or Mvar adjustments as a generator, condenser, or motor.

APPENDIX II

GENERATE- AFTER- SPIN STARTUP SEQUENCE

Step I Continued from Mode Selector Switch - Appendix I

Gen-Motor operating in Spin Mode

Gen After Spin Start Check Complete Relay

When conditions are satisfied for Gen After Spin Mode Start-Check Complete Relay will be energized because Start-check was previously verified under Spin operation. "Auxiliaries Ready to Start" lamp is lighted on the local and remote control panels.

Step II

Auxiliaries Start Control Switch turned to "Start" energizes the Auxiliaries Start Relay to initate the following:

Exciter Field Rheostat in "No Load" Position

Auxiliaries Start up Timer

Voltage Adjuster in Neutral Position

Governor Speed Adjuster in "Speed-No-Load" Position

Auxiliaries Start complete Relay

When conditions are satisfied for Gen After Spin Mode, Auxiliaries Start Complete Relay is energized. "Unit Ready to Run" lamp is lighted on the local and remote control panels.

Step III

Function Selector Control Switch turned to "Run" energizes Gen After Spin "Run" Relays initiating the folllowing:

Depression Air Valves Open

Gen After Spin Main Startin Timer

Runner Band Drain Valve Closes

Wicket Gates Open to Gen"Speed No Load" Position

Upper and Lower Runner Seal Ring Water Valves Close

Exciter Field Rheotat in "Full Load" position

Gen After Spin start complete Relay

When conditions are satisfied for Gen After Spin Mode, the Main Start Complete Relay is energized to light the "In Service" lamp on the local and remote control panels.

CHAPTER V

RECENT DEVELOPMENTS IN CONTROL OF HYDRO STATIONS

5.1 General: As discussed earlier, the standard practice to provide facilities for the control of the hydro generators may comprise the following.

5.1.1 In manual starting schemes with a two level control, unit control board may be provided near the unit for local control and main control switch boards in the central control room. All control, instrumentation and annunciation are provided by direct wire from the control room for equipment located within the power house. Design is such that all control of the generators and circuit breakers are available in the control room except for starting auxiliaries and turbine and for stopping auxiliaries. Normally the operator at the unit control board on receipt of instruction from the control room operator would start the unit and adjust the speed and voltage. Then he transfers the unit to the control room operator for synchronising and loading. Similarly when a unit is taken out of service, the control room operator first unload the unit and then trips the generator circuit breaker. Unit come to a stop by application of frictional brakes at 30 to 40 percent of the rated speed, automatically. But the auxiliaries are stopped by the operator at the unit control board.

5.1.2 Complete control from a centralised control room by operators at only one level is provided so as to reduce operating personnel. The control engineers brought all controls of the unit in a central control room. A small loss in reliability resulting from unit shutdown for troubles that could have been corrected by local operators was accepted. The cost of modifying the control circuit was marginal as compared to the cost of maintaining a group of operators at the unit control board. With this type of control, only continuously attended place is the control room. The starting of unit may be by sequence-control switch which puts the unit in operation by performing the four sequences in stages, that is, opening the inlet valve and starting auxiliaries, opening turbine gates, synchronising and loading, or by semi-automatic or fully automatic method of starting as described in Chapter III.

5.1.3 Further developments in the control of modern hydro stations both conventional and unconventional, are due to the following general broad considerations.

1. Increasing necessity of providing remote control facilities in generating stations so as to not only economise on the operating personnel, but also for economic optimum operation so as to minimise consumption of water and transmission losses. For this purpose on line computers are being provided. Accordingly some plants have been designed to provide essentially the same control and instrumentation in the central control room

as that would be necessary at the remote control point. The circuits to control them are designed for easy extension to a remote controlling point and to operate automatically. A control scheme for this purpose provided for John Day and Monumental plants (4) is described in the subsequent sections.

2. In the interconnected system, hydro generating plants are normally assigned with the duty of meeting the system peak loads as they are best suited for rapid starting and stopping. Normally hydro unit can be brought to full load from stand still in about two minutes. To reduce this time certain modifications in the control are necessary. These are discussed in the subsequent paragraphs.

3. It is sometimes necessary to change the pumping mode of pumped storage plant to generating mode to meet the system emergency. The normal method of changing the mode of operation takes considerable time. To reduce the change over time a method known as the hydraulic reversal (23) is adopted. This is discussed in the subsequent section.

4. As stated earlier the hydro plants are assigned with a duty of meeting system peak load demands. In such cases units are subjected to a large number of start run-stop cycles in a year. Also a pumped storage plant operating on a daily cycle involves frequent

starting and stopping. With the frictional braking system, the frequent application of brakes result in heavy wear both of brake shoes and steel tracks. The particles released from the brake shoes are carried in the stator casing by the circulating air. These particles stick to the winding insulation and form a layer on the windings. This prevents effective transfer of heat from the winding to the cooling air. It is found that this affects the life of insulation and also increases the maintenance on the stator. These problems are overcome by adopting dynamic braking. This type of braking has been provided on some large machines in Australia (24). The broad feature of the system are described in the subsequent section.

5.2 Control of John Day and Monumental Plants

5.2.1 General : Unit control boards for the control of units are provided near the generators. These are mounted adjacent to the governor and in conjunction with the governor equipment. These boards provide controls, instrumentation and annunciation for complete manual control of the units during testing or in emergency. These switchboards also contain all protective relays and most of the control relays.

5.2.2 Control Room Arrangement: A typical arrangement of the control room equipment is shown in Figure 5.1. The console provides for the control and indication for the main units, station service, and spillway gates. Adjacent to the control room is an alarm recorder which provides control room operators with a coded log of abnormal conditions and plant operations in the sequence of occurrence. The operator's desk located at right angles to the console, provides equipment for communication throughout the project and with the power system despatcher. There is a two panel switch board facing the operator's desk on which are mounted recorders for station quantities.

5.2.3. <u>The Console:</u> A typical console layout for a twenty unit plant [b] is shown in figure 5.2(a). Except for unit load recorders and indicating lights, all control and indication on the console is selective. Only one unit and one breaker can be controlled at a time. The unit 0 indicator and symbol light circuits and the breaker indicating light circuits are connected all the time. The equipment mounted on the left side of the console shown in figure 5.2 (a) provides control and indication for the generators and circuit breakers. The devices mounted in the single bar and below are lighted push-button. Each of these push buttons has four lamps with colour caps and filters over the bulbs. The lamps are mounted behind a white frosted engraved lens which serves as a switch operator. The third from the bottom row of lighted push buttons provides unit selection and white light is the indication of unit running. All the rest of the lighted push buttons above this row provide breaker selection.

A red or green steady light is an indication of whether the breaker is open or closed and a flashing green light is an indication of automatic trip. The next to the bottom row of lighted buttons provide a flashing red light indication of unit shutdown and a flashing amber light which indicates unit trouble operation of these buttons silences an audible alarm, the bottom row lighted push-buttons provides the operation control on the selected unit or breaker.

Indicating instruments, digital indicators showing the unit or breaker selected, and load recorders are mounted on the vertical section of the console. A cabinet mounted on the right side of the console provides digital indicating of water levels.

5.2.4 Control of Unit. Control of unit is either manual or semi-automatic depending on the position of the control transfer switch mounted on the unit control board. When this switch is in local position the unit and auxiliaries must be started manually from unit control board. When the transfer switch is in the control position the unit and auxiliaries are started from the console. Normally the control switch is left in the control position.

5.2.5 Unit Starting: To start unit, the push button engraved with unit number is first depressed. The digital indicator on the vertical section of the console indicates the unit selected and the instruments are automatically connected to indicate quantities for that unit. The start button green light indicates that the transfer switch is in central position. When start button is depressed light changes immediately to red indicating the master start relay energised and latched in. Through auxiliary relays the unit is started and comes up to rated speed and voltage, and instruments indicate the MW the gate limit and generator voltage. The button engraved with breaker number green light on, is then depressed. The breaker selection digital indicator shows the breaker selected. The breaker close button which operates through auxiliary relays to energise the automatic synchronising equipment, then depressed. When the breaker closes the light indication changes from green to red. Then speed level and voltage push-buttons can be operated to load the unit by using the wattmeter and varmeter indications. The unit and the breaker remains selected until the reset button is operated. The two load control buttons next to the reset button place the station of selected unit on or off the area load frequency control signal from the central dispatching centre.

5.2.6 Stopping: Except in emergencies, the unit would be normally unloaded before stopping. To stop a unit the selector button is depressed. This will stop the unit and trip the breaker as the gates pass through the speed-no-load position. If the central transfer switch is in local position, the operator at the console can stop the unit by selecting the unit lowering the gate limit to zero and then trips the generator circuit breaker.

5.2.7 Control Circuitry: The method of control is illustrated in figure 5.3 with a typical circuit for generator voltage control. Operation of unit selector switch energizes transfer relays mounted on unit control board at the generator. The transfer relays connect the equipment for the unit that was selected to a common control cable. The common control cable connects to the equipment of all units in parallel through the transfer contacts. Because of the selective control and instrumentation only one multi-conductor cable is required for all units for control and instrumentation. The circuit used for the selector switches is shown in figure 5.4. This circuit is designed so that only one unit and one generator breaker can be selected at a time and that the operation of the transfer relays can be checked with the indicating lights behind the reset button.

5.2.8 Instruments: Transducers are used for telemetering watts, vars and current to the control room. Generator var indication is obtained by switching the transducer output to the input of an operational amplifier. The var amplifier operates the standard switch board type instrument on the console. The var transducers are also connected to the total station megavar recorder. The watt transducer circuits are similar except that the transducer output leads are all brought directly to the unit load recorders on the vertical section of the console. The output of the watt transducer also provides the unit MW signal for use with the load frequency control equipment. Figure 5.5 shows the block diagram of these circuits. Current telemetering to the control room is obtained from suitable current transformer secondary circuits. These circuits are switched with transfer relays. Similarly gate limits are obtained by slide wire potentiometer and voltage by potential transformers.

5.3 Control of Peaking and Pumped Storage Plants.

5.3.1 General: In the large interconnected system, the thermal plants are often run as a base load plants. They operate at full load as it is uneconomical to run them at any other load. So thermal units seldom provide any spinning reserve in the system. In the interconnected system, the hydro plants are normally assigned with the duty of meeting peaking load demands because they are best suited for rapid starting and stopping due to no thermal restrictions on their rate of loading. In such cases it is necessary to reduce their starting time. The methods recommended for this purpose are as follows (26).

1. Governor oil pressure be maintained at the value necessary for instant starting by means of pressure switch control. The pressure switch must bring into operation an oil pump when pressure in oil air pressure falls below the minimum value, or, the pumping unit must be made to run continuously to maintain required pressure and should be provided with unloader valve in the delivery side to

release the oil pressure when 10 seconds.

2. The main inlet valve may be fitted with limit switches at 30 percent to initiate guide vane or needle opening when starting the unit from the standstill or when changing from the condenser operation to generating mode.

3. High-pressure oil injection pump may be provided to inject the oil into the thrust bearing before guide vane or needles are opened. This greatly reduces breakaway and acceleration time.

4. Automatic synchronisers of the anticipating type employing variable time lead on synchronism according to the speed difference can achieve switch closure in 15 seconds from ready to synchronise.

5.3.2 Hydraulic Reversal in Pumped Storage Plants

In pumped storage plant, the system frequency monitoring relay is normally used to automatically off load the pump when system emergency develops. If the rapid dumping of the pumping load proves insufficient to allow the system to stabilise, it is possible to have quick change over from pumping to generating by a method called Hydraulic reversal(23). The procedure is to allow the water which was being pumped to the upper reservoir to reverse under gravity and bring the pump-turbine to a standstill and then reverse the machine's rotation to the generating mode. From initiation of offloading as a pump to full-load generation takes about 2½ minutes.

5.3.3. **Dynamic Braking.** The large moment of inertia of the rotor may cause the rotating parts of the generating set to continue revolving for a long time after the set has been disconnected from the system and the turbine gates are closed. The prolonged rotation at low speed under unfavourable conditions of lubrication may cause heavy wear of the thrust bearing. Provision for braking is therefore made in all hydro-generators. This is normally done by using a frictional braking system which begins to operate when the rotational speed of the unit has dropped to approximately 30 to 40 percent of the rated value. This takes long time. Besides, it affects, as explained earlier, the life of stator winding insulation.

If the field excitation is maintained at the time when the unit is disconnected from the busbar, the voltage will be induced in the stator winding. If the resistive load is connected across the generator terminals, the rotor has then to supply electrical load in addition to the rotational losses. This brings the unit to a rapid stop. This type of braking is called dynamic braking. In case of large hydro generators the field is supplied with a separate source and a three phase short-circuit instead of resistive load, is applied. The procedure recommended (24) is as below.

1. Stopping sequence is initiated and unit allowed to decelerate naturally until 70 percent speed.
2. The main field switch is then opened.
3. A three phase short-circuit is applied to the generator terminals by a power operated isolator.

4. A six-phase rectifier bank is closed on the main field by a d.c. circuit breaker.

5. The rectifier is energised by closing an a.c. contactor.

6. Current equal to generator full load current flows through the short circuit.

7. When the machine has come to rest, a timing relay reverses all the switching sequence leaving the unit ready to run up again with main field switch closed.

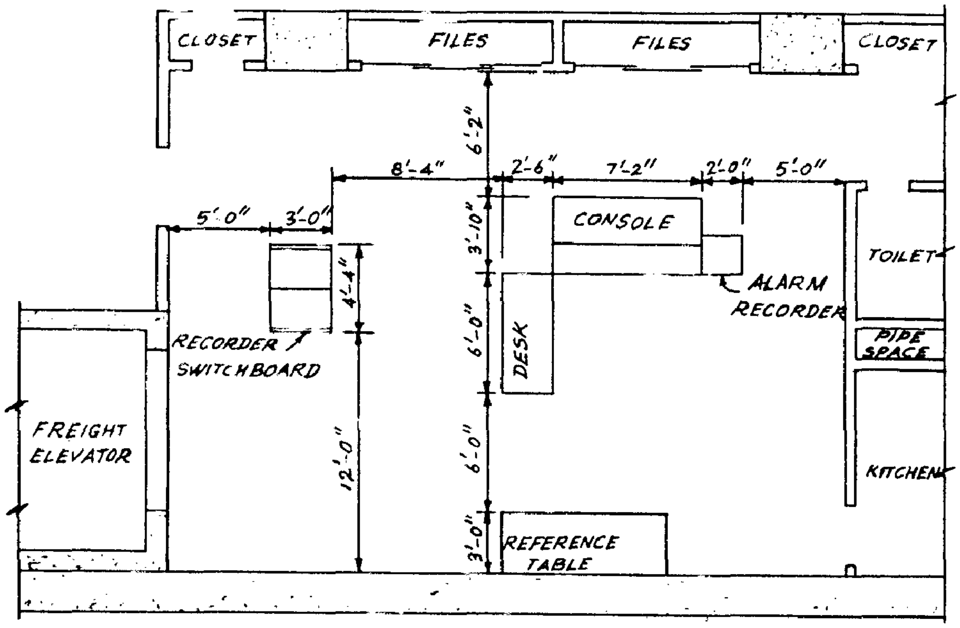
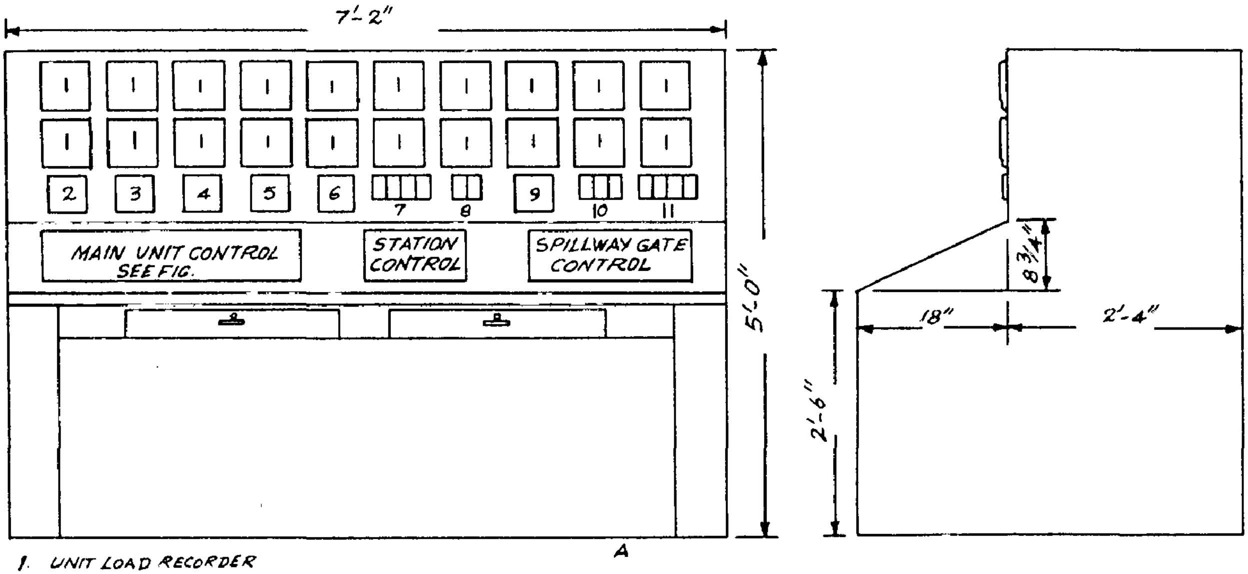
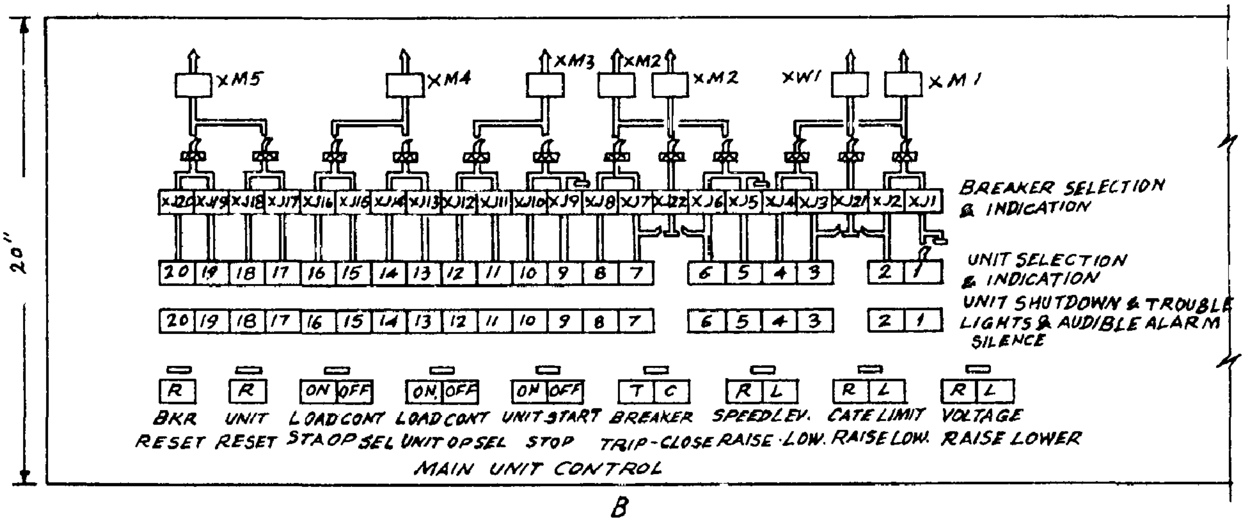


FIG. 5·1 CONTROL ROOM ARRANGEMENT



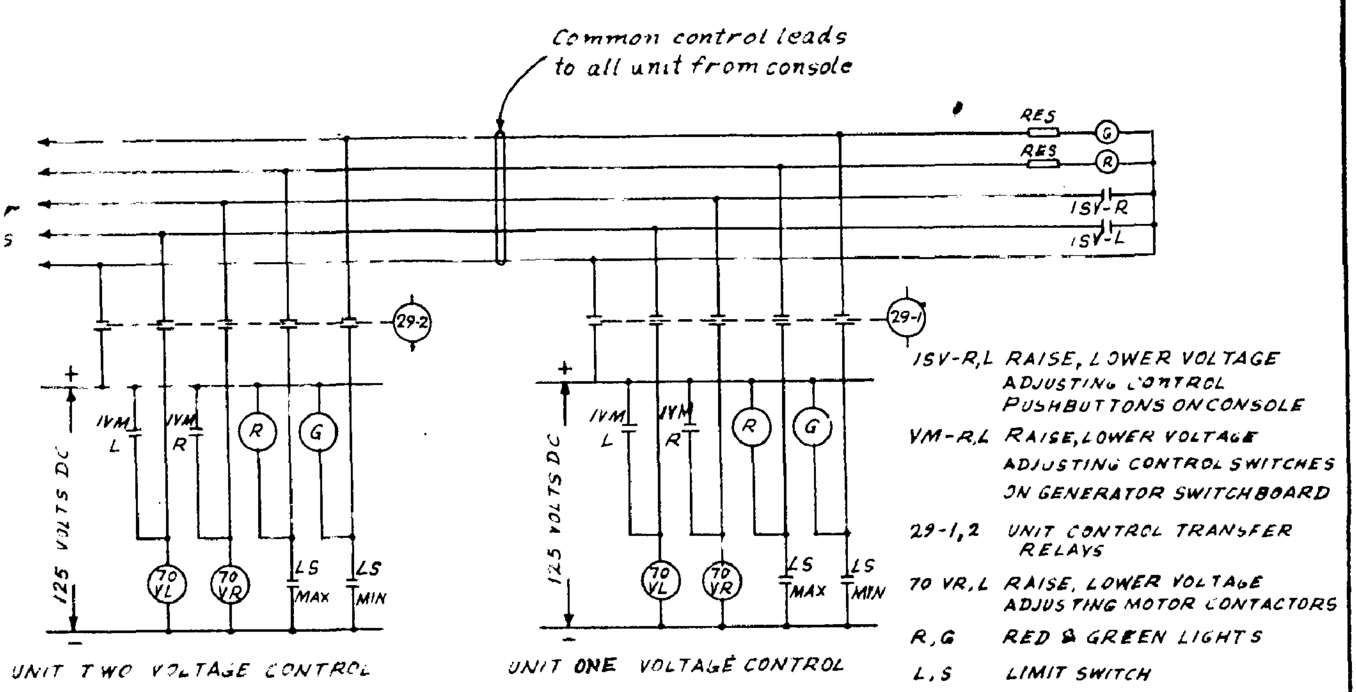
1. UNIT LOAD RECORDER
2. SYSTEM VOLTS
3 UNIT WATTS
4 UNIT GATE LIMIT
5 UNIT VOLTS
6 UNIT VARS
7 BREAKER SELECTION
8 UNIT SELECTION
9 STATION SERVICE AMPS
10 WATER LEVEL
11 SPILLWAY GATE POSITION

(A) CONSOLE ARRANGEMENT



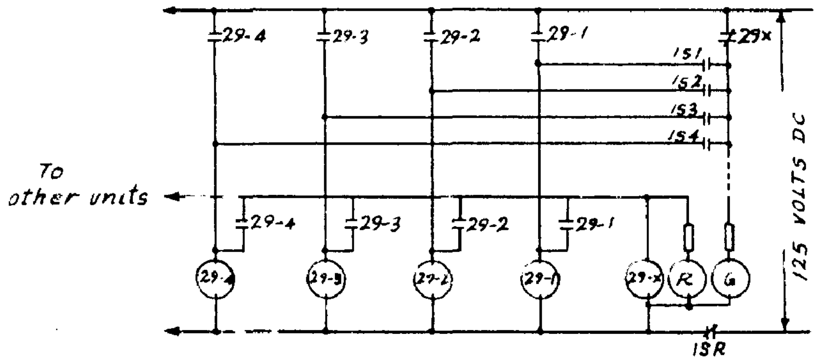
(B) CONSOLE MAIN UNIT CONTROL EQUIPMENT

FIG.5.2 MAIN CONTROL CONSOLE



1SV-R,L	RAISE, LOWER VOLTAGE ADJUSTING CONTROL PUSHBUTTONS ON CONSOLE
VM-R,L	RAISE, LOWER VOLTAGE ADJUSTING CONTROL SWITCHES ON GENERATOR SWITCHBOARD
29-1,2	UNIT CONTROL TRANSFER RELAYS
70 VR,L	RAISE, LOWER VOLTAGE ADJUSTING MOTOR CONTACTORS
R,G	RED & GREEN LIGHTS
L,S	LIMIT SWITCH

FIG. 5-3 GENERATOR VOLTAGE CONTROL SCHEMATIC DIAGRAM



1S1, 2,3,4	Unit selector pushbuttons on console
1SR	Unit reset
29 1,2 3 4	Unit control transfer relays
29X	Unit control transfer interlock relay
R.G	Red and green light

FIG. 5·4 SELECTOR SWITCH CONTROL SCHEMATIC DIAGRAM

CHAPTER VI

[illegible]

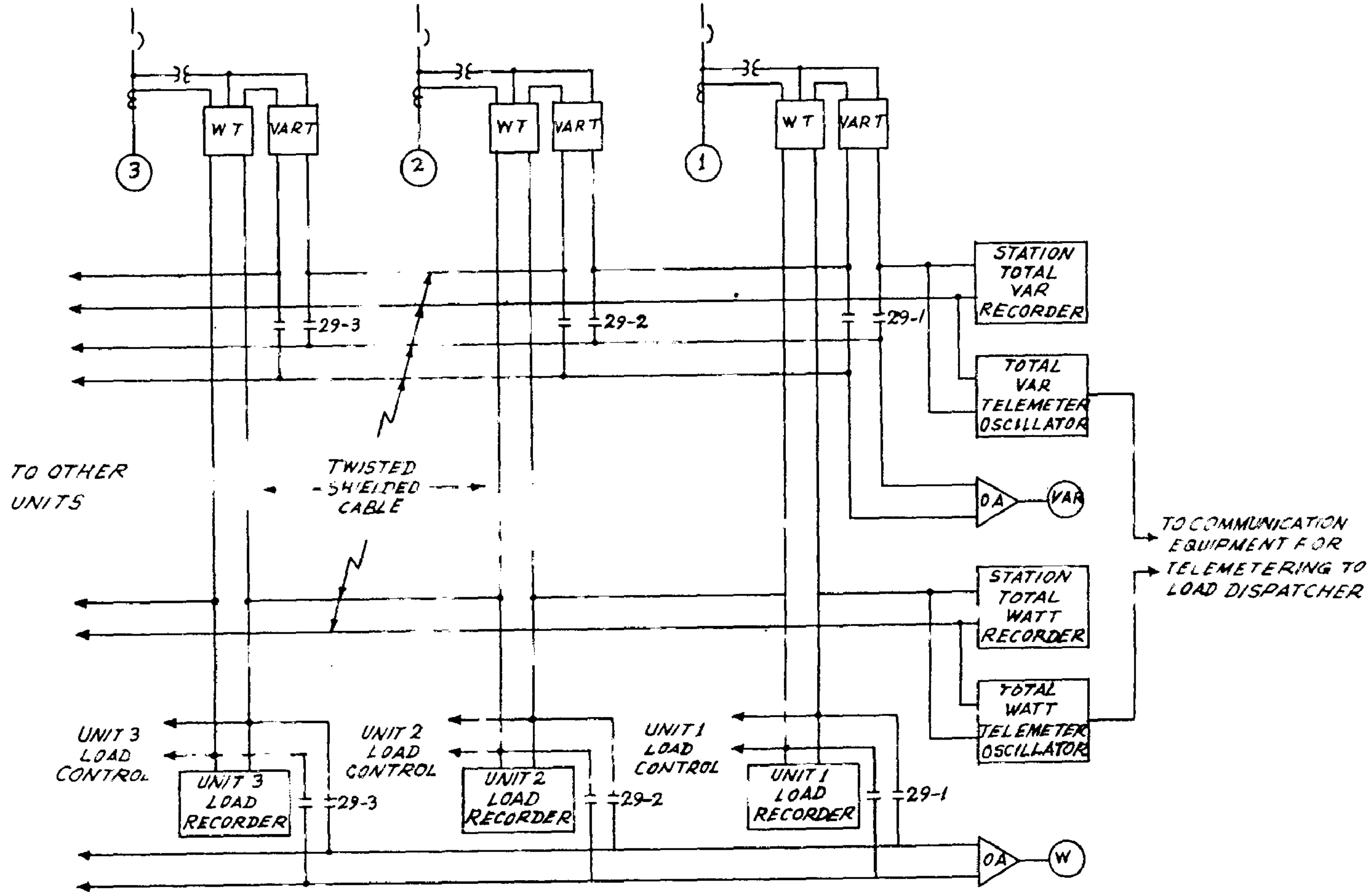
6.1. Remote Control

6.1.1 General: Remote control equipment is often employed for the automatic control of the hydro power stations. Economic considerations usually dictate the use of supervisory control equipment to provide necessary control and indications at remote controlling point. The equipment so manufactured today can be operated over a single pair of telephone wires or a power line carrier channel or a voice radio channel. The cost of providing a number of channels may be considerable and hence the limited width of the available transmission band has to be used very economically. The requirements demanded of a tele-operation system differ very widely in terms of the following three essential features(4).

1. Volume of information to be transmitted
2. Required rate of transmission
3. Required reliability of transmission (falsification or loss of information)

6.1.2 Importance of Remote Control: Interconnected power systems work on three basic requirements, viz.

1. To maintain a balance between the generated output and ever varying customer load.
2. To obtain the required generation at minimum cost.
3. To account for energy which has been exchanged with neighbouring area.



WT	WATT TRANSDUCER
VAR T	VAR TRANSDUCER
W	WATTMETER
V	VARMETER
OA	OPERATIONAL AMPLIFIER
29-1,2,3	UNIT CONTROL TRANFER RELAYS

FIG.5·5 BLOCK DIAGRAM OF WATT AND VAR TELEMETERING & RECORDING

CHAPTER VI

[illegible]

6.1. Remote Control

6.1.1 General: Remote control equipment is often employed for the automatic control of the hydro power stations. Economic considerations usually dictate the use of supervisory control equipment to provide necessary control and indication at remote controlling point. The equipment as manufactured today can be operated over a single pair of telephone wires or a power line carrier channel or a radio channel. The cost of providing a number of channels may be considerable and hence the limited width of the available transmission band has to be used very economically. The requirements demanded of a tele-operation system differ very widely in terms of the following characteristic features(5).

1. Volume of information to be transmitted
2. Required rate of transmission
3. Required reliability of transmission (falsification or loss of information)

6.1.2 Importance of Remote Control: Interconnected power systems work on three basic requirements, viz.

1. To maintain a balance between the generated output and ever varying consumer load.
2. To obtain the required generation at minimum cost.
3. To account for energy which has been exchanged with neighbouring area.

Remote generation control and economic dispatch computer control are employed to handle these requirements. Efficient operation of the system is possible only if upto date information regarding generator outputs, load flows and other operational data are available in the central controlling station. Since distances involved are very large such information can only be obtained over the telemetering equipment. Telemetry has made possible to bring controls, indications and metering of remote generating stations to a central controlling station.

6.1.3 Facilities over the Channels: The facilities to be handled over the channel include the following(24).

1. Supervisory remote control of plant and switchyard.
2. Remote indication of switchgear positions, alarms, gate positions, etc.
3. Telemetering of electrical and hydraulic quantities.
4. Intertripping of feeder end-breakers.
5. Phase comparison feeder protection
6. Telephony, speech and dialling circuits.
7. Teleprinters.

6.1.4 Facilities required for Hydro Power Stations: The normal facilities required at the remote point for controlling any generating station are (1).

1. Start-stop control of generators with supervision of generator circuit breaker.
2. Control of governor speeder motor with simultaneous telemetering of real power output.

3. Control of governor gate limit motor with simultaneous telemetering of gate limit position.
4. Control of regulator voltage adjusting rheostat with simultaneous telemetering of reactive power.
5. Control and supervision of other circuit breakers in station.
6. Supervision of generator shutdown.
7. Supervision of annunciation.
8. Supervision of local remote transfer switch.
9. Telemetering of bus voltage.
10. Communication.

Other functions which may be performed by the supervisory control equipment are dependent on the requirements of the particular installation. The following additional functions are some times provided by the supervisory control equipment

1. Telemetering of head water level.
2. Control of governor speed droop with telemetering of speed droop position.
3. Control and supervision of head water gates or valves.
4. Control of diversion and spillway gates with simultaneous telemetering of gate positions.
5. Supervision of door giving access to hydroelectric station when station is unattended type.

The figure $^{6.1}$ shows a typical overall arrangement of the supervisory control equipment.

Although supervisory control is closely associated with power engineering, it is essentially a branch of tele-communication engineering. It is, therefore essential to know the types of telemetering and method of data transmission. These are described in the following sections.

6.2 TELEMETERING

6.2.1 General:

Telemetering means metering or measuring of a quantity at a distance from it (23). If the measured quantity (known as measurand) itself or its electrical replica is transmitted at the other end, the method is effective for very short distances only. The reasons for this limitations are, (i) there would be large energy losses in the communication line, and (ii) there would be increased error due to variations of the communication line parameters with changes in atmospheric conditions. To overcome these difficulties, instead of measurand another auxiliary quantity (known as transmission quantity) derived from the measurand is transmitted over the communication channel. Telemetering thus involves sensing the measurand, deriving suitable transmission quantity from it, transmission on the channel, and displaying it at the receiving end.

6.2.2 Basic Parts of Telemetering:

The basic parts of the telemetry are:

1. Transducer: It is a sensing device converting the measurand into analog quantity that can be easily handled by the transmitter.
2. Transmitter: It transforms analog quantity into a suitable transmission quantity and transmits it on the communication channel.
3. Communication Channel: It is a link between the transmitter and the receiver and is one of the

following form.

(i) A physical link, cable or coaxial line

(ii) A radio link.

b. Receiver. It receives the transmission quantity and transforms into a form in which the information is to be utilized.

6.2.3 Types of Telemetry. Telemetry systems are divided into the following two groups according to the nature of the transmission quantity employed.

1. Intensity System: In this the magnitude of voltage of one unit to be transmitted over the connection line varies with the measurand. Direct current is used for transmission so that the inductance and capacitance of the connection line which is invariably physical link for this system, have no influence. Intensity systems are used for comparatively short transmission distances since for long distances errors caused by variations in the line parameters increase greatly. For this reason intensity telemetry system is often called as proximity telemetry system.

2. Frequency and Pulse Telemetry Systems. The transmission quantity for these systems is an alternating current of variable frequency or pulses of variable characteristics. In these the numerical value of the measurand is transmitted in the form of definite pulse

combination in accordance with some digital code. This is known as pulse code or digital telemetry. In the analog telemetry system characteristic of pulses or r.f. signal frequency varies analogously with the movement. Various methods in this type of telemetry are (26).

1. A.F. frequency system
2. Pulse number or pulse counting system.
3. Pulse duration or pulse width system.
4. Pulse frequency system
5. Pulse phase or pulse spacing system.

6.2.4 Multiplexing: In many communication systems, signals are required to share the same channel—sharing or multiplexing is achieved by either dividing up the frequency spectrum or by dividing up time. In the former method signals are stacked on top of each other in frequency. For example, if a channel occupies a band width of 4 kHz then one channel can occupy the frequencies zero to 4 kHz. A second channel may then be translated up in frequency to occupy a band 4 kHz to 8 kHz. These two channels are then transmitted simultaneously in a band width of 0 to 8 kHz. This method of multiplexing is termed as frequency division multiplexing (f.d.m.)

Time division multiplexing (t.d.m.) is achieved by sampling the information, e.g., by noting the amplitude at equal intervals of time on one channel and then the next and so on. Thus transmitting each sample in turn.

6.2.5 Modulation: In many cases the information signal is in unsuitable form for transmission between one point to another and some kind of translation to a higher frequency must take place. This process is termed modulation and retranslation back to the original signal is termed demodulation. There are two types of modulation and two types of waveform are used to carry the modulation. The waveforms used are continuous sine wave carrier and a pulse stream. The types of modulation are:

1. Analogue Modulation: It is the process of varying (modulating) a parameter of a waveform in sympathy with an information waveform. The carrier to be modulated is usually either sinusoidal or a pulse stream. The modulating signal waveform may be used to vary the amplitude of the carrier called amplitude modulation (AM), or it may be used to vary frequency of the carrier, called frequency modulation (FM), or to vary phase angle of the carrier, called phase modulation (PM). The modulating signal waveform may also be used to vary height of the pulses in pulse stream carrier, called pulse amplitude modulation (PAM) or to vary width of the pulses in carrier called pulse width modulation (PWM) and so on. In all these modulation methods the precise variation of the signal waveform is used to vary a parameter on the carrier and because the variation is continuous the modulation is called "analogue modulation".

2. <u>Digital Modulation</u>: In this only a fixed number of defined and discrete amplitudes can be transmitted from one point to another. The modulating signal must first be processed in order to define it in terms of the fixed number of amplitudes. The advantage of this type of modulation is that the receiver can have prior knowledge of the fixed amplitudes and need only make a decision as to which amplitude is being transmitted at a point in time.

6.2.6 <u>Types of Data Transmission</u>: Depending on the method of modulation used the telemetering is divided in the following two main types(1).

1. <u>Analogue Data Transmission</u>: In this analogue modulation is employed. To illustrate this, take a typical example of load telemetering as encountered in the dispatching office. The equipment required for this are shown in figure 6.2. The transducer converts the measured variable into a d.c. signal which varies proportionately with the line segment power flow. Power flow can vary from (-) 100 MW out of the system to (+) 100 MW into the system. A few discrete values are indicated in the figure. Therefore, transducer output can assume any value between (-) 50 to (+) 50 millivolts depending on the tie line flow. The analog transmitter converts the d.c. input signal into a variable frequency output signal. As shown it varies from 10 to 30 cps proportionately to the input signal. This

tone intermediate channel equipment which transmit the variable frequency to the analog receiver at the other end of the line. The transmitter is called analogue transmitter because its output is analogous to its input. The receiver converts the varying frequency signal back to a d.c. signal which can then operate a recorder, indicator or as a feedback signal for control purposes.

2. Digital Telemetering: This uses the same telemetering transmitting set (see figure 6.1). The [illegible] unit [illegible] of the receiving [illegible] definite numerical value on a digital dial form or as a number on a type written log sheet. This number is actually formed at the transmitted end. The system operates with the same transformer to convert a.c. [illegible] to a proportional d.c. signal. This is fed to digital (A to D) converter [illegible]. The digital output is in decimal or various forms of binary codes. Usually a binary coded decimal (BCD) code is desired. Binary code decimal means that each decimal digit is converted individually into a binary code. Binary is chosen because any number can be represented by 0's or 1's which in turn can easily be handled by electronic equipment since only two possible conditions [illegible] the 0-1-0-1 designations are called bits. It takes four of these to represent any decimal number from 0 through

9 (see Figure 6.3). Assume the interchange value is 87.5 MW. The converter would change an analog signal proportional to 087.5 MW into 16 separate bits of information (4 for each digit) which would appear as 0000-1000-0111-0101. The digital transmitter would then convert this binary readout into a digital code which can then be transmitted over the intermediate channel equipment to the digital receiver. One way to do this is to scan each bit in sequence and transmit a short pulse where zero appears and a long pulse where 1 appears. The transmitted message would then be a fixed number of long 1 and short 0 pulses which represent the number 087.5. The digital receiver takes the pulse code, verifies it, and converts the information to an output suitable for the device at the receiving end. If the device is a digital indicator, the receiver would present its output in decimal form.

Normally the cost of digital compared to analog would be too high to allow it to be used for telemetering only one quantity. The more normal application will have a scanning device prior to the A to D converter which would consecutively scan each of a number of transducers as shown in figure 6.4. The transmission in digital is not continuous as in the case of analog.

6.3 Factors affecting Selection of Analog and Digital

6.3.1 End Format of Data: If the information is required for indicating or recording or automatic logging or for control purposes, any of these can be achieved with either type. However, analog telemetering with continuous output signal lends itself particularly to indicating instruments and control functions. If the readings are to be logged, processed or fed into a digital computer then the readings could be taken as is from the digital receiver.

6.3.2 Accuracy: To arrive at an accuracy value for any system the errors from each part of the system shall be included. Since the transducer is common to both schemes, it can be eliminated from the accuracy comparison. Analog telemeters have an accuracy of ± 0.5% of full scale. Analog to digital converters can have an accuracy of ± 0.05% of point. The digital transmitter itself adds no inaccuracy.

6.3.3 Stability: Measurement of load data such as watts, vars, volts and amperes are necessary to the load despatcher. Their accuracy is also must. However high accuracy without good stability is particularly worthless. Analog telemeters have an excellent stability. In digital telemetering system the stability must be sought by the selection of proper A to D converters.

6.3.4 Speed: Speed is in two categories (i) speed of transmission, and (ii) speed of response. Transmission speed is how fast the transmitter can communicate with the receiver. Analog equipment is of low speed (normally

6.3.6 Channel Requirements: Both analog and slow speed digital equipment can use a low speed channel which is less expensive than the high speed. Usually analog telemeter transmits a reading continuously. Hence it occupies low speed channel full time. The slow speed digital transmits sequentially. Therefore it can send many readings over a single low speed channel. If more than one quantity is to be telemetered continuously with analog equipment either we use the required number of low speed channels or use one high speed channel and multiplex the signals at different frequencies. A high speed channel usually has a 400-3000 cps. frequency range. Thus 10 different readings could be transmitted simultaneously by multiplexing at 100 cycle frequency spacing. High speed digital equipment usually requires the full range of a high speed channel. Therefore, its channel costs are more than those for low speed digital or analog.

6.3.7 Cost Comparison: If there is only one reading to be transmitted then analog will be cheaper. If many different readings are to be telemetered digital can be less expensive; this assumes that all readings are to be logged. If all readings are to be indicated, the additional storage equipment would substantially increase cost per reading. Some times a problem in digital telemetering is scaling, i.e., a range of different variables is such that they have to be scaled up or down, and brought to a common base to utilize the A to D converter. Hence scaling would add considerable cost to the operates below 35 cps). Digital equipment comes in low or high speed ranges. The high speed range begins at about 400 cps and goes over 2000 cps. Speed of response is how long it takes the receiver output signal to respond to a change in the transmitter input signal. A good analog telemetering system will follow 99% of a change in the measured variable in less than one second. This is particularly instantaneous if the signal is being used for record or control purposes. A low speed digital system requires a few seconds to obtain a new reading. This is not too long to wait for a slowly changing reading such as gas or water level. It is definitely too long if the telemetered signal controls generation. High speed digital equipment can telemeter readings so rapidly within a second making them appear to be continuous. It can bring in up to 50 to 100 per second. The slow speed system would take 5 to 10 minutes to do so.

6.3.5 Reliability and Maintenance: More parts in any system means more trouble to be encountered. To telemeter single reading analog would be more reliable than the digital. When a scanner or a programmer is added to the digital equipment to scan a number of readings there are less components per function compared to an analog system. However, in this case the failure of one item would cause a loss of all readings. Spare analog equipment can be installed to use in emergency for vital informations, and during normal operation same could be used for other non-urgent jobs. Such a transfer is not practical with digital equipment.

6.3.6 <u>Channel Requirements:</u> Both analog and slow speed digital equipment can use a low speed channel which is less expensive than the high speed. Usually analog telemeter transmits a reading continuously. Hence it occupies low speed channel full time. The slow speed digital transmits sequentially. Therefore it can send many readings over a single low speed channel. If more than one quantity is to be telemetered continuously with analog equipment either we use the required number of low speed channels or use one high speed channel and multiplex the signals of different frequencies. A high speed channel usually has a 400-3000 cps. frequency range. Hence 10 different readings could be transmitted simultaneously by multiplexing at 100 cycle frequency spacing. High speed digital equipment usually requires the full range of a high speed channel. Therefore, its channel costs are more than those for low speed digital or analog.

6.3.7 <u>Cost Comparison:</u> If there is only one reading to be transmitted then analog will be cheaper. If many different readings are to be telemetered digital can be less expensive; this assumes that all readings are to be logged. If all readings are to be indicated, the additional storage equipment would substantially increase cost per reading. Some times a problem in digital telemetering is scaling, i.e., a range of different variables is such that they have to be scaled up or down, and brought to a common base to utilize the A to D converter. Hence scaling would add considerable cost to the digital system. However, as the readings per remote location increase digital equipment costs less per reading than a comparable analog system.

6.4 Analog Application

6.4.1 Continuous Analog: It is used where unit or station generation, interchange MW and primary bus voltages must be displayed or recorded continuously. It provides a continuous net interchange MW signal for automatic load control equipment. Its continuity, accuracy and speed of response are essential and it costs less than the comparable digital equipment.

6.4.2 Selective Analog: When supervisory control is required for remote stations it is convenient to combine an analog telemetering system with control and use it for selective telemetering (see figure 6.5). Here two way communication is involved. Therefore, an analog transmitter can be switched to any transducer by the central control room operator. This reading is indicated at the central station until removed by the operator or automatically by supervisory equipment. There is no limitation to the number of readings which can be selected via supervisory equipment over one channel. The cost of additional supervisory point is usually small when compared with the analog telemetering equipment.

6.4.3 Scanning Systems: To telemeter multiple analog quantities non-continuously over a single channel the scanning system shown in figure 6.6 is used. The scanner (programmer) sequences each transducer's output signal into the analog transmitter at a preset rate, about 5 seconds per point.

After one sequence, the scanner momentarily removes the signal from the channel. This makes the receiver signal failure relay to drop out. This action synchronizes the system. This system is used only to telemeter slowly changing or non critical variables. Time between updating a point depends on the total number of points and can be as long as 2 minutes with 24 points. If the individual indication is desired rather than recording all readings, modify figure 6.6 as shown in dotted lines.

6.4.4 Alarm System: Alarms can be intermixed with the telemetered variables in the scanning system by using the multipoint recorder with a high limit switch. The alarms hit the transmitter with a millivolt value higher the maximum value of the input range unit. This drives the recorder off scale and picks up the limit and lights an alarm light.

6.5 Digital Applications

KW and KWhr telemetering requires the accuracy of digital equipment. The centrally displayed data must exactly duplicate remote meters readings. It is simple to install contact devices on the watt hour meter to produce a digital type pulse for a decimal value of watt hour. So no analogue to digital converter is required. The only equipment required is digital transmitter to transmit these pulses without error to the central office. The trend in power telemetering is towards high speed data collection systems. When more than one remote location is involved calling control channel can prove to be more economical since these permit utilization of common receiving and logging equipment.

6.6 Reliability of Transmission

As mentioned earlier, the requirements as regards reliability of transmission vary very widely, and the susceptibility of the various forms and methods of transmission to interference also differs. The disturbances themselves differ widely in amplitude and nature. Reliable transmission is more important than the speed, but by encoding the information and building in degrees of redundancy reliability can be increased effectively at the expense of speed. By encoding, it is possible to make the information less sensitive to interference while it is being transmitted. However, the information must be available in digital form. The simplest digital form is binary code. Analog to digital (A to D) conversion at the transmitting end and D to A conversion at the receiving end is very simple and inexpensive. Binary code is widely used with telemetered system. The pure binary form loses its advantages as soon as the measurements are no longer fed to indicating instruments or recorders but are printed out or presented on the digital display tubes. Converting a quantity which is in binary form into a decimal number having more than one digit is extremely expensive. In such cases it is best to transmit the quantities from the outset in decimal form. Codes based on the decimal system are being increasingly used as more and more transmitted quantities have to be displayed or fed to a computer in decimal system.

It is absolutely essential to safeguard the information against any loss of bit. This can be done by introducing redundant bits; a so called parity bit is appended to each number or to the whole group of numbers. The parity bit makes the 1 bits of the code to an even number. Transmission can be safeguarded from errors by this simple method. If an odd number of 1 bits arrives at the receiving end, the information is rejected as false. The best known code for error detection and correction is the hamming code. It consists of several overlapping parity checks. Another widely used method to avoid falsification is to send the same information more than once, successive messages must be checked at the receiving end for incidence. This comparison can be used with equivalent two way links. The message is returned by the receiver to the transmitter where it is compared with the original message. If they are the same, a go-ahead signal is given, if not, the transmission is repeated.

6.7 Types of Remote Control

6.7.1 Simple direct wire control: Simplest form of supervisory control is the direct wire method which is economic for a distance upto approximately one mile from the control point. Such schemes make use of multicore pilot cables between the apparatus which is to be controlled and supervisory control equipment. By their simplicity and avoidance of coded signalling, these are particularly attractive. Such schemes usually operate from a d.c. supply derived from a battery at the control station. In case instances, however, the supply may be taken from the remote substation. With direct wire schemes, the provision may be easily made for simple metering facilities. Direct wire metering enables continuous reading of quantities.

6.7.2 Control over pilot wires: In cases where control has to be exercised over relatively long distances, direct wire schemes are prohibitive due to the high cost of providing and laying the necessary multicore cables. One solution to the problem is to restrict the number of cores to an absolute minimum, and carry out all signalling over these few wires by means of a system of coded signals. Another solution is to use separate frequency channels superimposed on the existing power lines.

6.7.3 Voice frequency signalling systems: Whilst direct current is normally used in supervisory control schemes, the use of voice frequency currents permits control over much greater distances. In fact, in the case of very long lines, and where amplifiers must be used to reduce the over all attenuation, d.c. signalling can not be employed(25). The method of signalling by voice frequency is very flexible for supervisory control purposes. Multi-frequency working is generally used, and has many advantages including maximum speed of operation. In the case of multi-frequency working discrimination between incoming and outgoing is effected by utilising two different frequencies; while with single frequency working, discrimination is accomplished by means of short and long pulses and therefore somewhat slower in operation.

6.7.4 Carrier Current Control on Power Lines

When the stations are separated by considerable distances, the cost of installing pilot wires may render remote supervisory control uneconomical. In such cases carrier currents are employed and superimposed on the power lines. A full range of facilities can be provided over the carrier channels. Carrier currents superimposed on the power lines provide an inherently reliable channel since, firstly, power lines have a very high factor of safety, and secondly, even if breakages of the line occur, carrier communication may still be possible. The control scheme of TVA's Raccoon Pumped storage plant(11) utilising this type of control as secondary with [illegible] signal control [illegible] for a [illegible] station by [illegible] (5) are described in the subsequent paragraphs.

6.8 Remote Control of [illegible] Pumped Storage Installations.

6.8.1 Example: A very recent example of large scale remote control operation is that of TVA's Raccoon Mountain pumped storage hydro project(21). There are four turbine pumps each rated at 425 MVA as generator and 5,40,000 HP as pump. The units are housed in a cavity 305 metres below the ground. The switchyard is approximately 2.4 km. This involves a vertical shaft of 305 metres long. The switchyard is connected to the TVA distribution system by one 500 kV and one 161 kV lines.

6.3.2 Control System: The plant is supervisory controlled from an Area Dispatch and control center (ADCC) located at Chickamauga Hydro Plant about 16 Mi from the Raccoon plant. This is one of the five such centers employing direct digital control scheme. These centers are middle link in a three level control consisting of

1. Power system control center (PSCC) located at the Chickamauga.
2. The Area Dispatch and Control Centers (ADCC) and,
3. the remote stations which may be either hydro plants or substations as shown in figure 6.7 (a).

In addition to the usual parameters and problems inherent to the design of supervisory control for generating plants, Raccoon Mountain has two other major problems. They are:

1. the powerhouse and switchyard controls are widely separated , and
2. the units must be controlled in two modes-generating and pumping.

6.3.3 Control of the Power Plant: Two sets of remote control supervisory equipment are used. One located at the powerhouse and the other at the switchyard as shown in figure 6.7(b) for data acquisition and supervisory control. Local manual controls are provided for power plant control near the units. Also controls are provided at the control room for the switchyard equipment. As a result of locating two sets of supervisory control equipment, cables for metering and controls between switchyard and the powerhouse are eliminated. Figure 6.8 shows the amount of data which the remote terminals at the powerhouse are required to handle. Both sets are required to handle analog and digital telemetering, sequence of events recording, visual and audible annunciation, supervisory control and status indication.

Operation recording equipment is provided for the switchyard and the powerhouse areas. This equipment detects the opening and closing of power circuit breakers, motor operated disconnect switches, the occurrence or the removal of these conditions. This information is transmitted via the data channel to the master station where it is recorded. Each trouble condition is preceded by a three character address to identify the remote station and the real time of the occurrence. Each trouble condition is stored in memory alongwith real time in the sequence of occurrence. The alarm events are also annunciated locally on a visual and audible system at each location.

The supervisory control equipment use the select-check-command-check operating procedure. The special purpose supervisory control points are required for generator load control, generator voltage setting and pump motor power factor setting. The output contacts which are closed for at least 100 ms. are capable of switching a minimum of 100 volt amperes at 40 volt D.C.

The Tucson Mountain computers communicate with the TCC computers via 1200 baud modems over a microwave channel as the primary path and a power line carrier channel as the secondary path. The data is transmitted from the plant to the TCC on a continuous basis with all telemetering data and at least ten alarm events transmitted every two seconds.

6.9 Supervisory Remote Control of Pumping Plant

6.9.1 Lenkurt General has recommended "Tone Signals" to monitor and control a water pumping station (6). Arrangement of equipment and frequency allocation for various activities are shown in Figure 6.9. Control is via frequency-shift equipment utilizing three frequencies in each control signal. This equipment is three state i.e. no-shift-center-tone. The center frequency is transmitted during the quiescent condition as a guard tone and only mark and space are used for control information. As shown in Figure 6.10, the operator sets a command selector switch and then pushes an operate button. The selector switch sets up a circuit before the command can be sent. The operate button keys three tones (i.e. shift three frequencies) which identify the address of the controlled point and the function to be performed. This identification is made at the remote location by a matrix decoder which determines the correct path for the command circuit closure. The circuit closure is made through relays in the interposing relay panel (IRP) which provide system control logic.

6.9.2 Control: To illustrate the control of the pump in "Hand condition", place selector switch in "Hand position" as shown in figure 6.10. This prepares the control center circuit. Press the operate button. Now, the 1075 cps and 1375 cps tone transmitter shifts from center frequency to space frequency and the 1675 cps tone transmitter shifts from center frequency to mark frequency. Now the control desk disagreement light will be lit if the supervisory information reported back from the pumping station indicate that the pump is in a condition other than "Hand".

The three signals go to matrix decoder when the operate button is pushed. In the matrix decoder the 1375 cps space and 1675 cps mark select relay MR-1. When contacts of MR-1 close, the circuit is ready to accept an operating command as shown on TTP diagram. That is having sent the 1075 cps space signal, a circuit closes from T-2 through 1075 cps space relay contact and through the contact of MR-1 to TP- 11. TP - 11 therefore energizes TP - 12 which latches in both TP - 11 and TP - 12. This closes contacts at terminals T-1 and opens contacts at terminal T-2. This agrees with the control output contact arrangement requirement.

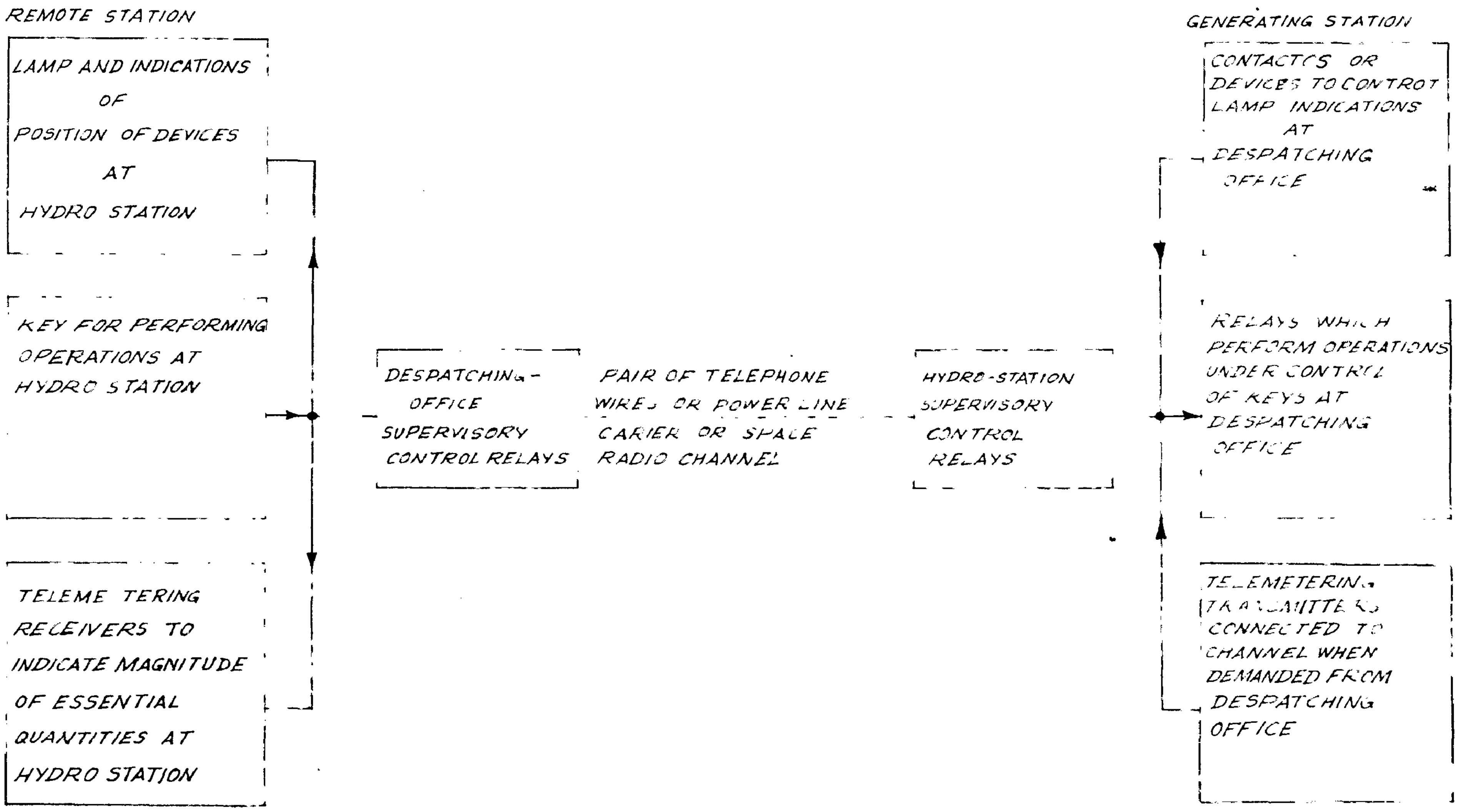
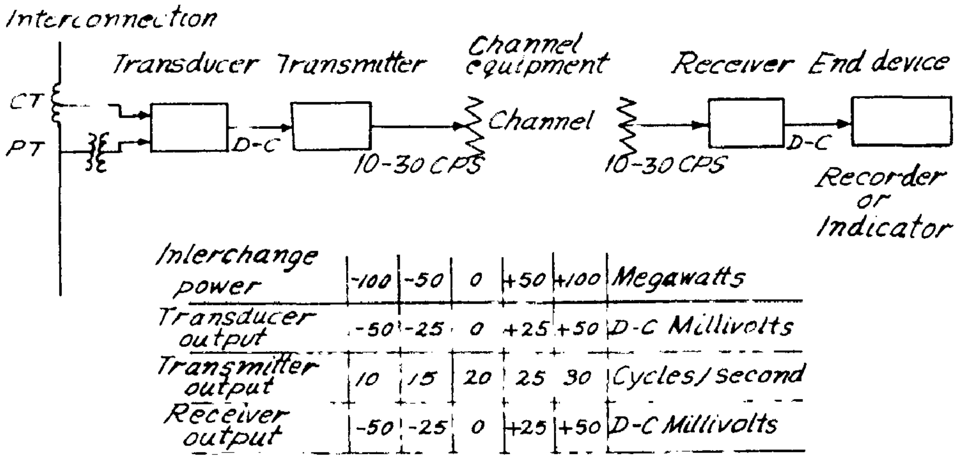
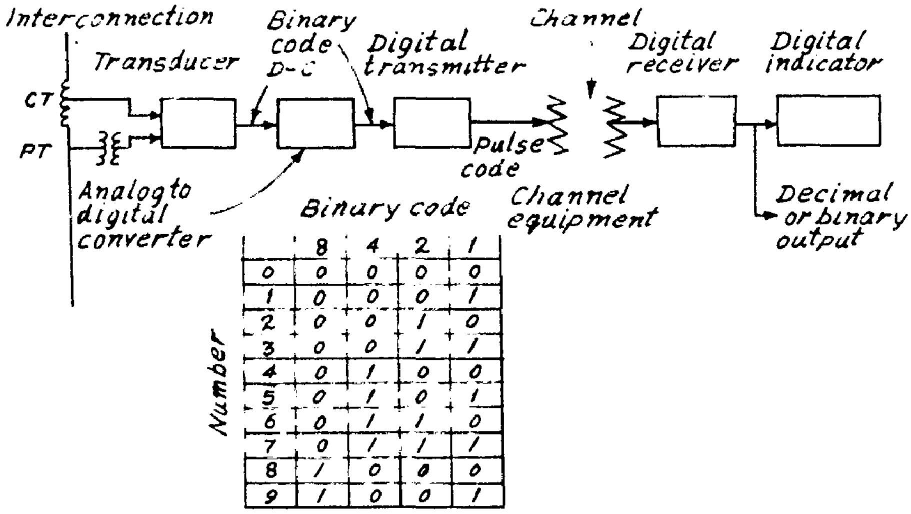


FIG. 6·1 BLOCK DIAGRAM OF SUPERVISORY CONTROL EQUIPMENT.



Interchange power	-100	-50	0	+50	+100	Megawatts
Transducer output	-50	-25	0	+25	+50	D-C Millivolts
Transmitter output	10	15	20	25	30	Cycles/second
Receiver output	-50	-25	0	+25	+50	D-C Millivolts

FIG. 6·2



Binary code

Number	8	4	2	1
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

FIG. 6·3

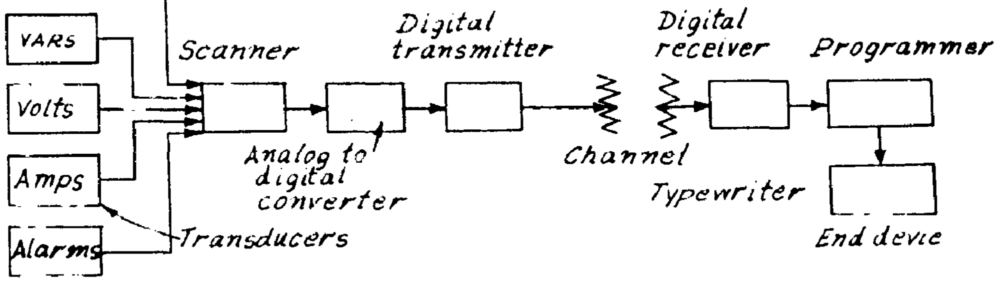


FIG. 6·4

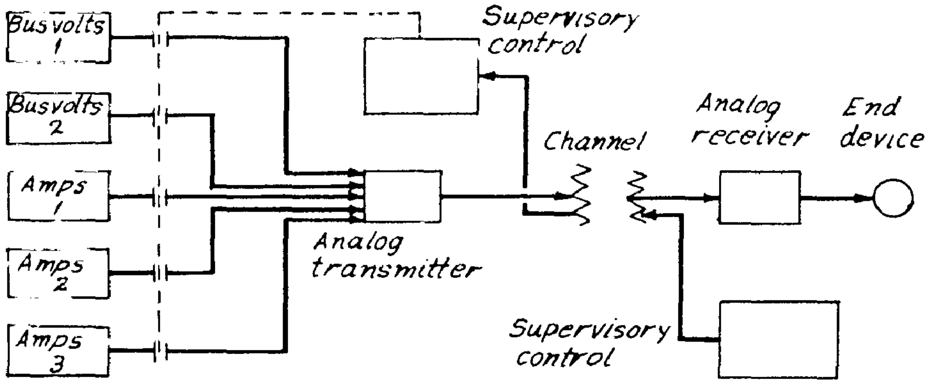

Bus volts 1
Bus volts 2
Amps 1
Amps 2
Amps 3
Supervisory control
Channel
Analog receiver
End device
Analog transmitter
Supervisory control

FIG. 6·5

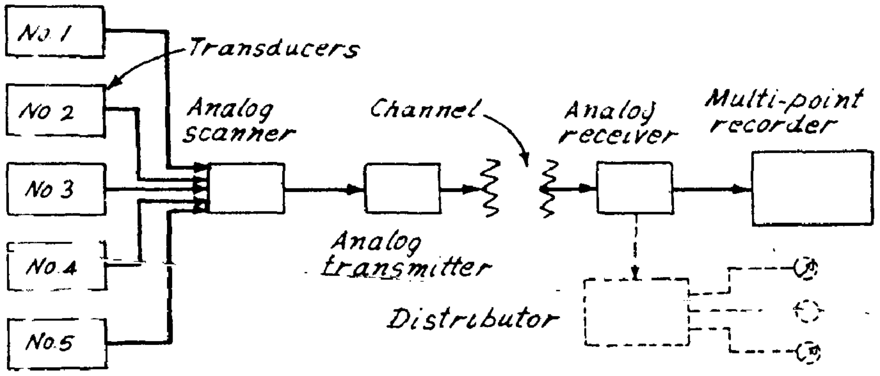

No. 1
No 2
No 3
No. 4
No. 5
Transducers
Analog scanner
Channel
Analog receiver
Multi-point recorder
Analog transmitter
Distributor

FIG. 6.6

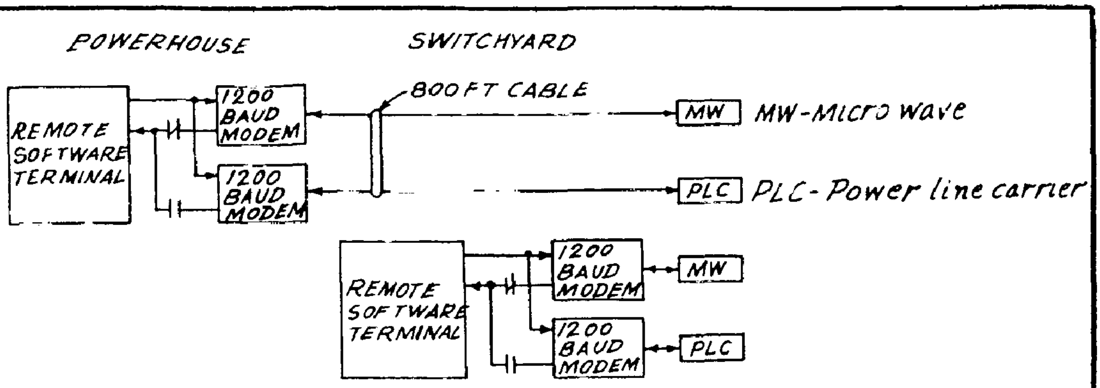


FIG.6.7(b) REMOTE TERMINAL CONFIGURATION

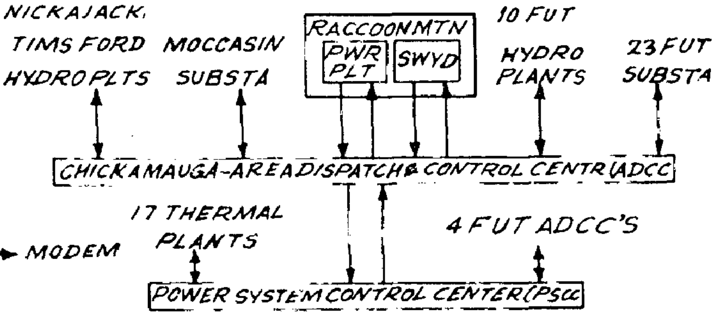
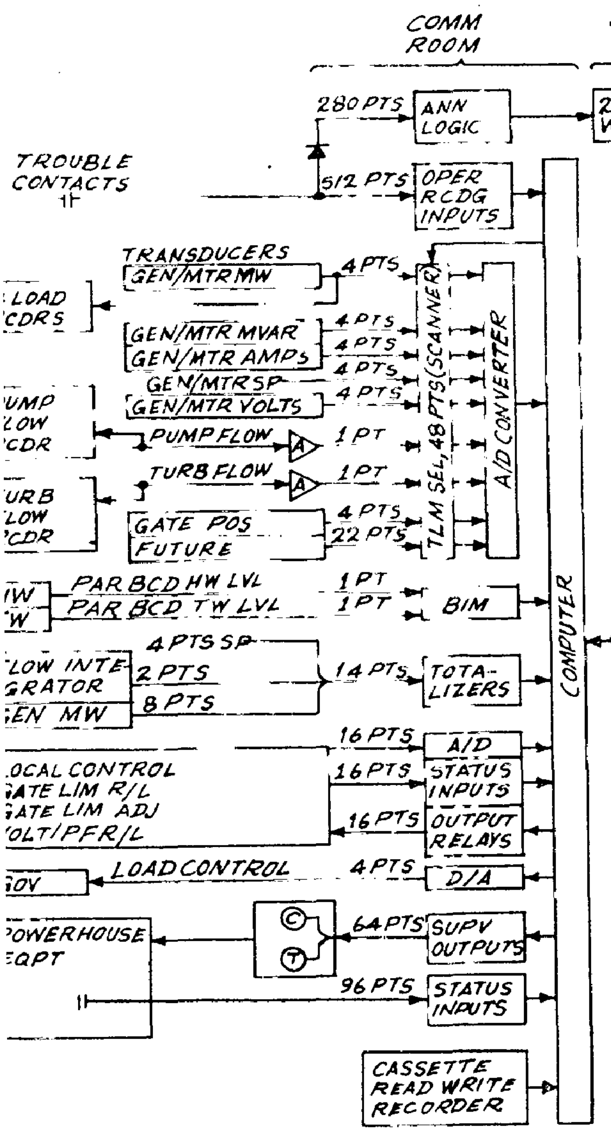


FIG.6.7(a) SYSTEM CONTROL – COMPUTER HIERARCHY



OWERHOUSE TERMINAL SHOWN – SWITCHYARD TERMINAL IS SIMILAR

FIG.6.8 REMOTE TERMINAL FUNCTIOAL DIAGRAM

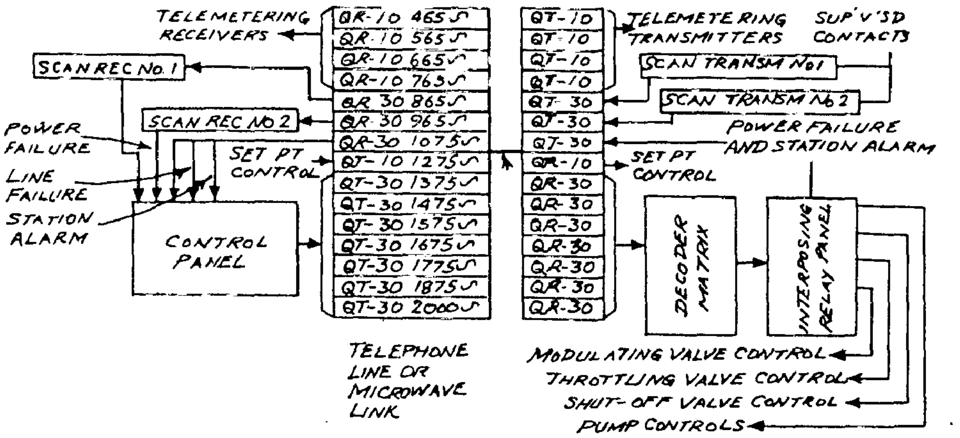
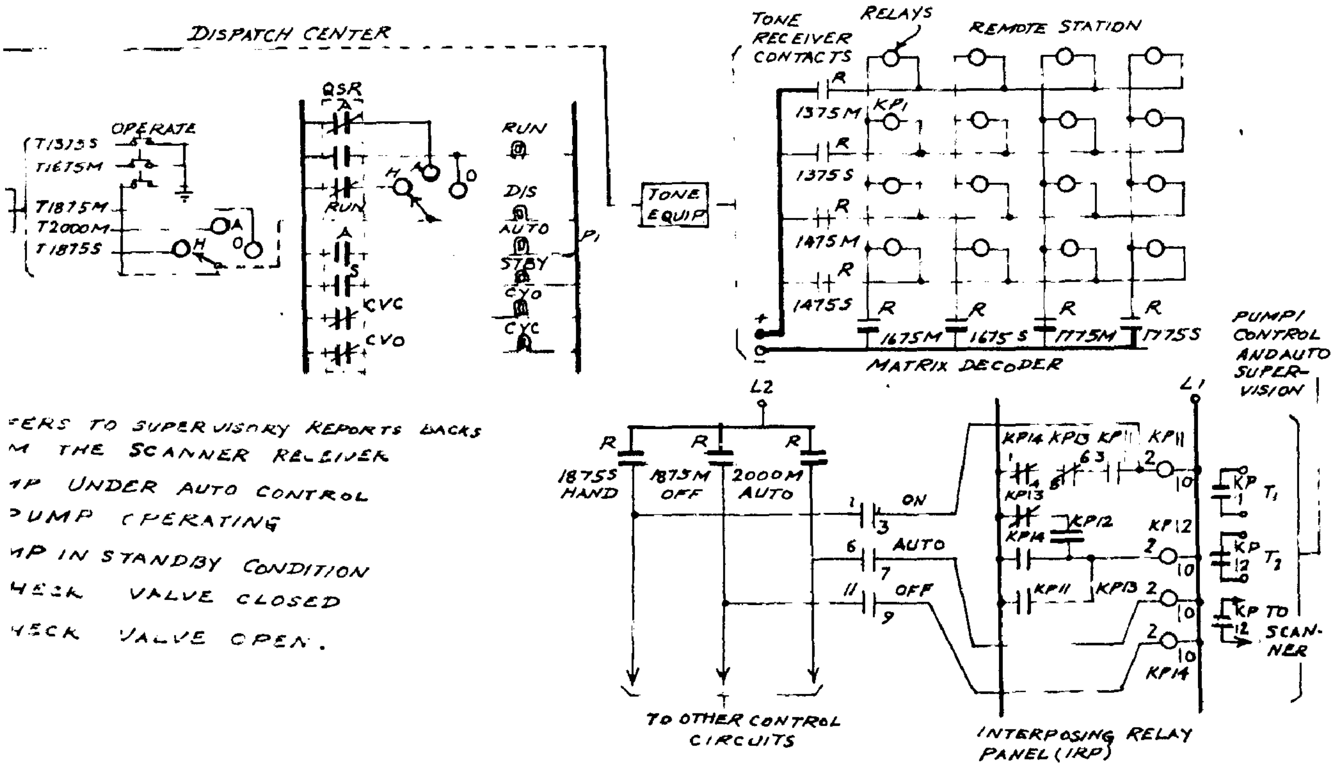


FIG. 6.9



ERS TO SUPERVISORY REPORTS BACKS
M THE SCANNER RECEIVER
IP UNDER AUTO CONTROL
PUMP OPERATING
MP IN STANDBY CONDITION
HECK VALVE CLOSED
HECK VALVE OPEN.

FIG. 6·10

CHAPTER VII

CONCLUSION

From the previous chapters it is apparent that the control scheme of any hydro power plant depends on the following facts.

1. The manual (mechanical) system of control requires large operating staff and takes more time for starting the unit. It is however comparatively cheaper and is therefore adequate only under the constraints mentioned. But it is restrictive if the installation of remote control is contemplated as a future development.

2. The manual (push button) system of control, though technically attractive, is costly as compared with manual (mechanical) control and can be fully justified only when future conversion to automatic control is intended or when operating staff are not readily obtainable or costly.

3. Manual (cottage attended) system of control is naturally limited to the case of small isolated power stations.

4. When starting time is important the effect of the human element renders fully automatic control the most suitable one, with semi-automatic control a close second. Manual push button starting is likewise quicker than the manual mechanical control on account of control centralisation.

5. Supervisory remote control is justifiable on economic grounds and also on the importance of the power station in the interconnected system i.e. its role in the load-frequency control of the system.

6. The high capital cost of hydro electric project necessitates the minimum running cost for economic generation. The running costs include the expenditure on staff housing and their maintenance in an isolated regions. In such cases it is economical to make all small stations completely automatic and unattended one. The supervisory remote control system is best suited to do this.

7. Peaking hydro stations which are subjected to frequent start-run-stop cycles must incorporate the modifications suggested in Chapter V for reducing the starting time. The dynamic braking if practicable shall be used to reduce the maintenance cost on the stator and increase the life of the stator insulation.

8. As regard the adoption of system of control for modern power stations in India, it is to be stated that since there is no dearth of operating staff and since our all developments are basically oriented to create more employment facilities, the use of remote automatic and computer controls are not favoured. Moreover the equipments required for this type of control are not indigenously available

The control equipment required for manual push button control or for semi-automatic control are available indigenously. The centralised control scheme with unit control by sequence controller switch proposed for Dehar power plant is preferred. This scheme is reliable and simple in control as compared with fully automatic schemes of Bhakra Right Bank power plant and could be built with indigenously available equipment.

9. The hydro power stations which are at present important role in the interconnected system may be relegated with the growth of the system and with the addition of the large size hydro and thermal plants. Under such circumstances to operate the present plants more economically in future it may be necessary to reduce or completely eliminate the operating staff stationed at the power plants. For this the design of the control schemes should incorporate the provisions for converting the stations to remote control. The control scheme discussed in Chapter V for the John Day and Monumental plants which incorporates the equipments and devices for future conversion to remote supervisory control is recommended.

REFERENCES

1. Brown H.T. & Dorr, H.A. "Automatic control of Hydroelectric Generating Stations", AIEE (PAS) Vol. 66, 1947, pp 343.
2. Frost A, G.H. & Brittlebank, "The Control of Hydroelectric Plant", Proc. I.E.E., Vol.98, Part I, 1951, pp 129.
3. Toshihiko Taniguchi, "Generator-Motor for pumped storage Power Stations" Hitachi Review, Sept. 1961, pp 51.
4. Druck, P.F., "Modern Control of Large Hydroelectric Generating Stations", IEEE (PAS) Vol.,1962, pp 147.
5. [illegible] J. William, "Hydro & Pumped Storage for Peaking" Water Power, July 1964, pp 271.
6. Ernest Galroni, "Tuned Signals Used to Monitor and Control Water System", Power Engineering (U.S.) March, 1964.
7. Glenn Carter, "Centralized Power Control of [illegible] Power Pump-motors at Grand Coulee," IEEE (PAS) Vol. 86, 1967, pp 135[illegible].
8. Dovey & Cross, J.L., "Electrical Design of Small Hydro-Electric Project," IEEE (PAS), Vol.87, 1968, pp. 593.
9. Robert H. Hitchcock, "Electrical Features of Boundary Hydroelectric Plant," IEEE (PAS), Vol.87, 1968, pp. 1454.
10. Kerlin C.F. & Joseph, E.M., "Electrical Features of Smith Mountain Hydro Project," IEEE (PAS), Vol.88, 1969, pp. 299.
11. John F.J. & Vanbuskirk H.H., "Electrical Design Aspects of Muddy Run Pumped Storage Plant," IEEE (PAS), Vol.88, 1969, pp. 1392.
12. "[illegible] Power Plant Electrical Control" [illegible], Memo.113, Nov. 1969.

13. Baptist F.V. & Hitta Roy, " Electrical Features of Grand Coulee Third Power Plant," IEEE (Spectrum) Jan. 1969. pp. 39.

14. Stroh D.G., Bradley C.C. & Lloyd L.M.," Rapid Reversal of Turbine Pumps at Grand Coulee", IEEE (PAS) Vol.89, 1970, pp 1106.

15. "[illegible] Power Plant Electrical Controls" [illegible] Memo.154, Nov. 1970.

16. Ingram L. & Goldsborough," The Kettle Hydroelectric Development on the Nelson River," IEEE (PAS), Vol.90 1971, pp 1207.

17. [illegible], [illegible],"Pumped Storage at [illegible] Design and Initial Operation", IEEE (PAS), Vol.90 1971, pp 1217.

18. Brown G.[illegible] & [illegible]," [illegible] Units for the Grand Coulee Pump-generating Plant", IEEE (PAS), Vol. 92, 1973, pp 1057.

19. Stuart, [illegible], [illegible] " Electrical Features of the Churchill Falls Development," IEEE (PAS) Vol.93, 1974, pp. 340.

20. "Operational Manual" [illegible] Right Bank Power Plant, 1974.

21. [illegible], Mullen, [illegible]," Remote Control of TVA'S Raccoon Mountain Pump Storage Plant", IEEE (PAS), Vol. 94, 1975, pp 694.

22. IEEE Committee Report, on "Protective Relaying for Pumped Storage Hydro Units Protection" IEEE (PAS) Vol.94, 1975, pp. 899.

23. "Foyers Pumped Storage Scheme", Water Power, May 1975, pp. 262.

24. Guthrie Brown, "Hydro-electrical Engineering Practice (Book), Vol. II.

25. Lythal " J & P Switchgear," (Book).

26. Gruenberg, L. Elliot, "Handbook of Telemetry and Remote Control".

27. USBR Design Supplement No.4 "Power Systems".