

Chapter- 6

POWER EVACUATION ARRANGEMENTS, MAIN SINGLE LINE DIAGRAM AND INTERCONNECTION WITH GRID

6.1 General

Hydro electric generating plants are generally located away from load centres. Accordingly power generated is stepped up to a suitable high voltage in step up sub station at generating end and transmission lines laid for interconnection with the grid at a suitable point. The development of a hydro plant electrical single line diagram is the first task in the preliminary design of the plant. In evaluating a plant for good electrical system design, it is easy to discuss system design in terms of the plant's single line electrical diagram. The relationship between generators, transformers, transmission lines, and sources of station service power are established, along with the electrical location of the associated power circuit breakers and their control and protection functions. Development of design for main single, power evacuation and interconnection with grid is discussed as follows:

- a) Generating station arrangement
- b) Step up voltage and high switching arrangements
- c) Interconnection with the grid

6.2 Generating Station Arrangement

Design Considerations

- i) Safety and reliability
- ii) Simplicity of operation
- iii) Good technical performance
- iv) Readily maintainable (e.g., critical components can be removed from service without shutting down the balance of plant).
- v) Flexibility to deal with contingencies.
- vi) Ability to accommodate system changes

6.3 Step Up Voltage

Economic generation voltage is generally limited to following values (CBI & P Manual).

Upto 750 kVA	-	415 volts
751 - 2500 kVA	-	3.3 volts
2501 – 5000 kVA	-	6.6 volts
Above 5000 kVA	-	11 kV or higher

Generally terminal voltage of large generators is 11 kV in India. Generator with high terminal voltages upto 20 kV is being made. Step up voltage depends upon following.

- i) Length of transmission line for interconnection with the power system.
- ii) Power to be transmitted.

High voltage increases cost of insulation and support structures for increased clearance for air insulation but decreases size and hence Cost of conductors and line losses. Many empirical relations have been evolved to approximately determine economic voltages for power evacuation. An important component in transmission lines is labour costs which are country specific. An empirical relation is given below.

Voltage in kV (line to line) = $5.5 \sqrt{0.62L + \frac{kVA}{150}}$ where kVA is total power to be transmitted;
 L is length of transmission line in km.

American practice for economic line to line voltage kV (based on empirical formulation) is as follows:

$$\text{Voltage in kV line to line} = 5.5 \sqrt{0.62L + \frac{3P}{100}}$$

For the purpose of standardization in India transmission lines may be classified for operating at 66 kV and above. 33 kV is sub transmission, 11 kV and below may be classified as distribution. Higher voltage system is used for transmitting higher amounts of power and longer lengths and its protection is important for power system security and requires complex relay systems.

6.4 Unit Switching Arrangements

A “unit” scheme providing outdoor switching of the generator and transformer bank as a unit on the high-voltage side only, is shown in fig. 6.4.1. The unit scheme is well suited to power systems where loss of large blocks of generation are difficult to tolerate. The loss of a transformer bank or transmission line in all other arrangements would mean the loss of more than a single generation unit. Small power systems and systems not able to compensate for the loss of multiple units, as could occur using other arrangements. The “unit” scheme makes maintenance outages simpler to arrange.

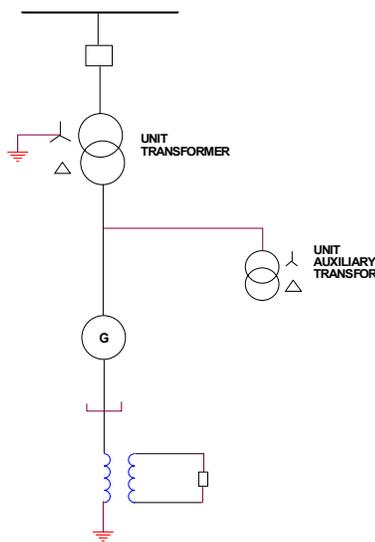


Fig. 6.4.1 Unit Generator Transformer Connection

In case of small generator feeding a large power system generators sharing a transformer (fig. 6.4.2) may be provided.

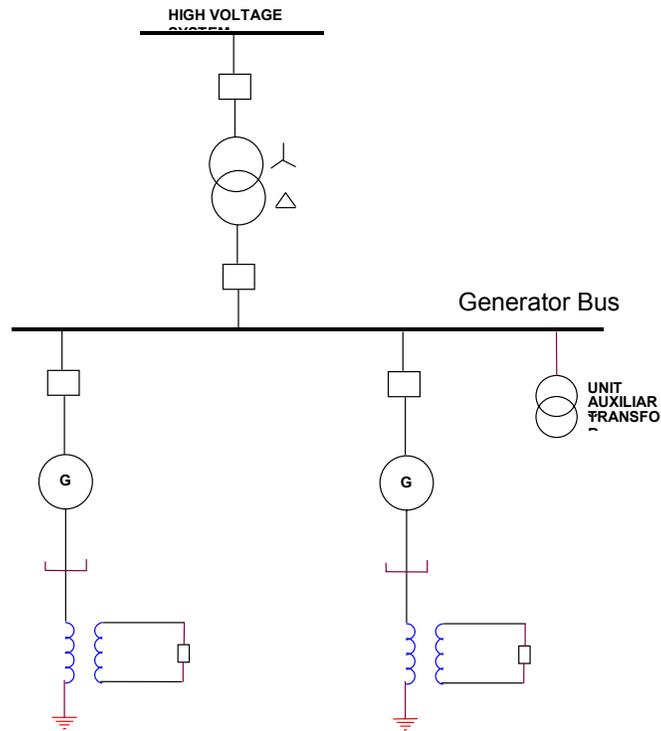


Fig. 6.4.2 Generators with Generator Breakers and Sharing a Transformer

6.5 Switching Schemes for Outdoor Sub Station

6.5.1 Types of Sub-Stations

Sub-Stations may be sub-divided into three types (Figure 6.5.1) as given below:

1. Step-up sub-station at generation end.
2. Transformer sub-station at load ends of the system.
3. Switching sub-stations located along the lines to parallel them especially in case of long E.H.V. lines.

Step-up sub-stations at generation ends may have unit-connected transformers or else transformers may be used to step-up the power from bus bars at lower voltage in the switchyard of generating stations. The latter type of sub-station is similar to the transformer step-down sub-station at load ends and will be discussed along with that type.

6.5.2 General Consideration for The Selection of Switching Scheme

Major considerations for the selection of an economical and suitable main single line diagram and switching scheme for a sub-station are given below:

- (a) Inter-connected transmission system
- (b) Voltage level
- (c) Site Limitation
- (d) General and special Considerations

Inter-Connected Transmission System

The scheme should fit in the planning criteria used to design the connected transmission system. A system should be stable if a permanent fault occurs on a line. It is, therefore, important to avoid system instability caused by outage of line, transformer or generators due to sub-station faults. Sustained generation outage by such faults should not exceed available spinning reserve. This could exceed the reserve to the extent by which important load may be connected to be dropped automatically by under frequency actuated relays.

Voltage Level

- (i) Power carrying capability of transmission lines increases roughly as the square of the voltage. Accordingly disconnection of higher voltage class equipment from bus bars get increasingly less desirable with increase in voltage levels.
- (ii) High structures are not desirable in earthquake prone areas. Therefore in order to obtain lower structures and facilitate maintenance it is important to design such sub-stations preferably with not more than two levels of bus bars.

Site Considerations

Practical site consideration at a particular location e.g. lack of adequate flat area for layout of equipment in the sub-station may also influence the choice in such locations. Pollution caused by location near to sea or some other contaminated atmosphere may also affect layouts. At some locations completely in door sub-stations even at 400 kV level have been made.

General Miscellaneous Considerations

Other considerations in the selection of a suitable arrangement and layout are given below:

Repair or maintenance of the equipment should be possible without interruption of power supply.

Expansion of sub-station should be easily possible.

In seismic prone areas height of structures should be as low as possible.

The outgoing transmission lines should not cross each other.

6.5.3 Switching Schemes for Different Types Of Sub-Station

Basic schemes

Fig. 6.5.2 to 6.5.6 show the single line diagrams for different schemes which may be considered for designing a sub-station.

- i) A double bus single breaker scheme as shown in Fig. 6.5.2.
- ii) A single bus single breaker scheme is shown in Fig. 6.5.3. Variations commonly employed in this scheme consist of provision of a transfer bus and/or sectionalizing of main bus.
- iii) A double bus one and a half breaker scheme Fig. 6.5.4.
- iv) Double bus, double breaker scheme as shown in Fig. 6.5.5.
- v) Ring bus scheme as shown in Fig. 6.5.6.

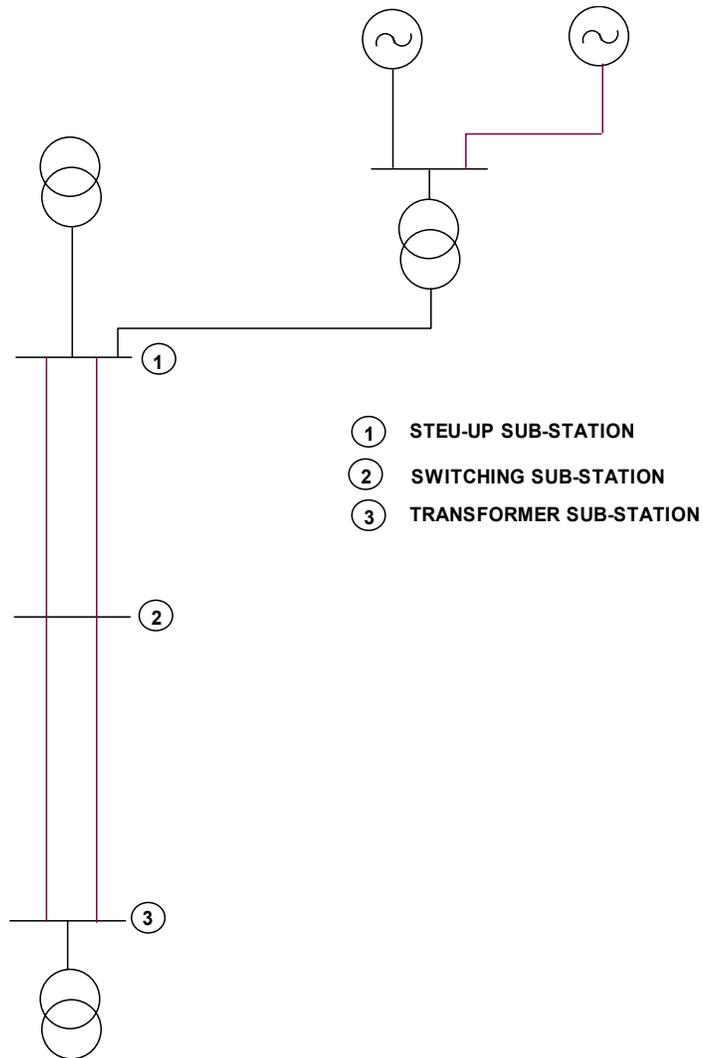


Fig. 6.5.1 Type of Sub Stations

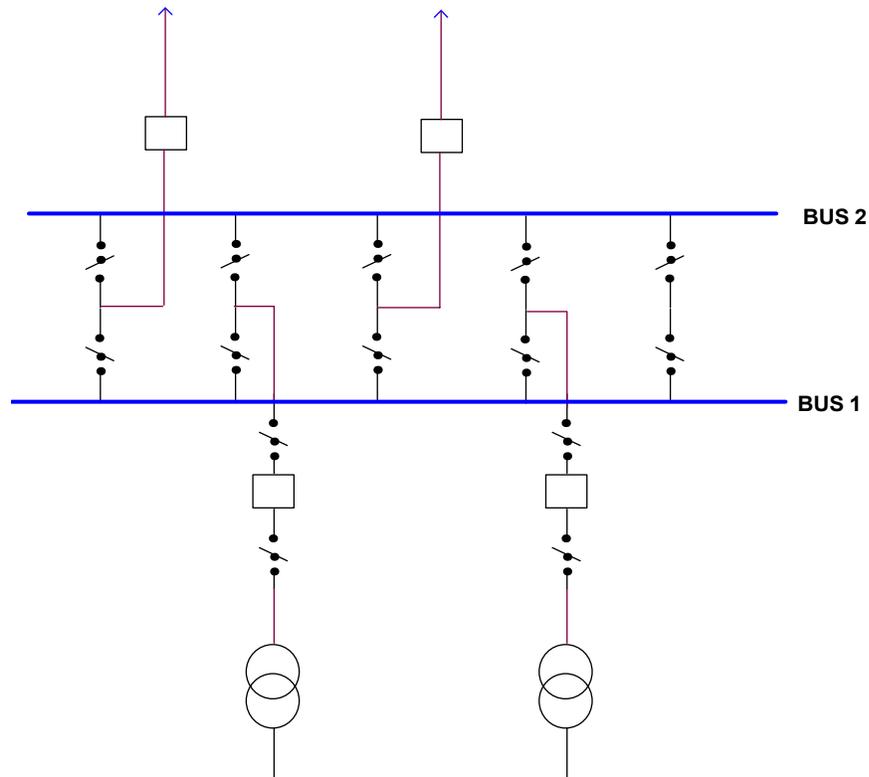


Fig. 6.5.2 Double Bus Single Breaker Scheme

This scheme is quite common on large and medium station upto 220 kV in India and continent being economical and maintenance of breaker is possible by utilizing bus coupler.

Disadvantages

1. Selection of bus is by isolating switches which is a weak link. Inadvertent operation on load inspite of interlocking arrangements may damage the switch.
2. Utilizing bus coupler during breaker maintenance will necessitate transfer of tripping circuits through auxiliary contacts.
3. Discretion of operator to select the bus is not desirable. If machines are on one bus then entire power generation will be lost in case of bus fault which is not desirable for large generating station.

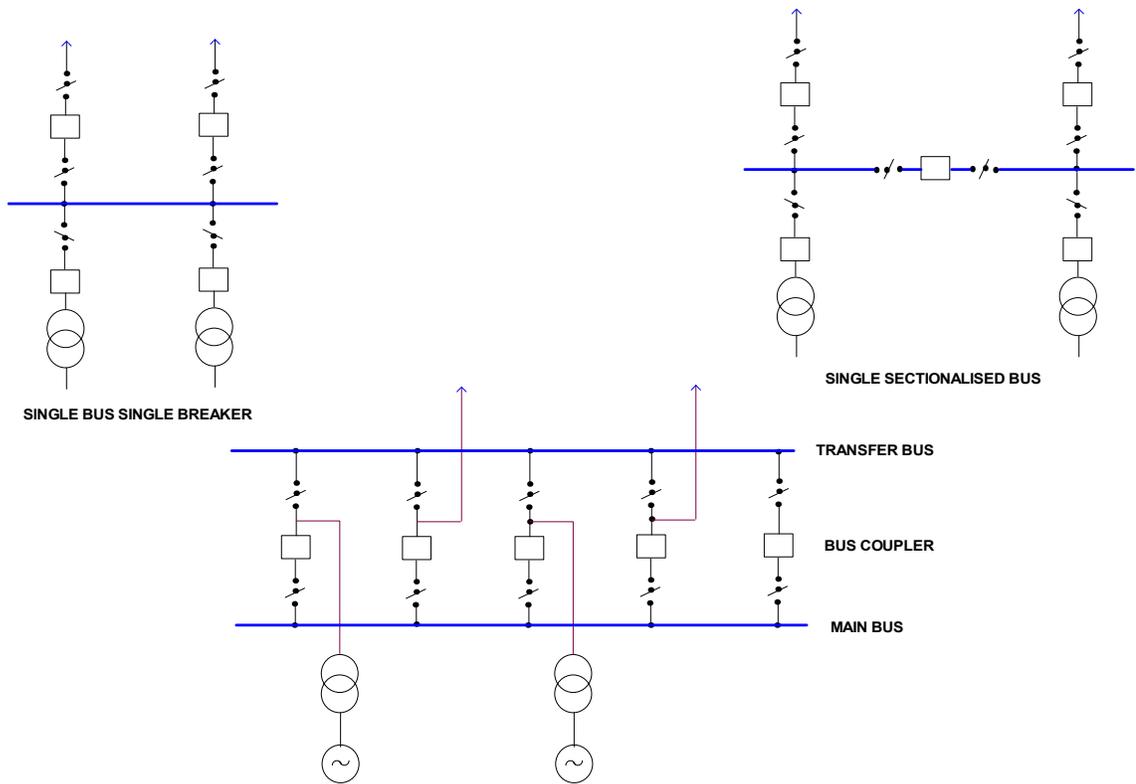


Fig. 6.5.3 Single bus With A Transfer Bus

Single bus scheme with or without a transfer bus

1. All units are connected on a single bus and entire generation will be lost in case of bus faults.
2. This is generally provided on small generating station. Gangwal and Kotta power houses (3 x 24 MW) were provided with this arrangement.
3. Single bus with a Transfer bus scheme is useful for feeder breaker maintenance, but involves transfer of tripping circuits through auxiliary switches. Generator breakers are maintained alongwith unit maintenance outage period.
4. Single sectionalized bus is very commonly employed being economical; generation outages can be controlled by sectionalizing. Simple arrangements does not require isolating switches to select bus and adopted even on large power houses i.e. 5 x 120 MW at Bhakra Right Bank and Dehar Power plant 220 kV (2 x 165 MW) and most medium station where parallel outgoing feeders are provided.

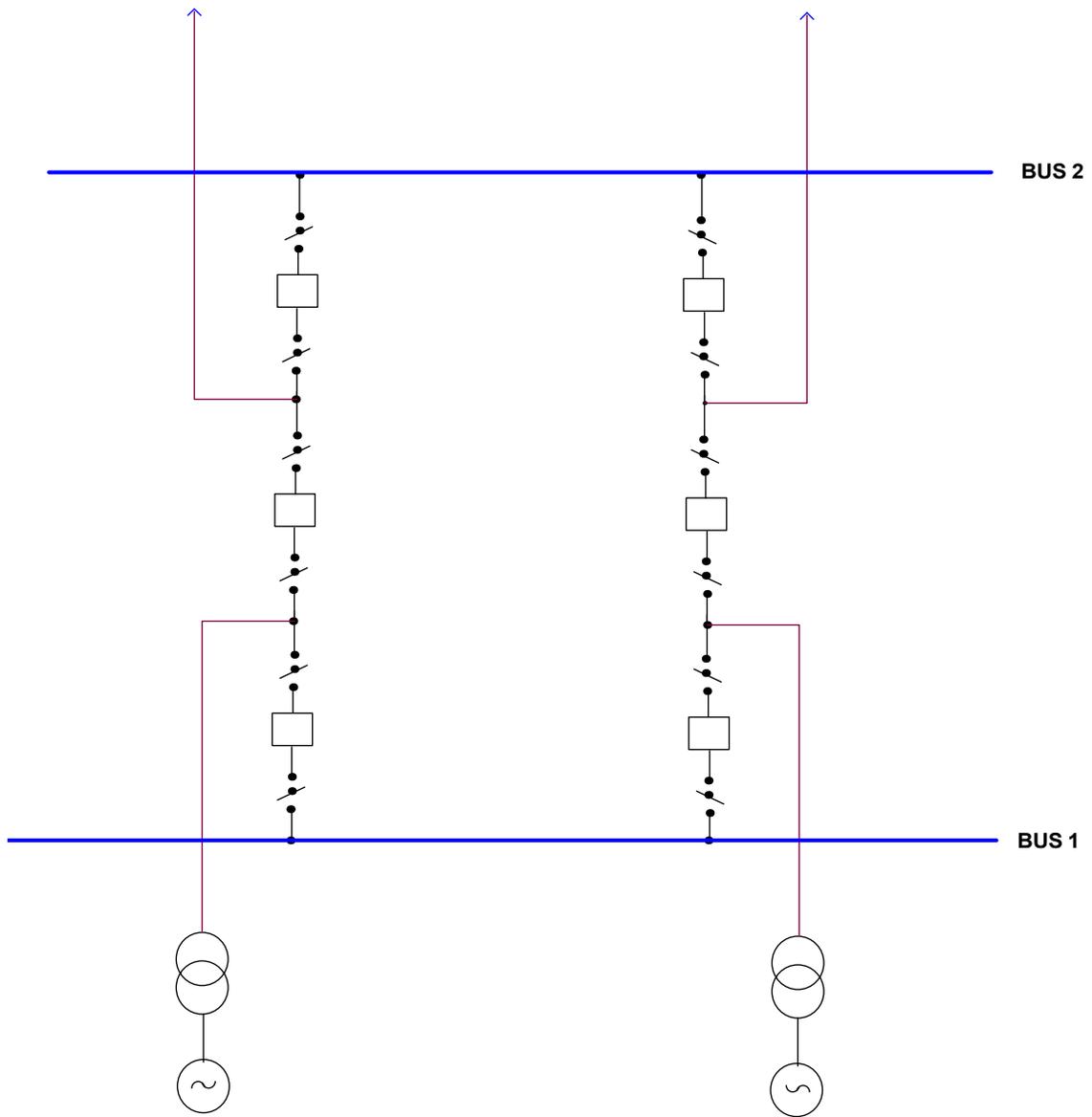


Fig. 6.5.4 Double Bus One and half Breaker Scheme

Very reliable and used on EHV system cost is high as one and half breaker is used for each element. In case of fault not more than one element is lost on any outage. Maintenance of any breaker is possible without outage.

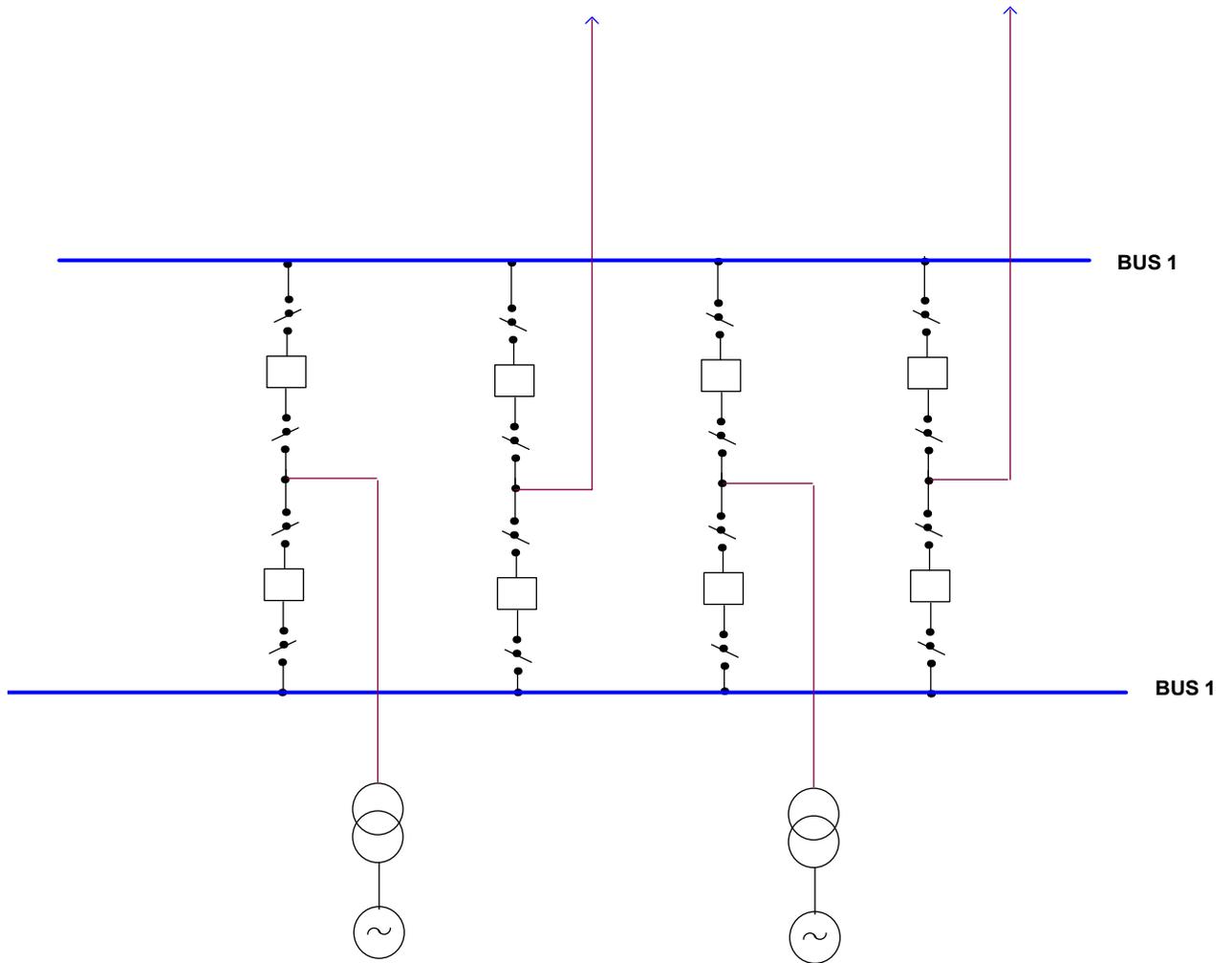


Fig. 6.5.5 Double Bus Double Breaker Scheme

Very reliable but very costly as it requires 2 breakers for each element. Generally recommended for switching station and EHV generating stations.

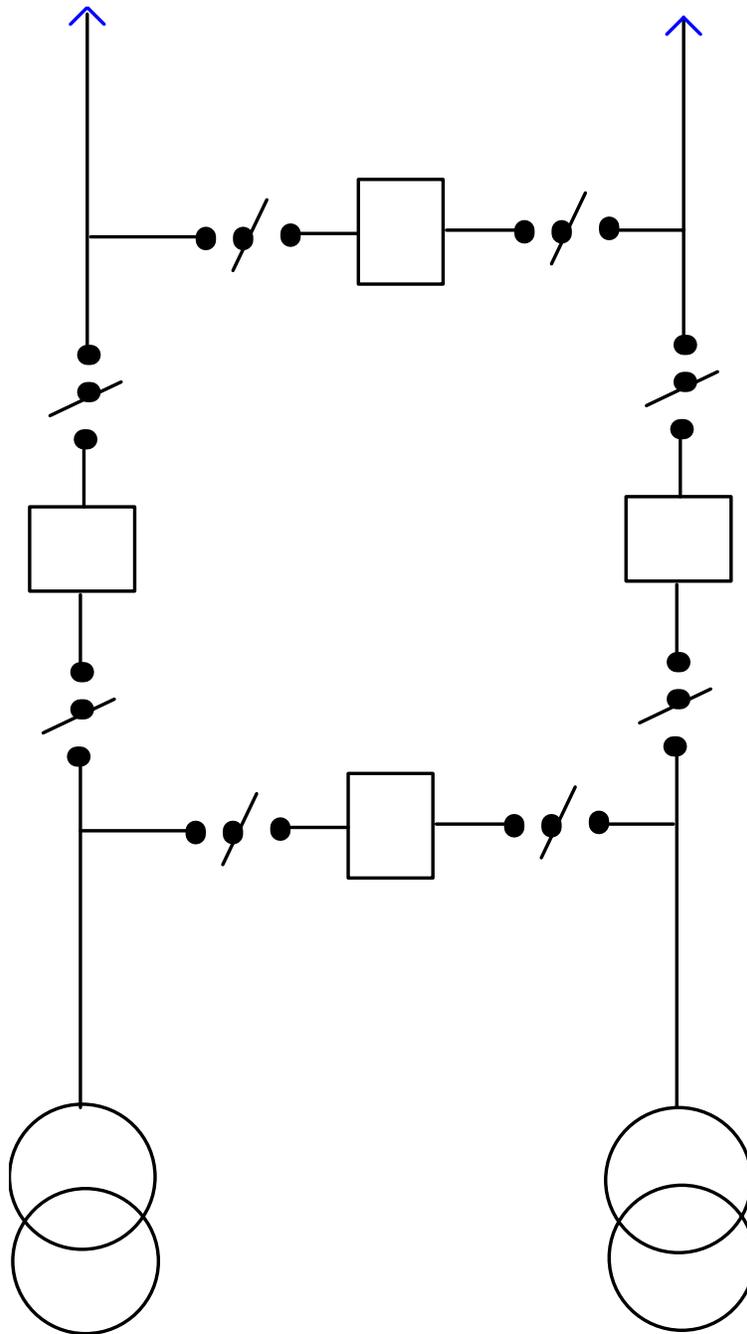


Fig. 6.5.6 Ring Bus Scheme

Reliable and economically as only one element is lost in case of any fault, but protection is complicated and hence not used in India. It is used in British grid system for sub-station and not generating station.

6.6 POWER EVACUATION AND INTERCONNECTION WITH GRID

6.6.1 Power evacuation in large power stations

- i) Step up voltage at the generating station may be fixed in accordance with Para 6.3 and detailed economic studies.
- ii) Interconnected transmission and switching scheme be designs in accordance with Para 6.5.2.
- iii) Transmission line protection be provided as per Chapter 7. The high voltage transmission lines must be disconnected both at receiving end as well as sending end by carrier or other communication signals.
- iv) Provide for no voltage closing for receiving and breakers and synchronizing check relay closing at sending end breakers.
- v) It is normal practice to provide synchronizing facility on the sending end breaker of the transmission lines.

6.6.2 Grid Connected Small Hydro Power Stations (including microhydels)

6.6.2.1 Introduction

Specific provisions required for equipment and protection for interconnection of small hydels with grid at 11 kV and above is generally required for following modes of operation;

- i) grid connected operation
- ii) isolated operation
- iii) islanding operation

6.6.2.2 Provisions in Generating Equipment

- i) Isolated and islanding operation will require adequate flywheel for stable operation for commercial load changes. This may be checked by full load rejection in the field and the speed rise should not exceed 35% or even lower in case of special (large motor) load characteristics.
- ii) In case isolated operation is not required flywheel effect could be reduced and the criteria of speed rise on full load rejection can be increased upto 55% - 60%.
- iii) Excitation system for generators should have a provision for power factor control in grid operation mode and voltage control mode in isolated mode operation. Voltage control mode is required before the unit is synchronized to the grid. Accordingly change over from voltage control mode to power factor control mode after synchronizing to grid is required.

In case of micro hydels manual excitation control with excitation limit could be provided.

- iv) The transformer for micro hydels for interconnection with the 11 kV grid should be cast dry outdoor type as per REC specifications 30/1984 which

- corresponds to IEC 726. These transformer are suitable for harsh condition and require less rigid maintenance schedule.
- v) The transformer should be connected with star on the low side and delta on the high side due to reasons explained in Para 3.
 - vi) Generator breaker and bus bar at generator voltage be provided for islanding operation.
 - vii) For 33 kV and above line side electrically operated circuit breakers should be provided.
 - viii) For islanding operations synchronizing arrangements should be made from generator breakers as well as from the interconnecting LV/MV grid breaker.
 - ix) Reclosing on receiving end grid breaker should be prevented/blocked.

6.6.2.3 Protections

protection and islanding based on the IEEE C 37.95 is recommended. A typical simple scheme of interconnection of an SHP with 33 kV grid with local 415 volts feeder is at figure 6.6.2. Minimum protective relays to ensure adequate protection of both the generator and interconnection are shown in the figure. The transformer is connected grounded star on low side so that grounded neutral system is provided for local load in case SHP is shut down. HV (33 kV) side is a grounded system from sending end. HV side is protected by HV breaker installed at receiving end transformer grid sub station for ground fault.

Transformer Protection

Figure 6.6.2 shows transformer protected by transformer differential (87T) bucholz relay (63) and high side overcurrent (50/51) and ground fault (51G) relays. In case of smaller hydels bus differential relays could be replaced by 11 kV side fuses and overcurrent relays (50/51) should on the LV side.

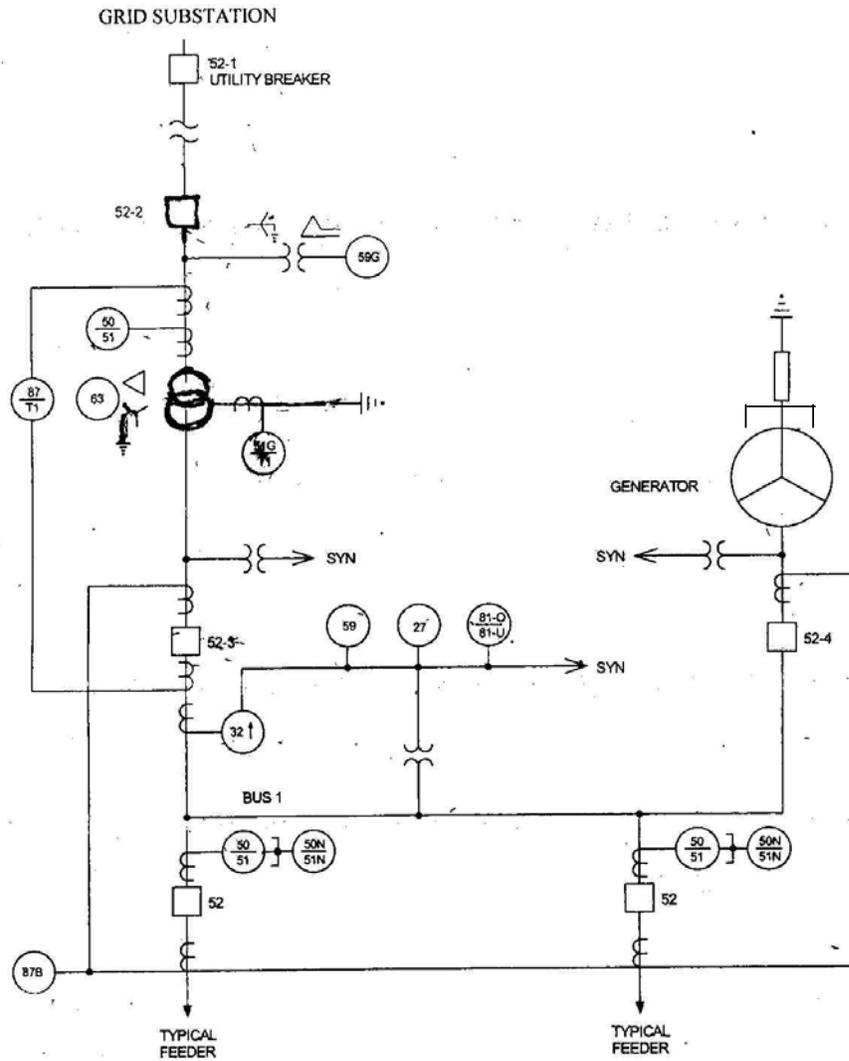
Transformer low –side bus and feeder protection

Bus differential (87B) provided can be removed and common bus and transformer differential can be provided if the local feeder load is beyond the capacity of local generation.

Back up protection for both the transformer and the feeders is provide by transformer overcurrent relays (50/51) and (51G). The settings on these back up relays should be co-ordinated with the over current relay which protect the feed (50/51) and (50N/51N).

Protection of Interconnecting Line

Reverse power relay (32) which can detect when SHP can not supply power to the grid and will operate the grid supply HV side breaker. In normal cases overvoltage (59), undervoltage (27) and over/under frequency relay (81) will separate the grid from SHP in case of line outage.



- 52 - Circuit Breaker
- 32 - Directional Power relay
- 27 - Under Voltage Relay
- 59 - Overvoltage Relay
- 59G - Zero Sequence Overvoltage Relay
- 87T - Transformer Differential
- 63 - Transformer Sudden Pressure Relay
- 50 - Phase-Instantaneous Overcurrent Relay
- 50N - Ground – Instantaneous – Overcurrent Relay
- 51 - Phase – Time – overcurrent Relay
- 51G - Transformer Neutral Overcurrent Relay
- 51N - Ground-Time-Overcurrent Relay
- 87B - Bus Differential Relay
- 81-0 - Over frequency Relay
- 81-U - Under frequency Relay

FIG. 6.6.2 Supply to a remote SHP substation with generation
(as per IEEE 37.95 – 2007)

Ground fault protection on the HV line should be provided by overvoltage relay 59G in open delta. A line delay can be provided to clear temporary faults.

Synchronising

Suitable interlocks, check relays and operating procedure should be designed for following condition.

- i) Planned or inadvertent outage of the power plant
- ii) Grid failure/disturbance

For the sample system in figure 6.6.2, both breakers 52-3 and 52-4 should be equipped with facility to synchronise the SHP generator to system. Dead line and synchronising check relay for breaker should be used on breaker 52-1 & 52-2. Electrical interlock be provided on breaker 52-2 and 52-3. This will permit following operating procedure.

Breaker 52-1, 52-3 and 52-2 should trip for any fault on the (33 kV) interconnecting line.

- i) Breaker 52-1 should be closed once it is confirmed that (33 kV) line is energized.
- ii) Circuit breaker 52-2 may be closed if circuit breaker 52-3 is open.
- iii) If SHP is in operation bus 1 is energized then breaker 52-3 may be synchronized and closed by SHP operator.
- iv) If bus 1 is de-energised and breaker 52-4 is open, breaker 52-3 may be closed and generator brought on line by synchronizing and closing breaker 52-4.

6.6.3 EXAMPLE

Consideration involved in power evacuation arrangement to be provided are discussed with respect to Neora hydropower project as detailed below.

Introduction

Neora small hydro project comprises of 3 units each of 1000 kW; 1250 kVA; 600 RPM. Entire power of the 3 x 1000 kW Neora Power House is to be fed into the grid. The power house is interconnected with the grid at Chalsa 66 kV grid sub station by 16 km long 11 kV line with DOG conductors. A second 11 kV line originally proposed is not connected. A 5 MVAR, 12 kV capacitor bank was also proposed at chalsa receiving end sub station to improve voltage profile by meeting reactive requirements and is also not installed. Problem of evacuation of power on the system is as per drawing attached (fig. 6.6.1).

Present Field Data

The line no load voltage at the generating station bus before synchronization is intimated to be varying from 9.8 to 11.8 kV. Assuming negligible voltage rise due to capacitance effect of 11 kV line. This voltage is assumed to be the grid voltage at receiving end at Chalsa grid sub station. Small power house can not change the grid voltage and frequency. Therefore the design of the interconnecting line and the system has to be based on this fact. Actual voltage

regulation for transmission of 3150 kW at unity power factor on the line is given as follows as per field data supplied.

Generating Station bus voltage	:	12.05 kV
No load voltage (before synchronizing) At the generating station bus	:	10.5 kV
Chalsa grid sub station voltage	:	10.45 kV (assuming 0.05 kV voltage rise Due to line capacitance as per test results)
Voltage regulation	:	1.6 kV i.e. 14.5% voltage regulation

Accordingly the sending end voltages at the power house for evacuating 3150 kW with 11 kV line and dog conductor will be as follows:

Receiving end Chalsa grid S/S voltages (as per field data)	:	9.75 kV	11.75 kV
Sending end bus voltage required at power house 11 kV bus bars with 11 kV dog conductor	:	11.35 kV	13.35 kV

The above voltages are for transmission of power at unity power factor. If reactive power is also supplied from the power house (assuming load at 0.8 power factor). The voltage drop will be double and voltage to be maintained at power house will be approx. about 15 kV. Based on the kW; km quick estimating charts. The voltages as above are not permissible. Reducing generator terminal voltage and VAR limits by changing excitation system even if admissible as per generator capability curves will not help in any way.

Alternative Measures

Alternative measures necessary for evacuation of power, voltage regulation at 66/11 kV grid sub station Chalsa and meeting reactive power requirement of the load are discussed for optimization.

Grid Standard for operation and maintenance of transmission (Draft CEA: regulation 2006)

- i) **Frequency** should not be allowed to go beyond the range 49.0 to 50.5 Hz except during transient period.
- ii) **Voltage** the steady state voltage shall be maintained within $\pm 10\%$.

Alternative 1: Modifications in the existing system of interconnection by one 11 kV line with dog conductors (Installing Voltage Boosters).

Current carrying capacitive of dog conductor of 11 kV as per IS 398/1961 is about 300 Amperes which is sufficient for transmission of 3000 kW at 0.8 power factor from temperature rise limits.

Voltage regulation for 3000 kW transmission is about 15% and for 3000 kW at 0.8 power factor will be about 29%. These are prohibitive and can not be allowed.

It is suggested that 200 A pole mounted automatic voltage booster/regulator midway about 8 km from the power stations may be provided for voltage boost or buck in suitable steps of say 2.5% as per REC specification No. 37/1993 but rated 200 A for 3000 kW. Installation can be as per REC standard drawing A 14 (fig. 6.6.2) suitably modified to accommodate 200A booster/ regulators.

Alternative 2: Provide second 11 kV line with dog conductors as originally proposed.

Alternative 3: Upgrade the existing 11 kV line to 33 kV

The interlinking line be converted into 33 kV line with existing conductor (dog) by changing cross arms and insulators provided adequate clearances are available/ can be manipulated. and provide 11/33 auto transformer at both ends.

Approximate Voltage regulation for 33 kV line with dog conductor (6/4.72, 7/1.57 ACSR line, 65 sq. mm. copper equivalent area, 103.60 sq. mm. aluminum area as per IS 398-1961) will be as follows for evacuation of 3000 kW power at varying load factors.

PF	1.0	0.9	0.8
Regulation	.29 kV	.48 kV	.64 kV

Accordingly generating station 11 kV bus voltage for evacuation of 3000 kW at varying power factors will be as follows:

Receiving and grid voltage at Chalsa	Min.	Max.	Remark
	9.8 kV	11.8kV	
Sending end power house voltage	PF		
For evacuation of 3000 kW power	1.0	10.09 kV	12.09 kV
	0.9	10.28 kV	12.28 kV
	0.8	10.44 kV	12.44 kV
			} Not admissible without line compensation

Accordingly with the arrangements proposed 3000 kW can be evacuated at all the time and at unity and lower power factor for most of the time only by upgrading 11 kV line to 33 kV line.

Capacitor Bank at Chalsa Power Station

Reactive power requirement of load corresponding to 3000 kW capacity of Neora will be about 2000 kVAR. It is recommended detailed load flow studies carried out to optimize the requirement of condenser capacity to be provided at Chalsa / supplied from power house end for optimum operation based on the alternatives adopted.

Excitation Control

As already mentioned grid voltage and frequency can not be changed by small hydro station. The excitation control should be designed with this end in view. Automatic voltage regulation control in SHP is not feasible. Many AVR in SHP have been

damaged. The SHP should be provided with power factor control (Automatic Power factor control) with minimum and maximum excitation limiters based on stator heating and leading power factor operation limit of the generator. A typical specification for exciter control for such an operation is given below.

(a) Power Factor and Voltage Regulators

In the “Power Factor” mode, the reactive component of generator current shall be compared to an adjustable DC reference and the amplified error signed shall be used to drive a motor operated potentiometer which raises or lowers the voltage regulator set point, thereby changing field excitation to obtain required reactive current loading. The “Power Factor” regulator shall maintain the reactive current ampere loading on the generator within $\pm 5\%$ without hunting under steady load conditions when the system voltage deviation does not exceed $\pm 10\%$ from nominal.

The operation of the regulator, when in the “Power Factor” mode, shall automatically switch into the “Voltage” mode whenever the unit breaker is open. Thus during the synchronizing period of time, the synchronizer can be used to drive the motor operated potentiometer to adjust the terminal voltage to the required condition for synchronizing.

In the voltage mode, the average generator three phase terminal voltage adjustable DC reference and the amplified error signal applied to the excitation system to maintain the terminal voltage with $\pm 0.5\%$ without hunting under steady load from no-load to full load condition. The range of control shall be from 10% below normal to 10% above normal generator voltage.

The “Power Factor” and “Voltage” regulator shall include reactive droop compensation.

(b) Field Current Regulator

The “Field Current” regulating mode shall provide a back-up system for the “Power Factor and “Voltage” regulators. In this mode, the generator terminal voltage (KVAR loading) shall be under the operator’s manual control. Variations in system voltage which effect KVAR loading must be compensated by readjustment of the “Field Current” regulator “Set Point” adjust. The range of control shall be from approximately 10% less than no-load field current to approximately 5% above maximum required field current.

Maximum Excitation Limiter (Operational and “Power Factor” and “Voltage” Regulating Modes Only).

(c) Selection of “Power Factor”, “Voltage”, and “Field Current” regulating modes shall be via remote/local control. The control shall permit transfer when the unit is on line.

(d) Local/Remote controls of “Set Point” adjust for the “Power Factor” and “Field Current” regulators. The “Power Factor” regulating mode shall be the normal operating mode.

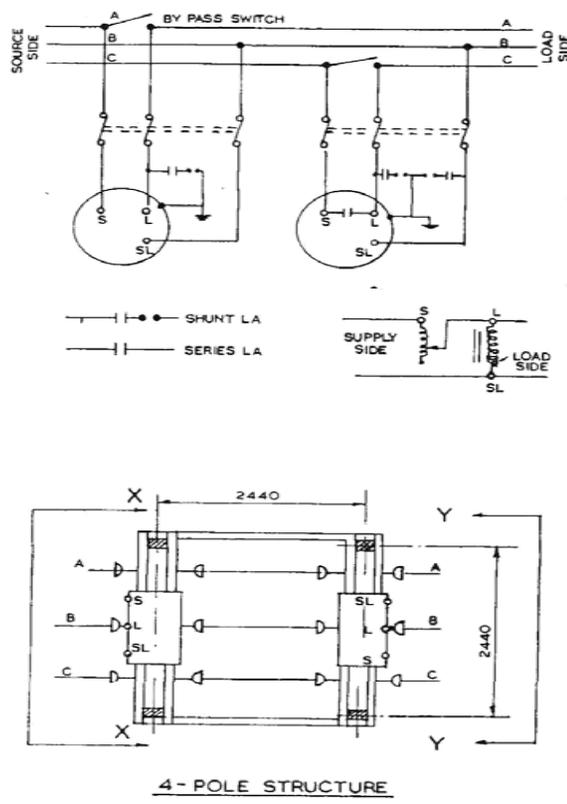
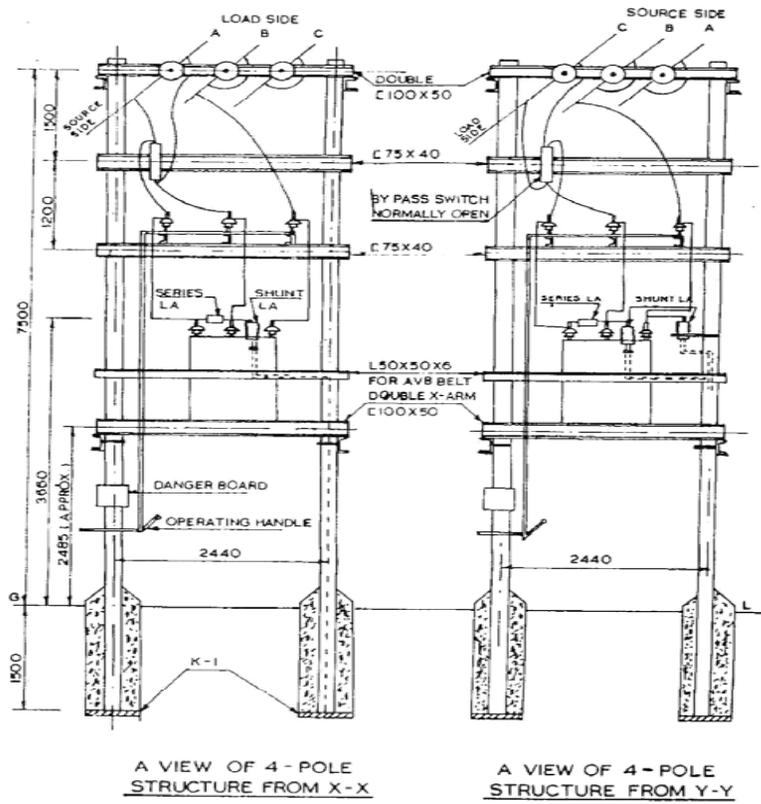
- (e) Provide minimum excitation limiter to automatically limit the decrease of generator excitation. The limiter shall hold the generator field current at a preset value determined from the reactive capability curve of the generator.
- (f) Provide maximum excitation limiter to limit the field current after an adjustable time delay to prevent sustained field overcurrent. The time delay shall be inversely proportional to rate of change in field current. An instantaneous overcurrent limiter shall be included to prevent excitation from exceeding ceiling current.

Control

The start-stop control shall be arranged for automatic start when the machine speed reaches a pre-set value, and for automatic shutdown whenever an “OFF”, “Unit Breaker Trip” or “Lockout” signal is received. The control shall be designed for a soft shut-down on a normal stop command, with the field current being reduced to zero by the phase control action of the SCR’s before any circuit disconnect device operates.

Protection

Protection for grid operation and islanding (if required) be provided as per IEEE std. 1020/C37.95. In any case reverse power relay, under frequency and $\frac{df}{dt}$ relay should be provided for grid separation to prevent damage to machine due to asynchronisation. Special synchronizing arrangement from grid breaker are required in case islanding operations are provided. Provision of synchronizing check relay for feeder breaker closing at the power house and no load charging at the receiving end grid sub station breaker should be provided.



REC
CONSTRUCTION STANDARD
A-14

NOTES

1. TWO SINGLE PHASE AVB's CONNECTED IN OPEN DELTA ON A FOUR POLE STRUCTURE
2. SUITABLE POST INSULATORS MAY BE USED TO MAINTAIN PROPER CLEARANCE.
3. FOR EARTHING ARRANGEMENT OF AVB's, SHUNT LA'S STRUCTURE, AB SWITCH ETC. REFER LATEST REC CONSTRUCTION STANDARDS F-5 & F-10
4. BY-PASS SWITCH: NORMALLY IN OPEN POSITION WHEN AVB IN OPERATION. FOR ISOLATING AVB OPEN AB SWITCHES AND CLOSE BY-PASS SWITCHES TO MAINTAIN CONTINUOUS SUPPLY TO LOAD. ALL SWITCHING OPERATIONS SHALL BE PERFORMED UNDER NO LOAD CONDITIONS.

Fig. 6.6.3.2