

CHAPTER 6: ELECTRICAL AND INSTRUMENTATION FACILITIES

6.1 INTRODUCTION

Electrical systems that are to supply electrical power for an entire STP consist of power receiving and transforming equipment, power distributing equipment, cables, drives and standby generators.

Instrumentation facilities are also installed for the purpose of measuring and collecting process data such as flow rate, pressure, water qualities, and so on, at all times. These are utilized to monitor and control treatment processes at optimal conditions for a stable treatment. The instrumentation facilities consist of sensors for processes, signal converters, operating devices (actuators), controllers (PLC: Programmable Logic Controller), monitoring devices (PC: personal computer), etc.

This chapter describes the following electrical and instrumentation facilities:

- A. Power receiving and transforming equipment (Substation & transformers)
- B. Standby power supply system (Generators, Engines, UPS: Uninterruptible Power Supply)
- C. Prime movers and motor controllers (Motors, Starters, Cabling)
- D. Instrumentation system
- E. Supervisory control and data acquisition system (SCADA)

A typical single line diagram (SLD) depicts the entire electrical power flow system of an STP. The single line diagram not only presents the type and number of equipment but also the electrical specifications. This is an important document for an O&M person who would like to refer to it in case of any operational or maintenance need. Every STP should have:

- A SLD kept for record and displayed properly in the STP facility particularly near the electrical sub-station
- SLD periodically reviewed and updated suitably in case of any change
- All those personnel involved in the electrical and instrumentation work should understand the SLD

A typical electrical SLD is shown in Figure 6.1 overleaf.

6.2 POWER SUPPLY SYSTEM

Power supply systems have the following three major functions:

- Transfer power from the transmission system to the distribution system
- Reduce the voltage to the specified level (Typical voltage level is 415 volt for STPs) suitable for connection to local loads
- Protect the entire network by identifying and isolating electrical faults selectively

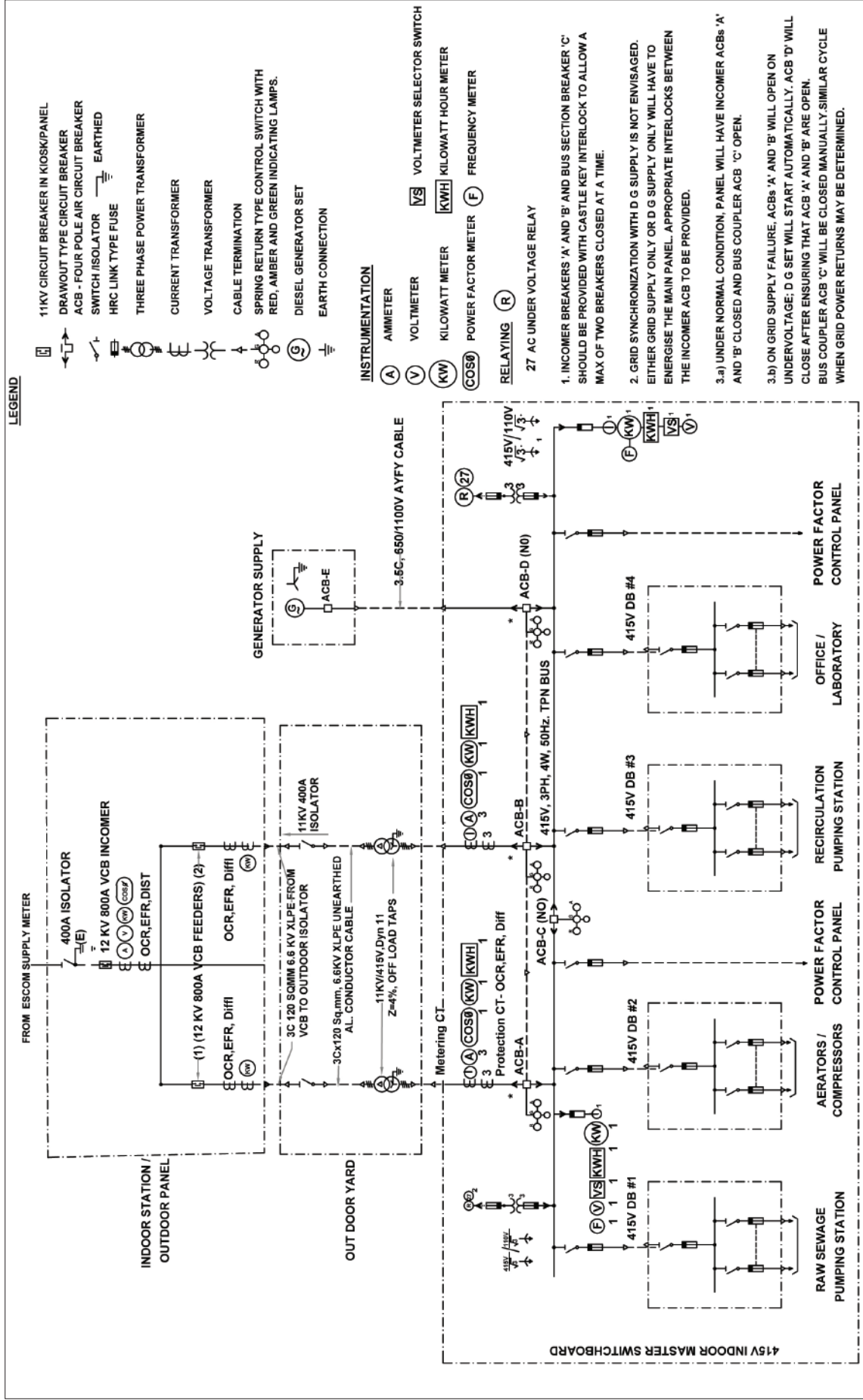


Figure 6.1 Typical Electrical Single Line Diagram of 11 KV Yard and Master Switch Board

6.2.1 Power Receiving and Transforming Equipment

If the STP facility receives the electrical supply at high voltage i.e., 66kV, 11kV, 6.6 kV, or 3.3 kV, it has to be reduced to the operating voltage level, which is usually 415V. A substation, which is used to step-down high voltage to low voltage, consists of the following equipment or devices:

6.2.1.1 High Tension (HT) Substation

The HT substation is composed of the following equipment and devices.

6.2.1.1.1 Disconnecting Switch

Disconnecting switches are devices to open/close a high voltage circuit when high-voltage equipment are inspected, tested or cleaned. The devices are capable of safely breaking no-load current but not load current. For safe O&M work, be sure to open/close the disconnecting switch only after opening a circuit breaker, which is located on the secondary side, just downstream of the disconnecting switch.

6.2.1.1.2 Circuit Breaker

Circuit breakers are switches that open/close electric-circuits in normal and abnormal conditions (especially in short circuit). Therefore, the circuit breakers must be capable of tripping the circuits in conjunction with protective relays and by cutting off the short-circuit current definitely and safely, avoiding accidents due to high current.

Circuit breakers for high voltage are categorised into the following types according to their techniques of eliminating arcs:

- A. Air Circuit Breakers (ACB)
- B. Vacuum Circuit Breaker (VCB)
- C. Inert Gas Method (SF₆)

6.2.1.1.3 Power Fuses

The function of a power fuse is to sense and prevent flow of excess current in electrical devices and electrical wire by melting the fuse element and thereby breaking the electric circuit when subjected to a short-circuit. Power fuses are typically used for smaller electrical systems because they have the capability and speed for breaking the circuit as compared with circuit breakers.

A proper O&M, practice is that even if only one fuse melts due to an accident such as a short-circuit in a three phase switch, all power fuses including the melted one should be replaced.

6.2.1.1.4 Voltage Transformer (VT) or Potential Transformer (PT)

Voltage transformers are used mainly in high-voltage distribution equipment to step-down voltage in measurement circuit for safe measurement; single-phase and three-phase types are manufactured.

The typical secondary voltage of the voltage transformer is 110 volt (Phase-to-Phase). They are also applied to protective relays.

O&M issues to be observed in case of a PT are as follows:

- If once short circuit occurs on the secondary side of a VT, excess current flows into the primary side and that may cause the fuse on the primary side to blow. The primary fuse has also to be checked when there is a fault trip or metering mismatch.

6.2.1.1.5 Current Transformer (CT)

Current transformers are used for stepping down current to be measured safely. It is also applied to protective relays.

The typical secondary current of the current transformer is 5 Amp or 1 Amp.

O&M issues to be checked are as follows:

- If the secondary side of CT is open-circuited, all the current flowing to primary side is excited by magnetic saturation and causes damages to the CT by over-heating. Therefore, the secondary side should never be left open-circuited. Even when the downstream instrument is removed for any repair, the secondary should be shorted.

6.2.1.1.6 Protective Relay

Protective relays should detect electrical faults promptly, isolate the faults from system and activate alarms when there is a faulty condition sensed in the electrical supply to the circuits or electrical equipment (short circuit, earth fault, single-phase, reverse power flow etc.)

The protective relays should have the following three characteristics:

- A. Certainty: The relay should always be sensing the parameters for action when there is a fault or specified abnormality.
- B. Selectivity: The relay should obey a selection of the limits beyond which a fault will be judged.
- C. Promptness: The relay should sense and operate within the shortest possible time.

Categories according to protective functions are as follows:

- A. Over current relay (OCR): Monitor and protect against over load and short-circuit.
- B. Under voltage relay (UVR) and over voltage relay (OVR): Detect and protect under voltage (power failure) or over voltage.
- C. Earth fault relay: Protect by detecting current leakage to earth.

Protective relay is shown in Figure 6.2 overleaf.



Figure 6.2 Electromagnetic Protective relay

Categories according to design as follows.

An electrochemical protective relay converts the voltages and currents to magnetic and electric forces and torques that press against spring tensions in the relay. The tension of the spring and taps on the electromagnetic coils in the relay are the main processes by which a user sets a relay.

In a Solid State relay, the incoming voltage and current waveforms are monitored by analog circuits, not recorded or digitized. The analog values are compared to settings made by the user by a potentiometer in the relay.

A Digital Relay converts all measured analog quantities into digital signals. Compared to static relays, digital relays introduce Analogue to Digital Converter (A/D conversion) of all measured analogue quantities and use a microprocessor to implement the protection algorithm.

The microprocessor may use some kind of counting technique, or use the Discrete Fourier Transform (DFT) to implement the algorithm. Since late 1990s most of the protective relays are of digital type.

Advantages of Digital Relays

- High level of functionality integration
- Additional monitoring functions
- Functional flexibility
- Capable of working under a wide range of temperatures. Internal power requirement is very low.
- They can implement more complex functions and are generally more accurate
- Self-checking features and self-adaptability
- Able to communicate with other digital equipment of contemporary design
- Less sensitive to temperature-related aging
- Economical because can be produced in required numbers and can be set at site
- More accurate
- Signal storage is possible

Limitations of Digital Relay

The devices have short lifetime due to the continuous development of new technologies.

- Needs to be protected against power system transients
- As digital systems become increasingly more complex they require specially trained staff for operation
- Proper maintenance of the settings and monitoring data

These limitations are overcome by progressive improvements in design, ruggedness, cost, low power and heat generation factors, standardized modular design, scalability and simpler training to operating staff.

6.2.1.2 Transformer

A transformer is the most important component in substations. Transformers receive electrical power at high voltage and transform it to lower service voltage. They also provide isolation between high voltage and low voltage supply.

Cooling system for oil-immersed transformer: Oil serves as direct cooling medium to disperse the heat that is generated from windings and core. The oil is in turn cooled by indirect cooling medium such as air at the oil radiator.

Cooling system for dry transformer: Utilize surrounding air or SF₆ as cooling medium.

Transformer Efficiency: The efficiency of a transformer varies between 96% and 99%. It not only depends on design, but also on operating load. The transformer losses are mainly attributed to:

- Constant Loss: This is also called iron loss or core loss, which mainly depends upon the material of the core and magnetic circuit of the flux path. Hysteresis and eddy current loss are two components of constant loss.
- Variable Loss: This is also called load loss or copper loss, which varies with the square of the load current.

The best efficiency of a transformer occurs at a load when constant loss and variable loss are equal.

For distribution transformers, installed in an STP, the best efficiency would occur around 50% load. O&M checks to be made are as follows:

- Check connections of cables for looseness and overheating
- Check the transformer for abnormal vibration and noise
- Check oil and winding temperature regularly with respect to manufacturer's manual
- Check for moisture ingress by observing the colour of the silica gel
- Check for level of oil in the conservator

A typical transformer is shown in Figure 6.3.



Figure 6.3 Transformer

6.2.1.3 Low Tension (LT) Panel

LT panels or LT switchboards are designed to distribute stepped-down voltage to power equipment and control panels.

They typically consist of moulded case circuit breakers (MCCBs), power contactors (PCs), protective relays (PRs), meters, indication lamps, control switches, etc.

A. MCCB

An MCCB is designed to “open/close” low voltage feeder circuit or branch circuit at normal condition. It also breaks the circuit automatically in case of abnormal condition such as overload, short circuit, etc.

B. Power Contactor

A power contactor is typically used for “on / off” control of motors. A relay can be installed on the circuit for overload protection. Electromagnetic force works to “open /close” the contacts.

The O&M checks to be made are as follows:

- Check for abnormal noise or overheating of exciting coils, abnormal noise and discolouration of contacts (carbonized or worn contact surfaces by arcing)
- Check for the proper working of all display indicators like voltmeters, ammeters, energy meters and indicator lamps
- Check whether the name of the panel is written on it and it is correct as per the SLD
- Check for the proper earthing of the panels

6.2.1.4 Bus-bar

Bus-bars are conductors to carry power among the various components in the power circuit in an outdoor station or distribution board. They are to be rated to carry the maximum rated current continuously and short-circuit current for a short time without damage.

The O&M issues to be cared for:

- Check connections for looseness and overheating, and check the bus bar for discolouration
- Check bus bars are properly colour coded (Red, Yellow or Blue) to represent the phases
- Check bus bars are properly enclosed within panels

6.2.2 Power Control

Correcting power factor is a typical power control technique. Power factor correction is described in this section.

6.2.2.1 Power Factor Correction

Active power, measured in kilowatt (kW), is the real power (shaft power, true power) used by a load to perform a certain task. However, there are certain loads like motors, which require another form of power called reactive power (kvar) to establish the magnetic field. Although reactive power is virtual, it actually determines the load (demand) on an electrical system. Electrical capacity required for some electrical equipment is referred to as “apparent power (kVA)”, that is, the vector sum of “active power” and “reactive power (lagging / leading)”.

Most of the power machineries in STPs are driven by three-phase induction motors, which are inductive loads. When an inductive load is driven, the sine wave of the load current flows at the same frequency as the sine wave of the voltage, but lags the voltage wave cycle slightly. When both current and voltage source waves cross zero and maximum value at the same time, the power factor is said to be unity, and the entire power can be utilised as real power. The ‘Apparent Power-kVA’ is equal to ‘the real Power-kW’. When the current wave is slightly lagging the voltage wave, the power factor is said to be lagging and is less than unity. The real power is less than the apparent power due to this lag.

A lagging power factor is not beneficial to a power consumer as the billing includes charges towards the kVA used, while the actual utilisation is less.

It is also not beneficial for the power supplier whose system power factor is also affected.

Equipment used in most industries such as drives, controllers, etc., are inductive loads, which lower the power factor. The power factor is the ratio between active power (kW) and total power (kVA), or the cosine of the angle between active and total power. A high reactive power will increase this angle and as a result the power factor will be lower. A vector diagram of power factor is shown in Figure 6.4 overleaf.

$$\begin{aligned}
 \text{Power Factor} &= \frac{\text{Active power}}{\text{Total power}} \\
 &= \frac{\text{kW}}{\text{kVA}} \\
 &= \cos \phi
 \end{aligned}
 \tag{6.1}$$

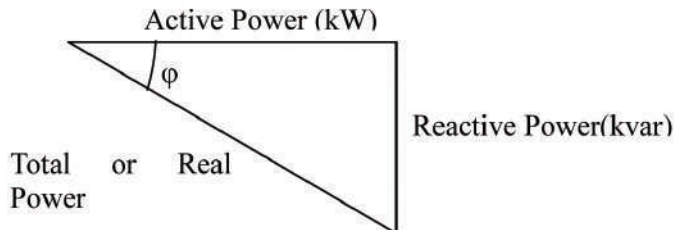


Figure 6.4 Vector diagram of Power Factor

In a typical STP since a large number of induction motors are used, the power factor will be low and needs to be improved or corrected. The power factor can be improved by installing power factor correction capacitors to the plant's power distribution system.

They act as advancing reactive power generators and therefore reduce the amount of lagging reactive power, and thus the total power, generated by the utilities.

To improve or correct the power factor, apparent electrical capacity required for the electrical equipment should be decreased by canceling the lagging reactive power by the use of leading reactive power unit that can also reduce energy loss in cables, transformers, etc., before reaching to load equipment.

Rating of capacitor to be required for power factor correction can be calculated by the following vector equation.

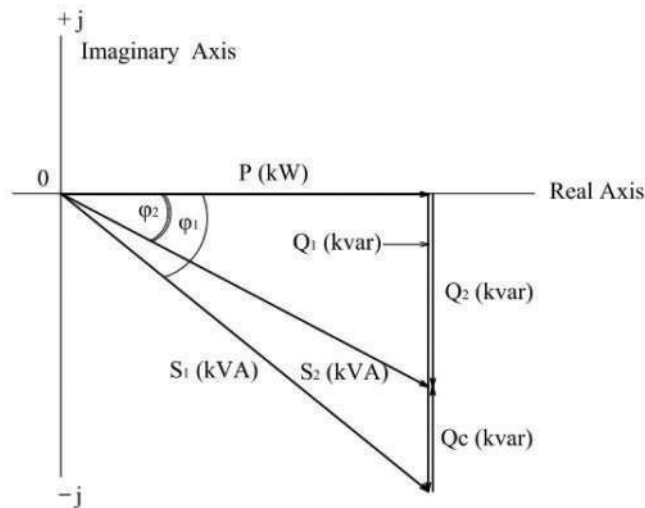
$$\begin{aligned}
 Q_c &= P \times (\tan \phi_2 - \tan \phi_1) \\
 &= P \times \left\{ \frac{\sqrt{1 - \cos^2 \phi_1}}{\cos \phi_1} - \frac{\sqrt{1 - \cos^2 \phi_2}}{\cos \phi_2} \right\} (kVA)
 \end{aligned}
 \tag{6.2}$$

Where, Q_c : Capacitor rating in kvar

A vector diagram of power factor control is shown in Figure 6.5 overleaf.

6.2.2.2 Capacitor Panel

Capacitor panels consist of some equipment such as condensers for power factor correction, series reactors meters, relays, etc.



- Where, S_1 : Apparent power (kVA) = $P - jQ_1$ (Before correction)
 S_2 : Apparent power (kVA) = $P - jQ_2$ (After correction)
 P : Active power (kW)
 Q_1 : Lagging reactive power (kvar) (Before correction)
 Q_2 : Lagging reactive power (kvar) (After correction)
 Q_c : Capacity of condenser (Advancing reactive power) (kVA)
 $\cos\phi_1$: Power factor before correction
 $\cos\phi_2$: Power factor after correction

Figure 6.5 Vector diagram of power factor control

6.2.2.2.1 Condenser (Capacitor)

Induction motors, which are inductive loads, generate lagged-phase reactive power. Phase-advanced condensers (capacitor) have the function of compensating the lagged-phase reactive power to improve power factor.

The effects gained from the condensers vary according to the points to be installed. For example, it is effective to install a condenser on the secondary side of a transformer if reduction in load and loss of the transformer is targeted.

With regard to O&M, the capacitor's reactive power acts during light load (when power equipment has stopped), and when the current leads the voltage in the circuit so that leading power factor occurs, and the terminal voltage of the load increases causing adverse effects on the equipment. To prevent this phenomenon, the capacitor may need to be isolated, or an automatic power factor regulator may need to be installed.

Normally, a capacitor unit comprises of individual capacitor elements arranged in parallel/ series connected groups within a steel enclosure. An internal discharge device is a resistor that reduces the unit residual voltage to 50V or less in 5 minutes. Capacitor units are available in a variety of voltage ratings from 240 V – 66,000 V and sizes (2.5 kvar – about 1,000 kvar).

The capacitors can be with external fuses or internal fuses, or both. An internal fuse is a small fuse wire connected to each capacitor element, encapsulated in a wrapper. When a fault occurs in a particular element, the particular fuse melts, disconnecting the affected element only, and permitting the other elements to function without interruption. An external fuse unit typically protects each capacitor unit in a bank. In an oil-impregnated capacitor, the internal pressure may increase resulting in expansion due to excessive current because of the failure of internal elements. This leads to leakage of oil from the capacitor unit and failure of the capacitor. Care should be taken to select capacitors with sufficient cooling volume.

When a capacitor circuit is switched on, there is an inrush current, which is likely to damage the capacitor. A choke or series reactor is used to control the inrush current.

6.2.2.2.2 Series Reactor

The major functions of a series reactor are to protect the capacitor by means of the following:

- Limiting inrush current during switching
- Limiting resonance and protection of capacitor banks
- Harmonic filtration
- Lower loss and noise level

6.2.2.3 Power Factor Correction at Motor Panel

Power factor can be increased by installing low voltage capacitor in parallel with the motor. This enables the current to be reduced. Moreover, distortion waveform can also be stabilized by connecting a series reactor.

6.2.3 Operation of Electrical Equipment During Power Supply Interruption

Power interruption is classified into two types: a scheduled power interruption and an unscheduled power interruption.

The former requires specific operational procedure before interrupting the power supply, which is to “open” the switches from the load side (power distribution panel) to the power source (power receiving panel) sequentially. To restart the power supply, “close” the switches from the power source (power receiving panel) to the load side (power distribution panel) one by one.

Make sure that the personnel in charge of the interruption/ restart operation thoroughly knows the configuration of the machinery, the operational characteristics, the operational procedures, the place or position of switches installed, the electrical scheme diagram and the load circuit diagram to avoid incorrect procedures.

During the work of starting, operating and stopping the load equipment, pay attention to meter readings, vibration, heat, and sound of equipment. If some abnormal state is found, report to the related person in charge immediately, investigate the causes and take appropriate measures.

In the latter case, investigate the cause of the power failure first. Power failures can be caused by the following: some failure attributed to the power company (outside power suppliers) and some local fault in the STP. To identify the causes, read indicated values or signs on the incoming supply voltmeter, under-voltage relay, earth fault relay, over current relay, etc.

Judgement by incoming supply voltmeter or under-voltage relay

- If the receiving voltmeter indicates “0” and the under voltage relay is “tripped,” it implies that power is interrupted on the power source side (attributed to power company). After confirming that the receiving circuit breaker is “opened,” the contact person or authority prescribed by the power company should be asked about the causes and the estimated recovery time. However, the related substation should try to restore power at the earliest.
- If the reading of the receiving voltmeter is within a specified range, the under voltage relay is “untripped” and the earth fault relay or the over current relay is “tripped,” that implies some failure (overload, short, earth fault, etc., in equipment or lines) has occurred in the STP and the circuit breaker for receiving power is “opened.” By studying the protective relay, circuit breakers, etc., which were tripped or opened, identify the line with fault and isolate the broken down point immediately before recovering from the failure.

6.2.4 Gas Engines

Generally, digester gas is used as fuel in boilers for heating sludge digestion tanks; surplus gas is incinerated in biogas combustion units or flared and discharged to the atmosphere. An example of flow of power generated from digester gas is shown in Figure 6.6.

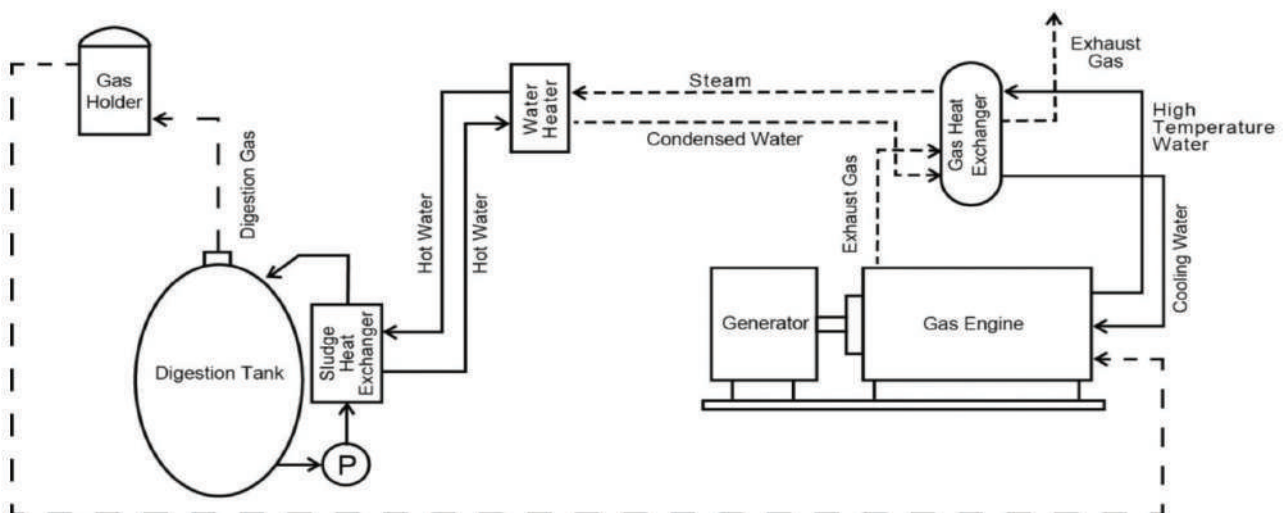


Figure 6.6 Example of flow of power generated from digester gas

A sewage gas generator uses the sewage gas as fuel to a gas engine and generates electricity, which is supplied to equipment within a STP. The digester gas engine consumes gas as fuel and employs spark-ignition method, which is the same as the one used in petrol car engines.

The O&M issues to be noted are mentioned overleaf;

- Typical concentration of NO_x in exhausted gas from digestion gas engines is about 2,000 ppm. NO_x should be reduced to prevent air pollution
- Replace the ignition plugs in the spark-ignition system periodically
- Periodic opening up, cleaning and inspection of a digestion gas engine is extremely important because siloxane compound gets deposited in the combustion chamber of such an engine, which causes faults in engine parts

6.2.5 Dual Fuel Engine

Dual-fuel (gas-diesel) engines are compression-ignition, not spark-ignition engines. To ignite, they simultaneously burn gas and a small amount of diesel fuel as pilot fuel. Their controls also allow automatic switchover to 100 % diesel fuel operation without changing load if the digestion gas supply is inadequate or is interrupted. This capability is a beneficial feature for standby units because they can start and operate even during power failures.

Dual-fuel engines typically use 1 to 5 % diesel fuel oil, but many can, if necessary, operate on 1 to 100 % diesel fuel. Such fuel flexibility is an excellent advantage, especially if the digester gas supply is disrupted. This option includes storage and handling equipment for diesel fuel, along with gas compressors to supply digester gas to these engines. The same O&M checks should be made for the diesel engine and the gas engine. Please refer to 6.3.2 and 6.2.4.

6.3 STANDBY POWER SUPPLY SYSTEM (GENERATOR)

Standby or emergency power can be supplied through AC(alternating current) generator and diesel engine. Most generators of STPs are installed for the purpose of standby power supply.

Therefore, they should be highly reliable because the STPs have to keep functioning without hindrance even in the event of unexpected power cut from the power company.

6.3.1 AC Generator

A generator is a machinery that converts mechanical energy to electrical energy by electromagnetic action to generate electrical power.

Synchronous generator, the principle of which is reverse as that of an electric motor, is an AC generator, which generates electric power synchronizing to rotating rate of magnetic field passing through armature windings.

Frequency of the synchronous generator is determined according to the rate of rotation, and accordingly, the frequency decreases as the rate of rotation becomes lower than the synchronous rate.

Therefore, the rate of the engine for the synchronous generator should be regulated to maintain the level of synchronous rate. The O&M issues to be taken care of are mentioned overleaf:

- Winding
 - Oil or dust on windings or air vent sleeves obstructs air ventilation and leads to overheating of the generator and deterioration of insulators, which may cause short circuit and ground fault. The dust should be blown-off by a compressed air and the oil and grease should be removed with cloth, cleansing oil, etc.
 - In the case of severe accumulation of oil and dust, it is recommended to have the winding cleaned and varnished with insulation paint after drying thoroughly, by a professional cleaning company.
 - Insulation coating over terminals should be checked for overheat or discolouration due to cracks or slacks.
- Bearing
 - Pay full attention to any abnormal noise from bearings during running to detect any defect at early stage. It is the simplest way to check bearing conditions.
 - Grease should be supplied through the openings periodically while the generator is running. If a drain valve is provided to the grease chamber, always open the valve during filling grease to purge out old grease.
- Brush (Static excitation system)
 - Worn brush reduces brush pressure and causes sparks that may make the surface of a slip ring rough. To prevent it, always check for abrasion, unsymmetrical wear or damage to brush, and pressure of the brush holder. The brush-lifting device should be inspected to ensure that it works properly.
 - Brushes should be replaced with new ones when the wear level reaches the designated value. The newly installed brushes should preferably be of the same material and shape as the currently used ones.
- Exciter (brushless)
 - Exciters hate moisture and dust. Dust should be blown-off by low-pressure compressor and wiped with dry cloth.
 - Check bolts and nuts on terminal area and terminal block for looseness, wires for discolouration and conditions of earthing and installation.

6.3.2 Diesel Engine

Diesel engines are generally used as drives for back-up power generators.

The diesel engine works by the action of high-speed diesel combustion, which pushes out pistons by the expansion based on self-ignition. The compressed air is hot enough to self-ignite when diesel fuel is injected. Piston action caused by the energy is converted in the crank-shaft to rotating energy, which drives the generator. High-speed diesel is typically used as fuel.

The O&M issues to be handled are as follows:

- For details of maintenance and inspections, follow the manufacturer's manual
- Regularly check the fault alarm to ensure it works properly
- During inspection and maintenance, take care not to allow dust contamination especially into fuel or lubrication system
- Check wiring for loose connection and check piping for leakage
- Do not place anything around an inlet port that obstructs suction
- Pay attention to abnormal noise and overheat
- Where it is necessary to store diesel for such engines, mandatory precautions regarding storage-area fire protection, clearances, etc., should be followed. Appropriate clearance from the jurisdictional authorities on pollution control and inflammable fuel storage should be obtained.

6.3.3 UPS

UPS stands for Uninterruptible Power Supply and is a power supply device, which works when the usual power source is interrupted. UPS is used to keep critical systems like monitoring, SCADA, communication and alarm systems running even when power is not available from main source. A typical UPS circuit is shown in Figure 6.7.

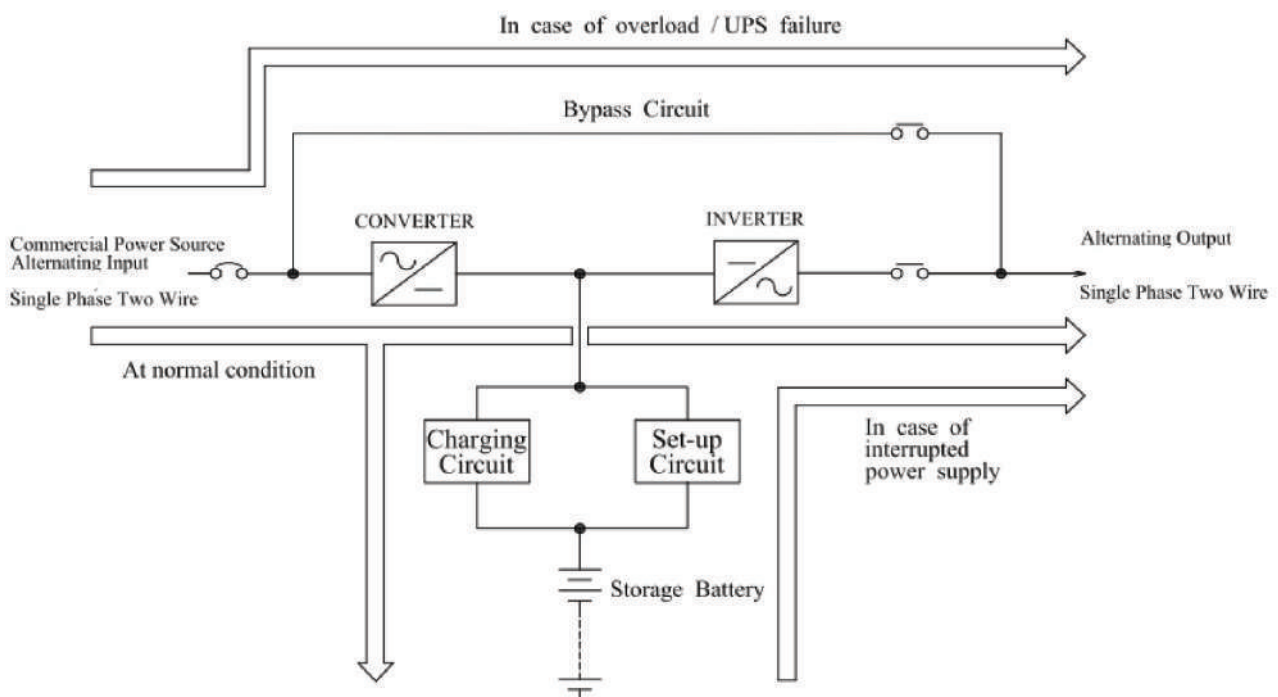


Figure 6.7 UPS circuit

In the normal condition, commercial AC (alternating current) power is sourced and converted to DC (direct current), which is then supplied to an inverter, and charges a battery.

When the commercial power source is interrupted, power charged in the battery is converted to AC and supplied to the load.

The UPS has a rectifier to convert AC supply to DC for charging the battery, a DC to AC inverter to convert the battery output to AC voltage, and a battery to act as a source of power during normal power interruption. Other components like protection, fuses, indication, surge controlling circuit etc., are also built into the unit.

The following points should be checked as maintenance tasks:

- Check for abnormal noise, smell and heat in UPS
- Check for looseness in each connection
- Check appropriate time for battery replacement
- Check for clogged ventilation opening
- Ensure spare fuses are kept in stock and are easily accessible nearby.

6.4 PRIME MOVERS

6.4.1 Induction Motor

Three-phase induction motor is widely used as a general-purpose motor due to high reliability and low price among driving forces for general industrial machinery. Most prime movers used for pumps or blowers in STPs are three-phase induction motors.

A three-phase induction motor rotates the rotor by a rotating electromagnetic field, which is generated in the stator core by AC current flowing in the stator winding.

$$\begin{aligned} N_s &= 120f / p \text{ (rpm)} \\ N &= (1-s)N \text{ (rpm)} \\ s &= (N_s - N) / N_s \end{aligned} \tag{6.3}$$

Where, f : Frequency (Hz)
p : Number of magnetic poles
s : Slip

Rotating speed of the revolving magnetic field is referred to as “synchronous speed” and expressed as N_s (rpm). The speed of the rotor itself is slightly lower which is expressed as N (rpm). The ratio of N_s to the differential speed (N_s/N) is referred to as “slip”.

6.4.2 Starters

An extremely large current of about five to eight times the rated current flows when a motor is started. The power factor is at an extremely low value of about 0.2 at the start. The duration of the starting current is short, but the motor winding coil is subjected to thermal stress load as Joule heat. Voltage fluctuation occurs in the power system and its effect becomes more pronounced.

The starting method of three-phase induction motor includes a method of restricting current at start as mentioned above, and other methods described below.

A. Direct-on-line Starter

Power supply voltage is applied as-is, and a starting current which is several times the rated current flows. This starter is used in motors requiring comparatively small starting currents.

B. Star Delta Starter

$1/\sqrt{3}$ of power supply voltage is applied on the Y (star) connection winding at start, while Δ (delta) connection is used during operation. Compared to the full voltage starter, the starting current is one third and the starting torque is also one third.

C. Reactor Starter

The voltage to be applied to the motor at start is reduced by the reactor and full voltage is applied after the motor picks up speed, and is operated. The starting current can be restricted to a smaller value compared to the Y- Δ starting method.

The circuit diagram of some of the starting methods are shown in Figure 6.8.

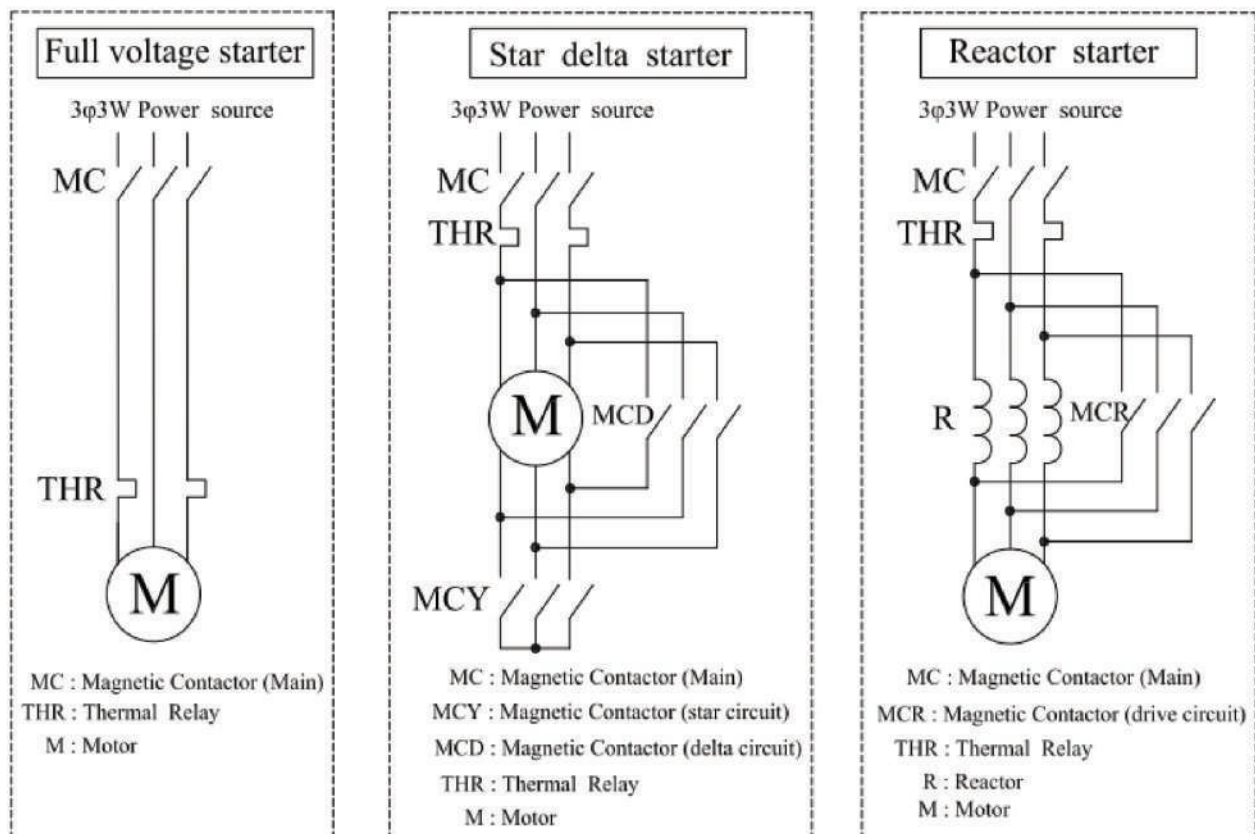


Figure 6.8 Starters

Another starting method is to use a starting compensator.

Equation for induced electromotive force:

$$E = K \times n \times \phi_m \times f \quad (6.4)$$

Where, E : Induced electromotive force (V)

n : Number of active coils

ϕ_m : Maximum magnetic flux (wb)

f : Frequency (Hz)

K : Factor of proportionality ($\sqrt{2} \times \pi \times 4.44$)

Torque equation:

$$T = K' \times V^2 / f \quad (6.5)$$

Where, T : Torque (N·m)

V : Voltage of power source (V)

f : Frequency (Hz)

K' : Factor of proportionality

6.4.3 Characteristics of Induction Motor

Theoretical analysis should be carried out to study torque characteristics and overheating of three-phase induction motor due to fluctuation in frequency and variation in voltage of the motor.

A. When power supply voltage is greater than the rated voltage

According to the equation for induced electromotive force, the frequency is constant, therefore the maximum magnetic flux Φ_m increases and the over-excitation phenomenon occurs. Heat is generated because of this excitation current. In a submersible pump, when a thermal protector is built-in in the internal coil for protection, it may activate.

B. When power supply voltage is smaller than the rated voltage

According to the torque equation, when the frequency is constant, the power supply voltage V reduces, so the torque reduces.

C. When the power supply voltage is unbalanced

When the power supply voltage is unbalanced, reverse phase current flows and the temperature increases because of load loss in the coil resistance.

D. When the frequency f is higher than the rated frequency

According to the torque equation, when power supply voltage is constant, the torque reduces.

E. When the frequency f is lower than the rated frequency

When the power supply voltage is constant, the maximum magnetic flux ϕ_m increases, and heat is generated because of the excitation current. According to the torque equation, when the power supply voltage is constant, the torque increases.

6.4.4 Performance Assessment of Motors

6.4.4.1 Efficiency of Motors

The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design and operating condition. Losses can vary from approximately 2 to 20 %. Table 6.1 shows the types of losses and their typical shares for an induction motor.

Table 6.1 Type of losses and shares for induction motors

Type of loss	% of total loss	Type of loss	% of total loss
Fixed loss or core loss	25	Friction & rewinding loss	15
Variable loss: stator I^2R loss	34	Stray load loss	5
Variable loss: rotor I^2R loss	21		

The efficiency of a motor can be defined as “the ratio of a motor’s useful power output to its total power output”. Factors that influence motor efficiency include:

- Age - New motors are more efficient
- Capacity - As with most equipment, motor efficiency increases with the rated capacity
- Speed - Higher speed motors are usually more efficient
- Type - For example, squirrel cage motors are normally more efficient than slip-ring motors
- Temperature - Totally-enclosed fan-cooled (TEFC) motors are more efficient than screen protected drip-proof (SPDP) motors
- Rewinding of motors can result in reduced efficiency
- Load, as described below

There is a clear link between the motor’s efficiency and the load. Manufacturers design motors to operate at a 50–100% load and to be most efficient at a 75% load. But, once the load drops below 50% the efficiency decreases rapidly as shown in Figure 6.9 overleaf. Operating motors below 50% of rated loads has a similar, but less significant, impact on the power factor. High motor efficiencies and power factor close to 1 are desirable for efficient operation and for reducing costs down of the entire plant and not just the motor.

6.4.4.2 Motor Load

Because the efficiency of a motor is difficult to assess under normal operating conditions, the motor load can be measured as an indicator of the motor’s efficiency. As loading increases, the power factor and the motor efficiency increase to an optimum value at around full load. It is necessary to see the percentage loading of the motor. If the motor runs at more than 70% load, then the power factor and efficiency will be good.

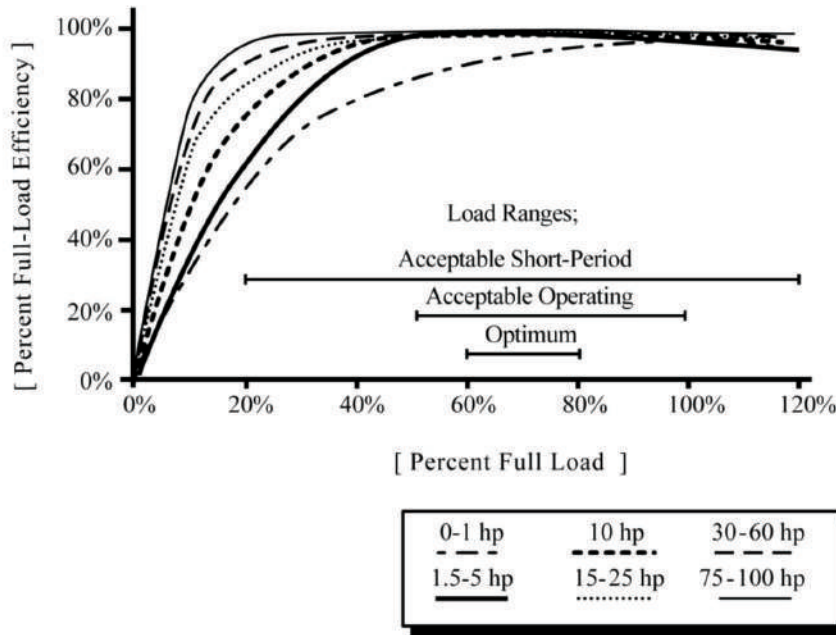


Figure 6.9 Motor part load efficiency

6.4.4.3 Energy Efficiency Opportunities

Apart from operational point of view, the motors should be seen from energy efficiency opportunities also. The following points may be considered:

- A. Replace standard motors with energy efficient motors
- B. Reduce under-loading
- C. Avoid over-sized motors
- D. Improve power quality
- E. Do not go for multiple time rewinding
- F. Improve maintenance practices

6.4.5 Condition Monitoring Techniques

6.4.5.1 Vibration Monitoring

The vibration in rotating machinery is caused by many reasons like unbalance, misalignment, loose foundation, mechanical looseness, bearing damage etc.

Vibration monitoring is the most common, versatile and powerful condition monitoring technique adopted in rotating machinery to identify problem areas. The severity of the vibration is specified by IS 2372, which is measured with reference to class of machine.

The criteria for class of machine are given in Table 6.2 overleaf. For the above class of machine, the vibration severity can be judged by the guidelines shown in Table 6.3 overleaf.

Table 6.2 Criteria for class of machine

Class of machine	Criteria
Class- I	Individual parts of engines and machines integrally connected with the complete machine in its normal operating condition. (Electrical drives up to 15 kW are typical examples of machines in this category)
Class- II	Medium sized machines (typically electrical motors with 15 to 75 kW output) without special foundation, rigidly mounted engines or machines (up to 300 kW) on special foundations.
Class- III	Large prime movers and other large machines with rotating mass mounted on rigid and heavy foundations which are relatively stiff in the direction of vibration measurement.
Class- IV	Large prime movers and other large machines with rotating masses mounted on foundations which are relatively soft in the direction of vibration measurement (such as turbo-generator sets, especially those with light-weight structures)
Class- V	Machines and mechanical drive systems with un-balanceable inertia efforts (due to reciprocating parts), mounted on foundations which are relatively stiff in the direction of vibration measurement.

Table 6.3 Vibration severity chart for machine vibration limits

Range for vibration severity in velocity (mm/sec)	Example of Quality Judgment for Separate Classes of Machines				
	Peak	RMS	Class -I	Class -II	Class -III
0.40	0.28	Good	Good	Good	Good
0.64	0.45				
1.0	0.71	Normal	Normal	Normal	Normal
1.58	1.12				
2.5	1.8	Still Acceptable	Still Acceptable	Still Acceptable	Still Acceptable
4.0	2.8				
6.4	4.5	Unacceptable	Unacceptable	Unacceptable	Unacceptable
10.0	7.1				
15.8	11.2	Unacceptable	Unacceptable	Unacceptable	Unacceptable
25.0	18.0				
40.0	28.0	Unacceptable	Unacceptable	Unacceptable	Unacceptable
64.0	45.0				

The guidelines for vibration frequencies and likely causes are mentioned in Table 6.4 overleaf.

Table 6.4 Vibration frequencies and likely causes

RPM / Frequency	Most Likely Causes	Other Possible Causes & Remarks
1xRPM	Unbalance	Misalignment (if high axial vibration) Bad belts Resonance
2xRPM	Mechanical Looseness	Reciprocating Forces Electrical Problem
3xRPM	Misalignment	Usually a combination of misalignment and excessive axial clearance (Looseness)
Less Than	Oil Whirl (Less than 1/2 of RPM)	Bad drive belts Background vibration Sub-harmonic resonance
AC Line Freq.	Electrical Problem	Common Electrical Problems
Many Times RPM (Harmonically related)	Bad Gears Aerodynamic forces Hydraulic forces Mechanical Looseness Reciprocating forces	Gear teeth times RPM of bad Gear No. of fan blades time RPM No. of impeller vane times RPM May occur at 2,3,4 and sometimes higher harmonics if severe looseness
High Frequency (Not Harmonically related)	Bad antifriction Bearings	Bearing vibration may be unsteady amplitude and frequency, cavitation, recirculation and flow turbulence cause random and high frequency vibration, rubbing

6.4.5.2 Vibration Analysis

If the measured vibration level is more than the acceptable level, then it calls for vibration analysis, which is a captured time waveform plotted as amplitude versus time, or data can be transformed using a Fast Fourier Transform (FFT) and expressed as amplitude versus frequency. Any random vibration signal can be represented by a series (a Fourier series) of individual sine and cosine functions that can be summed to yield an overall vibration level. The amplitude of this vibration signal defines the severity of the problem. Plotting the amplitude versus the frequency (the Fourier spectrum) allows for identification of discrete frequencies contributing most to the overall vibration signal, commonly referred to as a “signature analysis” or a “frequency spectrum”, Machine looseness, misalignment, imbalance, and soft foot conditions are all fairly easily identified in the frequency spectrum generated by an analyser. The vibration monitoring and analysis should be done periodically, typically once in 6 months for all rotating equipment.

6.4.5.3 Thermographic Analysis

Commonly identified with electrical equipment monitoring, thermography is also a useful tool for monitoring plant machinery.

Thermography measures infrared radiation energy emissions (surface temperatures) to detect anomalies. Infrared cameras have resolution to within 0.1 °C and digitally store captured images. Both the absolute and relative temperatures can be obtained on virtually all types of electrical equipment, including switchgear, connections, distribution lines, transformers motors, generators and bus work.

This technique is very popular because of the following reasons:

- It is a non-contact type technique
- Fast, reliable and accurate output
- A large surface area can be scanned quickly
- It can be easily scanned from a distance up to 50 m.
- Presented in visual and digital form
- Software back-up for image processing and analysis
- Requires very little skill for monitoring

This technique can be used very well for seeing the loose contact, corrosive contact of all types of electrical joints, body temperature of motor and transformers, panels, etc.

The criteria shown in Table 6.5 may be used to know the severity of the problem.

Table 6.5 Criteria for differential temperature of electrical equipment

SL	Criteria (A)	Criticality Condition	Recommended Action
1	Up to 10 °C	Non-critical	No action is needed.
2	Between 10°C to 20°C	Less critical	Regular monitoring is needed.
3	Between 20°C to 40°C	Semi critical	Close monitoring needed. Should be attended in the next opportunity.
4	Above 40°C	Critical	Should be attended immediately as per the severity.

The typical thermographic measurements are illustrated in Figure 6.10 overleaf.

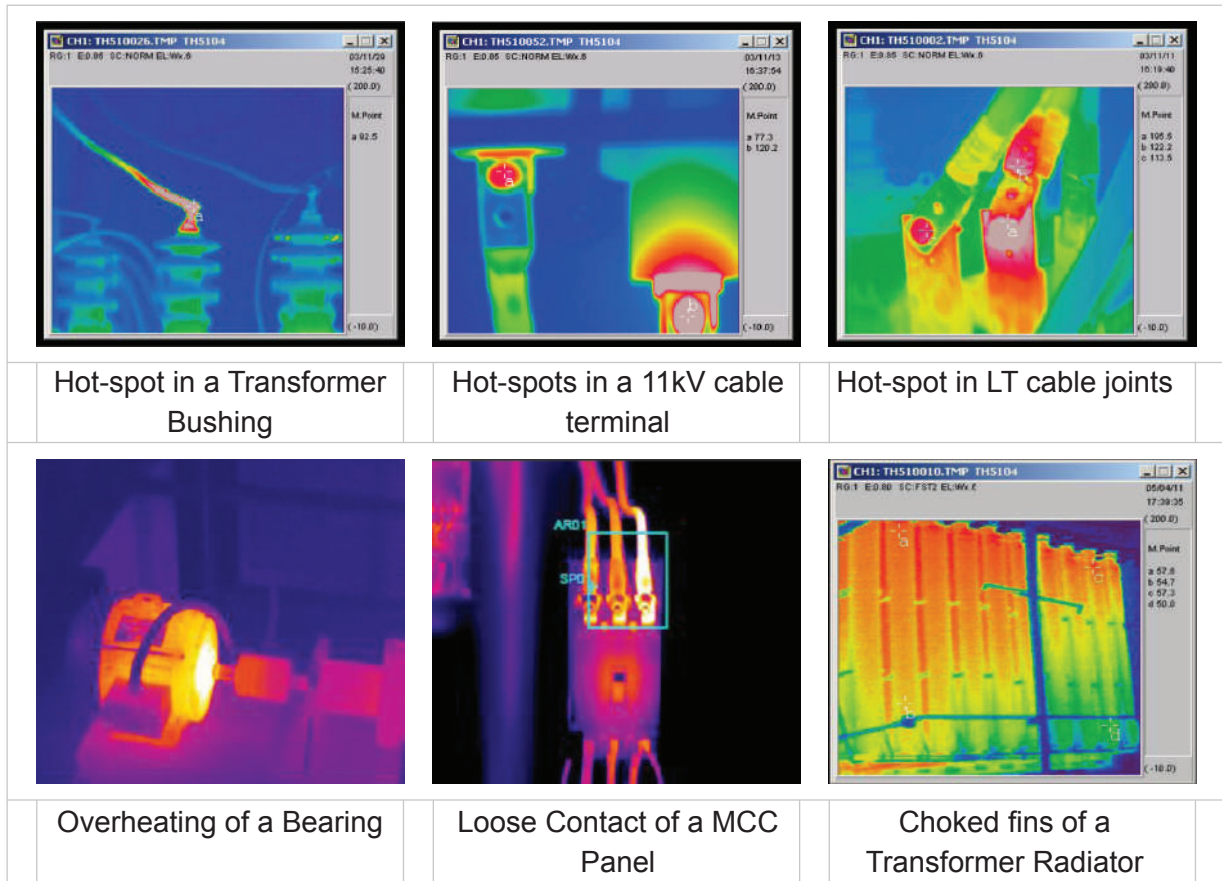


Figure 6.10 Thermographic measurement

6.4.6 Speed Control Equipment

The following five types of ASDs (Adjustable Speed Device) are available.

- VFD: Electronic devices to control the speed of the motor by controlling the frequency of the voltage at the motor.
- Direct current ASDs: Electronic devices to control direct-current motors by changing the voltage applied to the motor.
- Eddy-current drives: Electrical devices that use an electro-magnetic coil on one side of coupling to induce a magnetic field across a gap, creating an adjustable coupling.
- Hydraulic Drives: Devices that operate much like an automotive hydraulic transmission.
- Mechanical speed-control products including gearing, mechanical transmissions, and belt drivers with variable-pitch pulleys can be used.

6.4.6.1 Variable Frequency Drive (VFD)

VFD varies the revolving speed of an induction motor freely by changing the power supply frequency and the power supply voltage. A power transistor is used for the main circuit and IC, and a microcomputer is used for the control circuit of VFD.

Further advanced controlling technology has been applied due to improved semiconductor devices in recent years.

Moreover, generally, VFD is also called inverter control equipment or variable voltage variable frequency (VVVF) equipment. The fundamental configuration is shown in Figure 6.11.

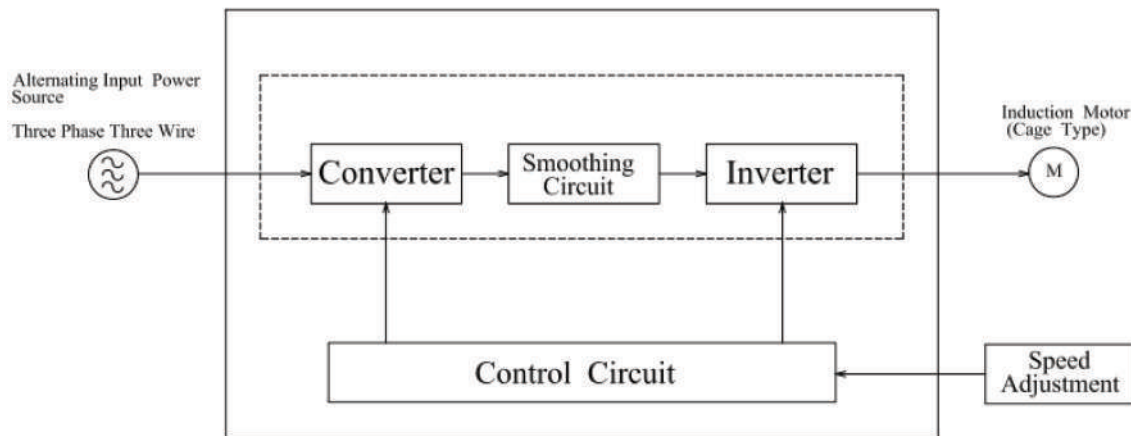


Figure 6.11 Variable Frequency Drive

After changing an alternating power source into direct current in a converter part and making it smooth, transform the direct current inversely to variable frequency alternating current at an inverter part

6.4.6.2 Advantages and Disadvantages of VFD

Advantages:

- Variable speed continuous operation over a wide range is possible
- Energy-saving possibility exists
- Brush, slip rings and so on, used in induction motor are not required
- Soft start and soft stop are enabled, extending the motor life
- Settings for acceleration timing and deceleration timing can be adjusted
- Starting current can be reduced

Disadvantages:

- Harmonic protection measures are necessary since high frequency current is generated
- Generation of leakage current and noise due to high frequencies need to be restricted
- Noise prevention for other equipment (especially measuring instruments) is necessary

Affinity Laws for Pumps and Hydraulic Machinery

One of the pump characteristics is that its load torque is proportional to the square of its revolving speed, and this torque is called square reduction torque load.

- Relationship between speed of revolution N (rpm) and flow rate Q ($\text{m}^3/\text{sec.}$)
Flow rate is proportional to the speed of revolution. $Q \propto N$
- Relationship between speed of revolution N (rpm) and head H (m)
Head is proportional to the square of speed of revolution. $H \propto N^2$
- Relationship between speed of revolution N (rpm) and power P (kW)
Power is proportional to the cube of speed of revolution. $P \propto N^3$
- Relationship between speed of revolution N (rpm) and torque T (N-m)
Torque is proportional to the square of speed of revolution. $T \propto N^2$

6.4.7 Motor Protection Equipment

Protection equipment for three-phase induction motors includes the following:

- Circuit breaker

It has overload and short circuit protection functions.

The former is a thermal function and has on-delay characteristics, while the latter is an electromagnetic function and has instantaneous characteristics.

- Thermal relay

Changes bimetal with Joule heat of overload current, opens or closes the contact, and performs on-delay operation.

- Comprehensive motor protection relay

This unit measures the current from all the three phases and checks for single-phase, unbalance and overload. The measurement and comparison of these three factors provide protections against short circuit, single-phase, earth fault, phase sequence and thermal protection to the motors.

Temperature sensing thermistors are also embedded in the stator winding of HT motors during manufacture and connected to relays to monitor winding temperature and raise alarm when needed

- Dry-run protection

In addition, dry-run protection is also provided by water level sensors in the sump, which sense any low level of water and prevent dry running, thereby protecting the pump and motor.

6.5 INSTRUMENTATION FACILITIES

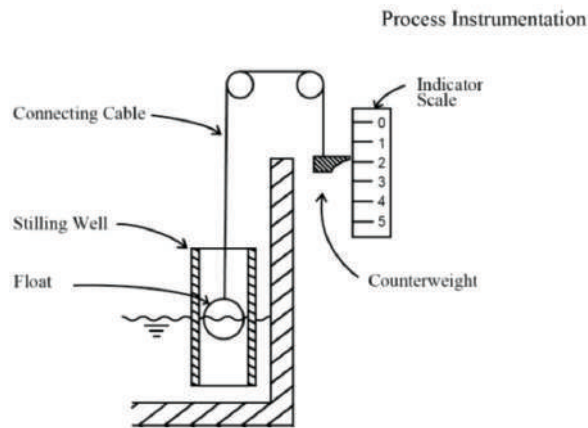
6.5.1 Flow Measuring Equipment

Please refer to Chapter 3 for “flow measuring equipment.”

6.5.2 Level Measuring Equipment

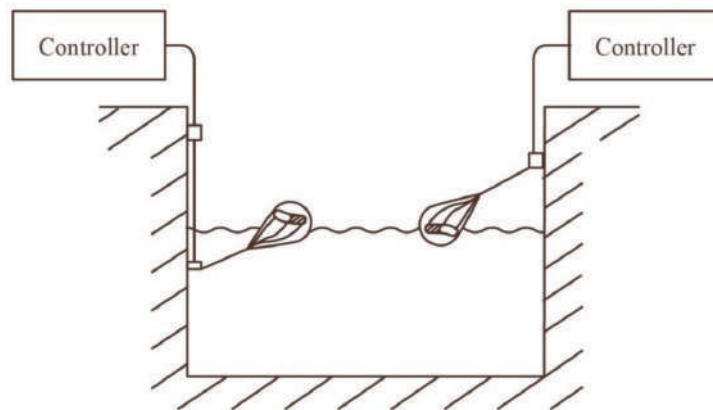
6.5.2.1 Float

A float device measures a liquid level from above. Floats, one of the oldest and simplest methods of level measurement, are used extensively in wet-wells or sludge sumps that require a discrete high or low level indication. They are also used for local indication of level in tanks and open channels as in Figure 6.12 and Figure 6.13.



Source: WEF,2008

Figure 6.12 Counter weighted float-level indicator



Source: WEF,2008

Figure 6.13 Float switches

A float level meter shown in Figure 6.12 senses water level through a slide rheostat as resistance and converts the changed resistance into current. It transmits analog output signal (DC 4 mA to 20 mA) proportional to the water level and sends the signal representing the water level continuously to the monitoring room.

The O&M issues to be cared for are as follows:

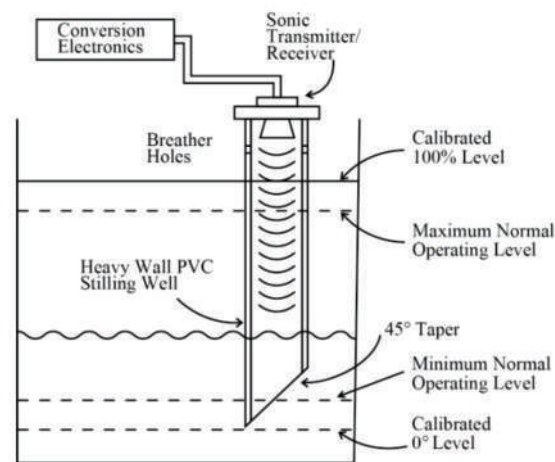
- Clean inside the stilling well regularly and keep it free from floating matter or scum to prevent malfunctions

- Check moving parts such as a counter weight, pulley and wires for corrosion or damage

The level switch shown in Figure 6.13 is used to control the pump and to issue alarms according to water level. The signals from the level switch are “on/off” digital signals, which compromise a sequence circuit. Float switches should be located away from the tank walls to prevent the floats from banging against the concrete wall and internal contacts from failures.

6.5.2.2 Ultrasonic

The ultrasonic level measuring device is installed above the liquid surface and measures the level by generating a pulse of ultrasonic waves that bounce off the liquid surface below. The instrument detects the echo, calculates the echo’s travel time and converts it to a level measurement as shown in Figure 6.14.



Source: WEF,2008

Figure 6.14 Acoustic level-sensor installation

Specifically, the relation between distance from sonic transmitter/ receiver to the liquid surface and the reaching time is expressed in the following formula:

$$H = \frac{1}{2} \times c \times t \tag{6.6}$$

- Where,
- H : Distance from transmitter/ receiver to liquid surface (m)
 - c : Sonic velocity in air= 331.5 + 0.61 × temperature in Celsius (m/s)
 - t : Time from transmission to receiving (sec)

O&M issues to be taken care of are as follows:

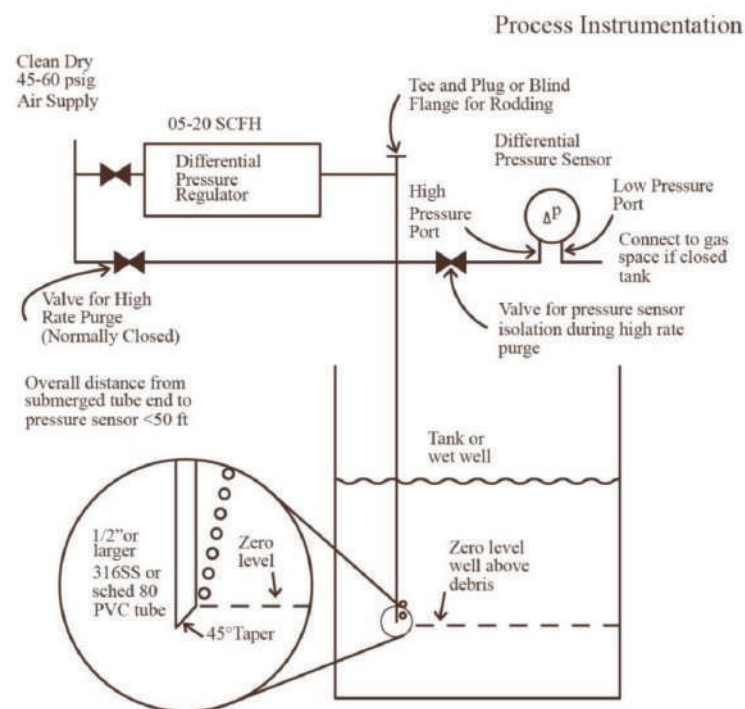
- Ultrasonic level meters require little daily maintenance because they have no moving parts and work without contacting the measuring objects. However, the junction boxes have to be regularly checked for any water ingress
- Keep clear the area around transmitter / receiver
- Keep liquid surface without scum, foam, wave, etc.

6.5.2.3 Head-Pressure

The head pressure level measuring devices, bubbler tubes and diaphragm bulbs measure the head pressure at the liquid level and are often used in open-channels or non-pressurized tank applications.

6.5.2.3.1 Bubbler Tube System

The bubbler tube system uses a small, regulated airflow that constantly bubbles into the liquid. Because the airflow is small, the system produces a backpressure equal to the static head of the liquid. A conventional pressure gauge or transmitter measures this back pressure as the height of an equivalent water column. A schematic of bubbler tube system is shown in Figure 6.15.



Source: WEF,2008

Figure 6.15 Schematic of bubbler-level system

Corrections are required when the liquid's specific gravity differs significantly from water. Because air is constantly bubbling out of the bubbler tube, the system is typically self-purging. Valves may be arranged to isolate the pressure-measuring device while providing high purge flow through the tube for preventive maintenance blow-down if fouling occurs.

Stilling wells are often used to protect the bubbler tube from turbulence and damage. To protect pneumatic instruments and regulators, operators should clean the air supply of excessive moisture and oils.

When bubbles are discharged into the liquid from the front end of pipe, the pressure within the pipe becomes equal to the static pressure of liquid at the front end of the pipe. This pressure is proportional to the liquid height h .

The calculation is expressed as given below:

$$h = P / \gamma(m) \quad (6.7)$$

Where, h : Water level from tube end (m)
 P : Internal pressure of tube (Pa)
 γ : Specific gravity of liquid (kg/m³)

Precautions for O&M are as given below.

The bubble type liquid level gauge does not have moving parts or mechanisms, so it has comparatively high accuracy. Moreover, it is suited to level gauges for corrosive liquids. However, daily maintenance of air sources such as compressor, purging set and air piping is very important.

6.5.2.3.2 Diaphragm Bulb System

The diaphragm bulb system operates on the principle that air sealed between the dry side of the diaphragm (in the capillary tube) and the receiver compresses or expands with the movement of the diaphragm.

A change in the static head of the liquid being measured moves the diaphragm, so the pressure of the trapped air is the same as the head pressure. Temperature changes because of sunlight or heat build-up, particularly along the capillary tube, can cause measurement errors as a result of expansion of the trapped air. To reduce the effect of temperature, the capillary can be filled with a fluid unaffected by operating temperature; however, this often affects the measurement response time.

The differential pressure from the diaphragm is detected by a piezoelectric semiconductor element. The output signal (4 mA – 20 mA DC) generated by the converter is changed to analog data in the central monitor and transmitted.

$$H = \Delta P / \rho \quad (6.8)$$

Where, H : Distance from transmitter/ receiver to liquid surface (m)
 ΔP : Differential pressure (Pa)
 ρ : Density (kg/m³)

The following precautions should be taken related to the use of differential pressure type level gauge:

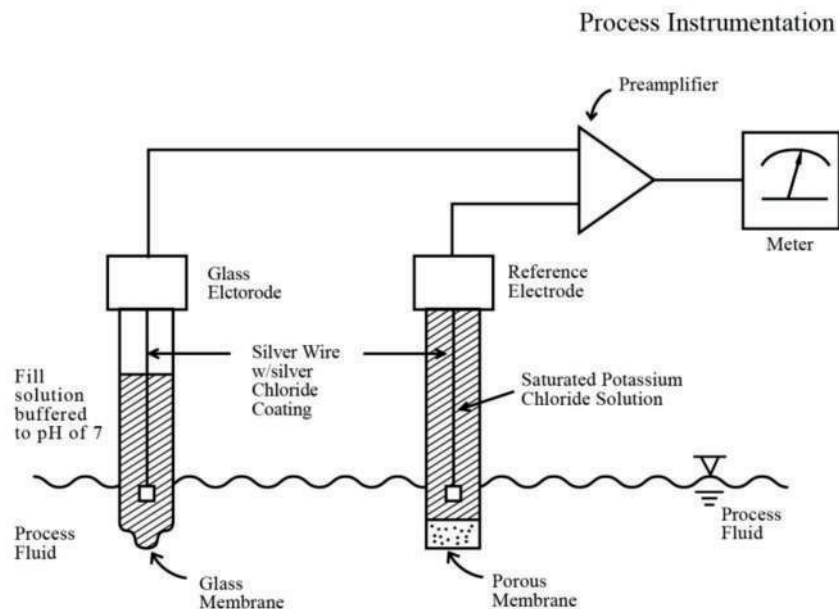
- The installed position of differential pressure transmitter should be lower than the minimum liquid level
- When the density of the liquid changes, correction is necessary (Span adjustment on the converter side is required)
- If the liquid has pulsing motion, the output of the differential pressure transmitter may become unstable

6.5.3 pH and ORP Measuring Equipment

6.5.3.1 pH

pH is a measure of the acidity of a process liquid. Continuous measurements of pH of incoming sewage are frequently made, particularly in plants where drastic changes in pH (as a result of industrial discharges) cause treatment problems.

A glass electrode, which is sensitive to hydrogen ion activity, measures the pH of an aqueous solution. The electrode produces a voltage related to hydrogen ion activity and to pH. The pH is determined by measuring the voltage against a reference electrode. While it is generally assumed that no other ions seriously affect the pH electrode in an aqueous system, sodium ions can have an effect. Temperature corrections are also necessary, but are typically done automatically by the meter. A typical pH sensor is shown in Figure 6.16.



Source: WEF,2008

Figure 6.16 Typical pH sensor

Precautions for O&M are as given below.

- Dirt on the electrode surface should be periodically removed and the surface cleaned
- Since the electrodes of the pH meter are made of glass, care is necessary to ensure that they do not break
- Due to long period use of glass electrodes, dirt sticks on them gradually, the zero point changes, and the electromotive force by pH reduces and it stops responding to changes in pH, making replacement necessary
- Standard liquid should be used in the pH meter and it should be calibrated. Calibration should include zero adjustment (standard liquid with pH7) and span adjustment (standard liquid of pH4 or pH9)

6.5.3.2 ORP(Oxidation-Reduction Potential)

Oxidation-reduction potential is a measure of easily oxidisable or reducible substances in sewage. An operator can control the process better by knowing if there is a large quantity of reducing substances (e.g., sulphide and sulphite) that may have an immediate, high oxygen demand and may result in an inadequate supply of oxygen for the microorganisms in the secondary process. Although not specific, the ORP measurement is instantaneous (an electrode is used) and can be used to help maintain dissolved oxygen in the aeration tank. Another application is to evaluate the progress of digestion and process stability in anaerobic digesters.

O&M issues to be cared for are as follows:

- Regular cleansing of electrode surface
- Precautions against breaking an ORP electrode, which is made of glass and is fragile
- Replacement of the electrode if it is insensitive to changes of potential difference, because of stains accumulated over a long time usage

6.5.3.3 DO (Dissolved Oxygen)

A dissolved oxygen meter is an electronic device that converts signals from a probe placed in the water into units of DO in mg/L. Most meters and probes also measure temperature. The probe is filled with a salt solution and has a selectively permeable membrane that allows DO to pass from the stream water into the salt solution. The DO that has diffused into the salt solution changes its electric potential. This change is sent by electric cable to the meter, which converts the signal to mg/L on a scale that anyone can read.

If DO is a critical analytical parameter, it is recommended to calibrate at 100 % saturated air, or use a known dissolved oxygen concentration (determined by the iodometric method) for the upper limit, and use a zero DO solution (even if it is not explicitly stated in a particular manufacturer's manual) for the lower limit. If DO meter does not allow for a second calibration point, the zero DO solution can be used as a check standard when DO meter is set to the measurement mode. The DO meter should be able to read less than 0.5 mg/L. If DO meter does not read less than 0.5 mg/L, then there may be a problem with the DO membrane.

If it is determined that the DO membrane needs to be replaced, consult the manufacturer's manual on conditioning the new membrane before use. It is also possible that other maintenance will need to be performed on the DO meter or the zero DO solution may need to be replaced. Other factors that affect the accuracy of DO measurements include—improper calibration, not verifying calibration after use and not correcting for ambient barometric pressure/altitude and instrument drift. A typical hand held DO meter with probe for field use is shown in Figure 6.17 overleaf.

O&M issues to be cared for are as follows:

- Regular cleaning of diaphragms
- Zero calibration and span calibration



Source: M/S YSI.

Figure 6.17 Hand held DO meter with probe for field use

- Regular replacement of internal electrode solution
- Regular cleaning of an electrode; and replacement if broken.

6.5.3.4 Temperature

Even though most of the major sewage treatment processes are not temperature-controlled, many temperature measurements are required. Obvious applications for temperature measurement are anaerobic digesters, chlorine evaporators, incinerators, and equipment protection. Less obvious are temperature controls for analyzers and flow meters. Temperature measurement devices include liquid thermometers, bimetal thermometers, pressure on liquid or gas expansion bulbs, thermistors, resistance temperature detectors (RTDs), infrared detectors, and crystal window tapes. The RTD is typically used on lower, ambient-range temperatures, while thermocouples provide better reliability in higher ranges. In addition, gas- and liquid-filled temperature sensors and thermistors are frequently used for equipment-protection and cooling systems.

For continued accurate service, operators should periodically calibrate the instruments using a standard temperature measurement device with high accuracy.

6.5.3.4.1 Thermocouple

The thermocouple operates on the principle that current flows in a circuit made of two different metals when the two electrical junctions between the metals are at different temperatures. The various combinations of metals used are tabulated in most engineering handbooks, and the selection of metals is based on the maximum temperature to be measured. Thermocouples measure as high as 980°C, with an accuracy of 1% of the full scale.

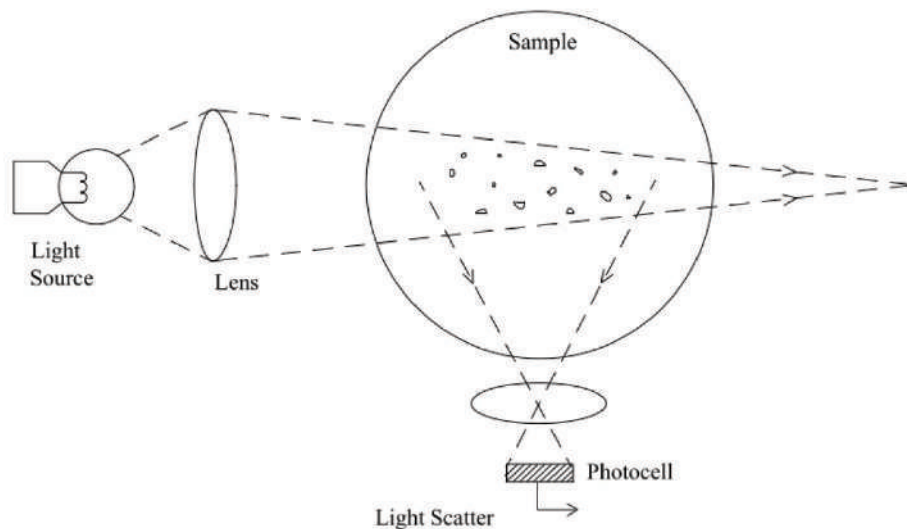
6.5.3.4.2 Resistance Temperature

A resistance temperature detector has a temperature-sensitive element in which electrical resistance increases repeatedly and predictably with increasing temperature. The sensing element is typically made of small-diameter platinum, nickel or copper wire wound on a special bobbin or otherwise supported in a virtually strain-free configuration. The detector is typically selected for high accuracy and stability. A common application is the measurement of bearing and winding temperatures in electrical machinery.

6.5.3.5 MLSS (Mixed Liquor Suspended Solid)

All solids concentration meters use indirect methods (such as optical, ultrasonic and nuclear). Indirect methods correlate the solids concentration with a measurable factor. The limitation of not relating perfectly to the quantity of suspended matter does not seriously affect the analysers ability to produce a repeatable signal of great value in process control.

When a light beam is directed on to liquid containing suspended particulates, the suspended particulates scatter some of the light. The nephelometer helps observe and measure the amount of light that the particulate matter scatters as shown in Figure 6.18.



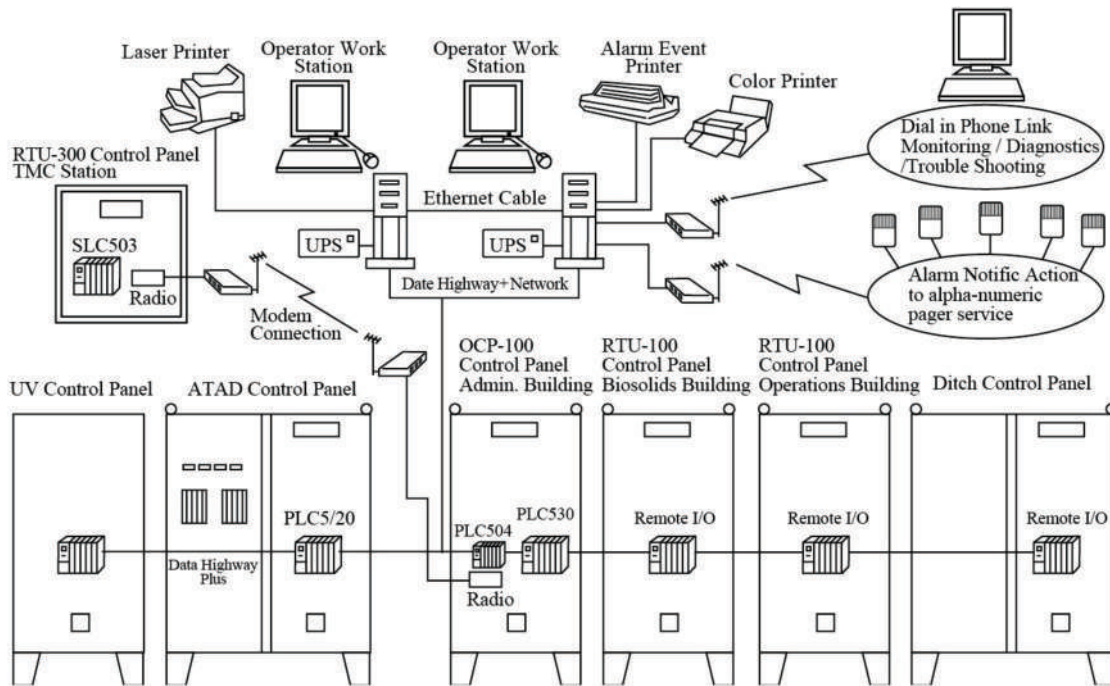
Source: WEF,2008

Figure 6.18 Nephelometer

The amount of scattered light relates approximately to the amount of particulate matter, particle size and surface optical properties. This is a photoelectric device that uses an incandescent light source (lamp), which produces light in wavelengths from blue to red. The light is directed to a liquid and if the liquid contains particles, some of the light strikes the particles and scatters. By placing a photocell or light detector at an angle to the light beam rather than directly in front of it, the detector receives only light scattered by the suspended particulate matter. Most nephelometers have the photo detector placed at a 90-degree angle to the incandescent light source.

6.6 SCADA SYSTEM

SCADA is an acronym for Supervisory Control and Data Acquisition. This presents the data as a viewable and controllable system on the screen of a computer. The data thus collected can be stored and analysed for optimization of the process and for better real time process control. It assists plant-operating personnel by monitoring and announcing abnormal conditions and failure of equipment. It allows the operators to perform calculations based on the sensor inputs. Daily, weekly, monthly reports can be prepared using the stored data. It also allows the operator to know the state of a process by an alarm associated with it. A typical SCADA is shown in Figure 6.19 overleaf.



Source: Kruger

Figure 6.19 Typical SCADA communication overview

6.6.1 Monitoring and Control Equipment

For maximum use and effectiveness, signals generated by various sensors and instruments are transmitted from the sensor to a receiver installed at another location. Often, the sensor output is transmitted to a control panel or computer system, which allows operators to inspect many process variables simultaneously.

The three components of a signal-transmission system are the transmitter, receiver and transmission medium (the connection between the transmitter and receiver). The transmitter converts a mechanical or electrical signal from the sensor into a form that the transmission medium can use. The transmission medium contains the signal and transfers it to the receiver. The receiver subsequently converts it into a form that the receiving system can use.

6.6.1.1 Signal

6.6.1.1.1 Analog Input Signal

“Analog input signal” means continuous signal such as process data, which is transmitted from a local transmitter to a central control unit (CCU).

For instance, process variables expressed in physical amount such as opening degree of a sluice gate (0–100%), sewage flow rate (0– ***m³/hr), and water level in tanks (0–***m) are converted into electrical signals and are transmitted to CCU. Standard electronic transmission systems use 4 – 20 mA DC.

There are several transmission systems. One is to connect directly with the CCU I/O (Input/Output) device via shielded cables. Another is the so-called link system with PLC, in which analog signal is converted to digital signal and is transmitted via coaxial cables or optical fibres.

6.6.1.1.2 Analog Output Signal

“Analog output signal” means signals continuously transmitted from CCU to local control panels or equipment to direct operational amount.

Electric operated valves and regulating valves for controlling pressure of pipe, and VFD for controlling frequency of aerators or pumps, etc., are typical examples, which are controlled by analog output signals. More specifically, there are electromagnetic valves and regulating valves used to control pressure in the piping.

There are also aeration blowers or VFD (inverter) equipment used to control pump rpm. One of the transmission systems for analog output signal connects directly to the I/O device of CCU via shielded cables.

6.6.1.1.3 Digital Input Signal

“Digital input signal” refers to a contact output signal generated and transmitted from local equipment. For example, answer-back signal to express equipment conditions, alarm signal for abnormal conditions and “remote / local” switch signal of local control panels are examples of digital input signal. Contact signals are electronically converted to an appropriate series of zeros and ones. Link systems with PLC are widely used for transmitting the signal, with which analog signal is converted to digital signal and is transmitted via coaxial cables or optical fibres.

6.6.1.1.4 Digital Output Signal

Digital output signal means contact output signal expressed “1 / 0” transmitted from CCU to an auxiliary relay on the control center panel. For example, “on/off” signal for equipment is regarded as digital output signal. Link systems with PLC are widely applied for transmitting the signal, with which analog signal is converted to digital signal and is transmitted via coaxial cables or optical fibres.

6.6.1.2 HMI (Human Machine Interface)

The PLC is a blind device. It does not have any provision of displaying the plant status to the operator, or to enter certain data like set points, or manual mode operation. An additional device is needed for these provisions, to communicate with PLC, which will have a display to show the status and also the means to enter set points. Such a unit is called Human Machine Interface (HMI).

There are two basic types of HMI:

- Industrial panel mounted type HMI as in Figure 6.20 overleaf.
- PC based system in which the computer acts as HMI as in Figure 6.21 overleaf.



Source: JICA, 2011

Figure 6.20 Industrial panel-mounted type HMI

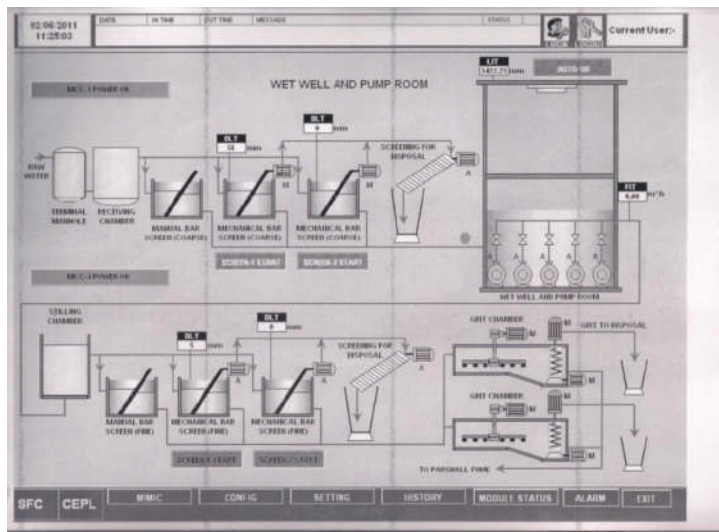


Figure 6.21 PC based system in which the computer acts as HMI

6.6.1.3 PLC (Programmable Logic Controller)

A PLC is electronic equipment that senses inputs and takes the decision to change outputs according to the set rules stored in the memory. It is primarily an electronic controller, housed in industrial housing, which has logic programming function and can be an interface to industrial devices.

6.6.2 Automatic Control

Automatic control systems can be categorized according to their control techniques as in Figure 6.22

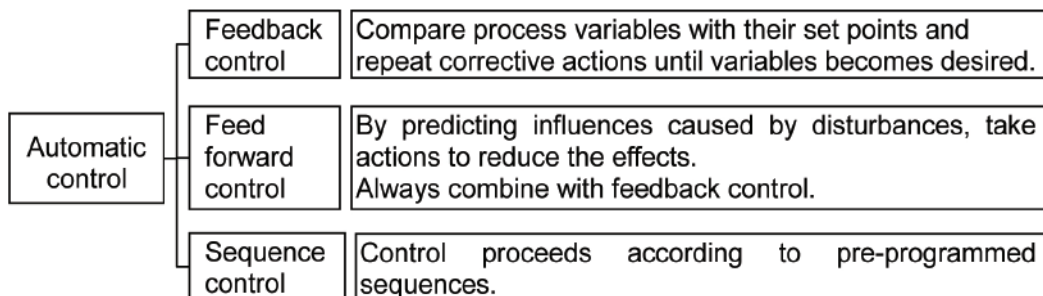


Figure 6.22 Automatic control system

Instrumentation facilities are established mainly based on feedback control in combination with feed forward control in most STPs for controlling process variables such as temperature, water level, pressure, flow rate, etc.

6.7 CABLES

The flow of power from transformer to switchgear and from there to starter and to motor and other related equipment like capacitors are through power cables.

Table 6.6 gives information on cables for different voltages.

Table 6.6 Types of cables for different voltages

No.	Range of voltage	Type of cable to be used	IS Ref.
1	1-230 V / 3-415 V	PVC insulated, PVC Sheathed	1554
2	Up to 6.6 kV	PVC insulated, PVC Sheathed	1554
		Paper insulated, lead Sheathed	692
3	11kV	XLPE- Cross Linked, Polyethylene insulated, PVC sheathed	7098
		Paper insulated, lead sheathed	692

Source: CPHEEO, 1993

The size of the cable should be so selected that the total drop in voltage, when calculated as the product of current and the resistance of the cable should not exceed 3%.

Values of the resistance of the cable are available from cable-manufacturers.

The following points should be considered when selecting the size of the cable:

- The current carrying capacity should be appropriate for the lowest voltage, the lowest power factor and the worst condition of installation that is, duct-condition.
- The cable should also be suitable for carrying the short circuit current for the duration of the fault. The duration of the fault should preferably be restricted to 0.1 sec. by proper relay setting.
- Appropriate rating factors should be applied when cables are laid in- group (parallel) and/or laid below ground.
- Suitable trenches or racks should be provided for laying cables

The following O&M tasks should be implemented:

- Measure insulation resistance between cables and the earth
- Visually observe deterioration, corrosion and discolouration

6.8 ENERGY AUDIT

Among all the power consuming components, pumping installations consume a large amount of energy in STPs. Need for conservation of energy, therefore cannot be over emphasized. All possible steps need to be identified and adopted to conserve energy and reduce energy cost so that sewerage charges can be kept as low as possible and gap between high cost of sewage treatment and affordable charge to users can be reduced.

Some adverse scenarios in energy aspects are quite common in pumping installations as herein:

- Energy consumption is higher than optimum value due to reduction in efficiency of pumps.
- Operating point of the pump is away from best efficiency point (b.e.p.).
- Energy is wasted due to increase in head loss in pumping system, for instance, clogging of strainer, encrustation in column pipes and encrustation in pumping main.
- Selection of uneconomical diameter of sluice valve, butterfly valve, reflux valve, column pipe, and drop pipe, etc., in pumping installations.
- Energy wastage due to operation of electrical equipment at low voltage and/or low power factor.

Such inefficient operation and wastage of energy should be avoided to cut down energy cost. It is therefore, necessary to identify all such shortcomings and causes, which can be achieved by conducting methodical energy audit.

Strategies as given below should be adopted for the management of energy.

- Conduct thorough and in-depth energy audit covering analysis and evaluation of all equipment, operations and system components, which have bearing on energy consumption, and identify the scope for reduction in energy cost.
- Implement measures for conservation of energy. Energy audit as implied is auditing of billed energy consumption and how the energy is consumed by various units, and sub-units in the installation and whether there is any wastage due to poor efficiency, higher hydraulic or power losses etc. and identification of actions for remedy and correction.

6.8.1 Frequency of Energy Audit

Frequency of energy audit recommended is as follows.

- Large installations: Every year
- Medium installations: Every two years
- Small installations: Every three years

6.8.2 Scope of Energy Audit

Scope of energy audit and suggested methodology includes the following, steps and processes:

- A. Conducting in-depth energy audit by systematic process of accounting and reconciliation between the following:
- Actual energy consumption, and
 - Calculated energy consumption taking into account rated efficiency and power losses in all energy utilising equipment and power transmission system, such as conductor, cable, panels, etc.
- B. Conducting performance tests of pumps and electrical equipment if the difference between actual energy consumption and calculated energy consumption is significant and taking follow up action on conclusions drawn from the tests.
- C. Taking up discharge test at rated head if test in B. above is not being taken.
- D. Identifying the equipment, operational aspects and characteristics of power supply causing inefficient operation, wastage of energy, increase in hydraulic or power losses etc. and evaluating the increase in energy cost or wastage of energy.
- E. Identifying solutions and actions necessary to correct shortcomings and lacunae in D. above and evaluating cost of the solutions.
- F. Carrying out economic analysis of costs involved in D. and E. above and drawing conclusions on whether rectification is economical or otherwise.
- G. Checking whether operating point is near the best efficiency point and whether any improvement is possible.
- H. Verification of penalties if any, levied by power supply authorities, such as penalty for poor power factor, penalty for exceeding contract demand, and so on.
- I. Broad review of the following points for future guidance or long-term measure:
- C-value or f-value of transmission main
 - Diameter of transmission main provided
 - Specified duty point for pump and operating range
 - Suitability of pump for the duty conditions and situation in general and specifically from efficiency aspects
 - Suitability of ratings and sizes of motor, cable, transformer and other electrical appliances for the load

6.9 MANAGEMENT OF RECORDS

Records are the key to an effective maintenance programme. Records can remind the operator when routine O&M is necessary. They help ensure that schedules are maintained and needed O&M are not overlooked or forgotten.

6.9.1 Record of Operation and Maintenance

Records must be permanent, complete and accurate. Write entries clearly and neatly on data sheets in ink. A pencil should never be used because notations can smudge or they can be altered or erased.

Minimum record keeping that may be required for operations is listed below and shown in Appendix C.6.1:

- A. Operational record: Power receiving and transforming equipment
- B. Monthly report: Electric power receiving
- C. Ledger: Electrical equipment

6.9.2 Record of Operation and Maintenance and its Utilization

Records are utilized like the following:

Review of operating records can indicate the efficiency of the plant, performance of its treatment units, past problems, and potential problems.

Records can be used to determine the financial health of the utility, provide the basic data on the system's property and prepare monthly and annual reports.

6.10 PREVENTIVE MAINTENANCE

Generally, preventive maintenance can be described as maintenance of equipment or system before faults occurs. Preventive maintenance should be only according to manufacturer's manual.

It can be divided into two subgroups:

- Planned / Scheduled Maintenance (PM)

Scheduled activities to ensure that an item of equipment is operating correctly and thereby avoid any unscheduled breakdown and downtime.

- Condition Based Maintenance (CBM)

Activities performed after one or more indicators show that the equipment is going to fail or that equipment performance is deteriorating.

The vast majority of electrical maintenance should be predictive or preventive. This section focuses exclusively on these activities. There are four cardinal rules to follow in any maintenance programme:

- Keep it clean

Dirt build-up on moving parts will cause slow operation, arcing and subsequent burning. Moreover, coils can short-circuit. Dirt will always impede airflow and result in elevated operating temperatures.

- Keep it dry

Electrical equipment always operates best in a dry atmosphere, where corrosion is eliminated. Moisture-related grounds and short circuits are also eliminated

- Keep it tight

Most electrical equipments operate at a high speed or is subjected to vibration.

- Keep it frictionless

Any piece of equipment or machinery is designed to operate with minimum friction. Dirt, corrosion or excessive torque will often cause excessive friction.

Of the four cardinal rules, none is essentially electrical in nature. The failure of a bearing in a motor can lead to an ultimate motor winding failure that is electrical, but the root cause of the failure could have been mechanical.

The goal of any electrical preventive maintenance programme is to minimize electrical outages and ensure continuity of operation.

6.10.1 Types of Planned Maintenance

Maintenance works can be classified as follows according to their inspection intervals. The results of maintenance can be utilized for preventing possible faults or breakdowns of equipment in future.

- Routine maintenance

Routine maintenance consists of observation for signs of overheating, dirt, loose parts, noise and any other signs of abnormalities. It will help grasping the state of electrical equipment.

- Periodic maintenance

Periodical maintenance includes inspections of electrical conditions such as electric current, voltage, insulation resistance, ground resistance, etc.

- Detailed examination

Examinations should be pre-programmed according to manufacturer's recommendation or legislation. Recommended maintenance tasks for typical electrical equipment are listed in Table 6.7 overleaf.

6.10.2 Inspection Tools

A wide, variety of instruments are used to maintain electrical systems. These instruments measure current, voltage and resistance. They are used not only for troubleshooting, but also for preventive maintenance as well.

These instruments may have either an analog readout, which uses a pointer and scale, or a digital readout, which gives a numerical reading of the measured value.

Table 6.7 Recommended maintenance on electrical equipment

Equipment	Frequency			
	Monthly	Quarterly	Semi-annual	Annual
Panel, Circuit-Breaker, Starter(*)	GI,CL	AJ		CB,GRT
Transformer Substation(*)	GI	GI,RE	TO,MR	GRT,CL
Motors(*)*		GI,CL	AL,MR	PG
Standby power generator	GI			CL,AL
Gas engine	GI			CL,AL
Dual fuel engine	GI			CL,AL
UPS	GI			CL
Flow Measuring equipment				CB,MR
Level Measuring equipment			CL	CB,MR
Other Instrumentation	CL	CB	ADL	MR
Cables				MR

* Details of the maintenance tasks of the marked equipment above are given in Appendix B.6.2. (Legend)

CL	Clean	GRT	Ground resistance test
MR	Megger and record	TO	Test oil
PG	Pressure grease	GI	General inspection
SG	Surface grease	AL	Add lubricant
RC	Remove condensate	AJ	Adjustment
CB	Calibration	RE	Replenish / Replacement
ADL	Add liquid		

6.10.2.1 Multimeter

A multimeter is used to measure voltage and low levels of current in a live system and continuity in a switched-off system. There are several types available in the market. A digital multimeter and an analog multimeter are shown in Figure 6.23. They are designed to be used on energized circuits and care must be exercised when testing.



Source: HIOKI E.E. CORPORATION

Figure 6.23 Digital multimeter (left) and Analog multimeter (right)

By holding one lead on ground and the other on a power lead, a user can determine if power is available, and also can tell if it is AC or DC, the intensity or voltage (1, 10, 220, 480, and so on) by testing the different leads. A clamp-on multimeter can measure larger currents typical in a motor.

- Only qualified and authorized persons should work on electric circuits.
- Use a multimeter or other circuit tester to determine if the circuit is energized, or if voltage is off. This should be done after the main switch is turned off to ensure that it is safe to work inside the electrical panel. Always be aware of the possibility that even if the unit is off, the control circuit may still be energized if the circuit originates at a different distribution panel.
- Check with a multimeter before and during the time the main switch is turned-off as a double check. This procedure ensures that the multimeter is working and that the users have good continuity to the tester.
- Use a circuit tester to measure voltage or current characteristics to a given piece of equipment for checking whether the circuit is “alive” or not. Switches can fail and the only way to find out that a circuit is dead is to test the circuit.
- In addition to checking for power, a multimeter can be used to test for open circuits, blown fuses, single phasing of motors, grounds and many other uses.

6.10.2.2 Clamp-on Meter

The clamp-on meter measures the current or amps in the circuit as shown in Figure 6.24. It is used by clamping the meter over only one of the power leads to the motor or other apparatus and taking a direct reading.

Therefore, the measurement by the clamp-on meter is a safe method in a high-current circuit. Each lead in a three-phase motor must be checked.



Source: HIOKI E.E. CORPORATION

Figure 6.24 Clamp-on meter

6.10.2.3 Megger / Megohmmeter

A megger or megohmmeter is used for checking the insulation resistance of motors, generators, feeders, bus bar systems, grounds, and branch circuit wiring. This device actually applies a DC test voltage, which can be as high as 5,000 volts, depending on the megohmmeter selected.

Figure 6.25 shows a hand-held that applies 500 volts DC and is particularly useful for testing low-tension motor insulation.

Battery-operated and instrument style meggers are also available in both analog and digital models. If a low reading is obtained, disconnect motor leads from power or line leads.

A low reading in the megger for motor generally indicates that the motor winding insulation has broken down. If this reading is low, the wiring to the motor is defective.



Source: HIOKI E.E. CORPORATION

Figure 6.25 Hand-cranked megohmmeter

Motors and wiring should be subjected to megger test at least once a year or preferably, twice a year.

The readings taken should be recorded and plotted to determine the deterioration of insulation and predict its breakdown.

6.10.2.4 Ground Resistance Testers (Earth Meggers)

When the electrical equipment is installed in housings, they may be charged against the ground. Therefore, they should be connected with earth (referred to as “earth”) to reduce the potential difference between the terminal and the earth to as low a value as possible (ideally 0 volt).

The purposes of the earth are as follows:

- A. Prevent electric shock: Discharge any electricity charged in equipment housing due to electrical insulation failure or a transformer breakdown to prevent shock; and
- B. Prevent breakdown of loaded equipment: Connect a neutral line on the load side of transformer with earth and prevent high voltage on the power source side from intruding into the load side in case of transformer fails so as to protect the loaded equipment

Value of ground resistance is depends considerably on the soil to be earthed, and the smaller the resistance, the better. Ground resistance testers are devices to measure the stated resistance when the circuit is earthed. Testers with measurable range from 0 to 1,000 ohms are widely used.

A typical ground resistance tester is shown in Figure 6.26 (overleaf)



Source: HIOKI E.E. CORPORATION

Figure 6.26 Ground resistance tester

6.10.3 General Precautions for Electrical Maintenance

The following should be ensured for safe electrical maintenance:

- Always refer to manufacturers manual for O&M and drawings for frequency of testing, lubrication, replacement of any component and follow all these.
- Do not touch any energized parts directly
- Fully understand configurations and operational characteristics of related electrical facilities and equipment
- When operating electrical equipment, follow the operational procedures, confirm the purposes of the operation, and predict the result of the operation
- When overheat, abnormal noise, or vibration, etc, is detected during inspection, report the condition to the person in charge of electrical work
- When overheat, abnormal noise, or vibration, etc, is detected during inspection, stop the equipment and investigate the causes if necessary.
- Always keep the surrounding of electrical equipment tidy and clean. Never allow outsiders to enter the electrical equipment site.

6.10.4 Rehabilitation

If the equipment in the electrical facility is old, frequent outages and high maintenance and repair costs are likely to occur. If some of the equipment is beyond repair, breakdowns lead to long and extensive power outages in the STP.

To prevent such occurrences, functional degradation of electric equipment and causes for breakdown and stoppages should be tracked at an early stage and repaired. Causes of fault also follow a certain trend. Training should be imparted on predicting faults beforehand, so that measures and repairs can be implemented.

Spare parts and tools should be kept ready on site so that repairs can be carried out. Inventory of spare parts and tools should be confirmed and the required number should be stored.

6.10.5 Planned Reconstruction

For reconstruction of electric facilities, plans should be formulated; therefore, scheduled O&M should have been implemented.

Items to be studied for planned reconstruction are whether abnormalities exist from routine inspection records, data, periodic inspections and repair records and a judgement of the condition of equipment.

Analyse collected and accumulated data, and understand the long-term deterioration trend of equipment.

6.11 TROUBLESHOOTING

Refer to Appendix B.6.3.

6.12 SUMMARY

The primary function of electrical system in sewerage is to receive power from outside, transform it and distribute it stably to each facility. The instrumentation system also plays an important role in indicating operating conditions.

For realizing these functions properly, the electrical system requires periodic inspection and maintenance for early detection of abnormal conditions. The instrumentation system should be inspected and adjusted regularly so that it can provide correct readings at all times.