UNIT-IV

Smart Grid Technologies

Introduction:

Operation of the generation and transmission systems is monitored and controlled by Supervisory Control and Data Acquisition (SCADA) systems. These link the various elements through communication networks (for example, microwave and fibre optic circuits) and connect the transmission substations and generators to a manned control centre that maintains system security and facilitates integrated operation. In larger power systems, regional control centres serve an area, with communication links to adjacent area control centres. In addition to this central control, all the generators use automatic local governor and excitation control. Local controllers are also used in some transmission circuits for voltage control and power flow control, for example, using phase shifters (sometimes known as quadrature boosters). Traditionally, the distribution network has been passive with limited communication between elements. Some local automation functions are used such as on-load tap changers and shunt capacitors for voltage control and circuit breakers or auto-reclosers for fault management. These controllers operate with only local measurements and wide-area coordinated control is not used. Over the past decade, automation of the distribution system has increased in order to improve the quality of supply and allow the connection of more distributed generation. The connection and management of distributed generation are accelerating the shift from passive to active management of the distribution network. Network voltage changes and fault levels are increasing due to the connection of distributed generation . Without active management of the network, the costs of connection of distributed generation will rise and the connection of additional distributed generation may be limited.

The connection of large intermittent energy sources and plug-in electric vehicles will lead to an increase in the use of Demand-Side Integration and distribution system automation.

smart substations:

The number of distributed energy resources and new appliances with power electronics in the distribution grid rapidly grows. This leads to power quality problems and power flow fluctuations.

An Intelligent Distribution Station is designed to maintain power quality and reliability in an economic way.

Station level includes sub-system like automation system, control system for standing area, communication system and standard time system, etc. It is used to meet the function of the primary device, to detective and control the whole or more than one station device, and to perform the function of data collection, monitoring control(SCADA), lockout operation, and synchronous phase collection, electric energy collection, information protection and relevant function. Smart Substation The number of distributed energy resources and new appliances with power electronics in the distribution grid rapidly grows. This leads to power quality problems and power flow fluctuations. An Intelligent Distribution Station is designed to maintain power quality and reliability in an economic way. Station level includes sub-system like automation system, control system for standing area, communication system and standard time system, etc. It is used to meet the function of the primary device, to detective and control the whole or more than one station device, and to perform the function of data collection, monitoring control(SCADA), lockout operation, and synchronous phase collection, electric energy collection, information protection and relevant function.

According to high-speed network communication, smart substations realize information sharing and interoperation, measurement and monitoring, control and protection, and information management and intelligent condition monitoring through standardized digital information.

Advantages of smart substation:

They can **provide power for switchgear to change the configuration of the network, help isolate lines and clear faults before power can be restored safely**. They also can power communication and control equipment, which is fast becoming more important in smart digital substations

Substation automation equipment:

The components of a typical legacy substation automation system are shown in Figure 6.2. Traditionally, the secondary circuits of the circuit breakers, isolators, current and voltage transformers and power transformers were hard-wired to relays. Relays were connected with multi-drop serial links to the station computer for monitoring and to allow remote interrogation.

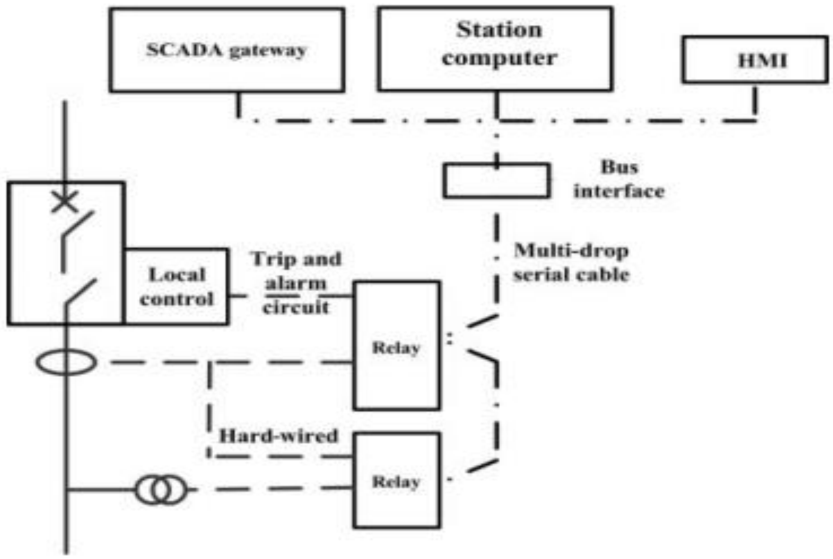

Figure 6.2 Substation components [3, 4]

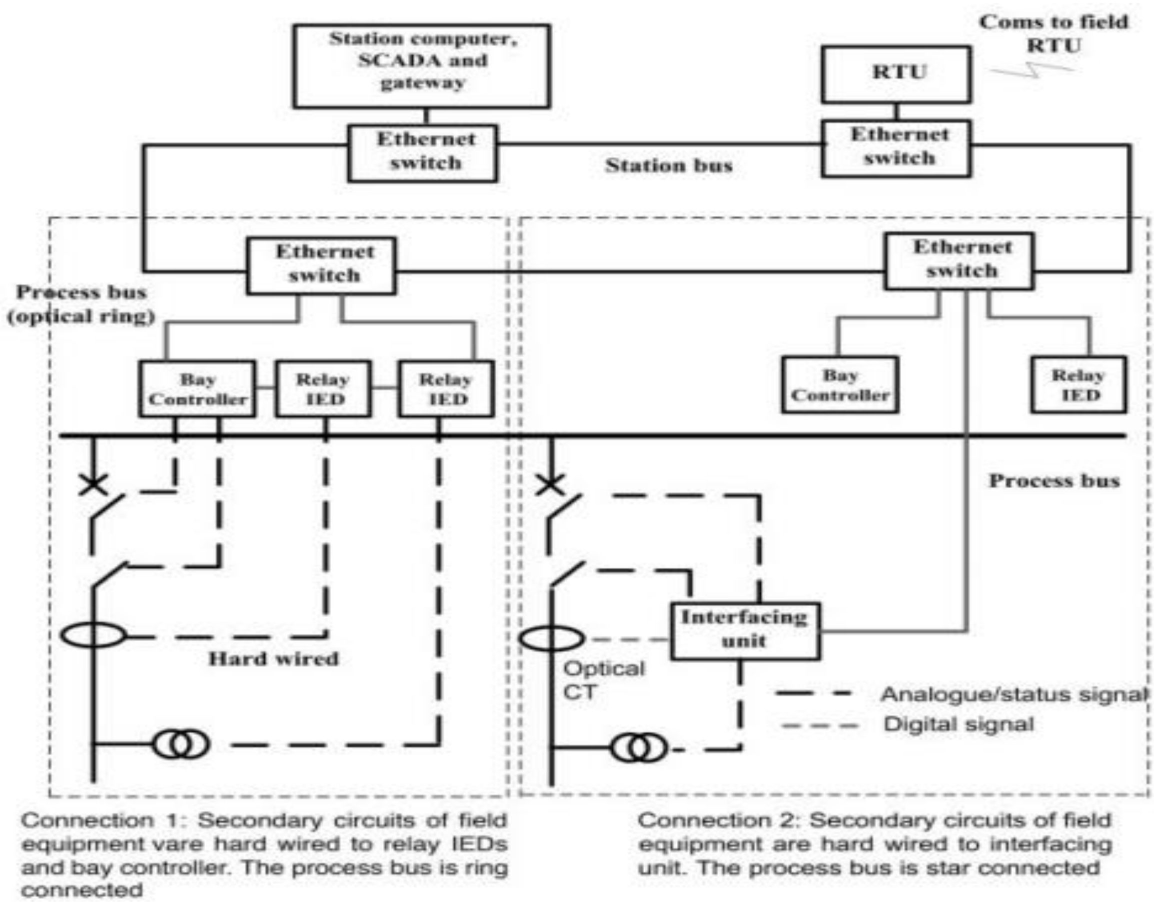

Figure 6.3 A modern substation [3, 5]

The real-time operation of the protection and voltage control systems was through hard-wired connections. The configuration of a modern substation automation system is illustrated in Figure

6.3. Two possible connections (marked by boxes) of the substation equipment are shown in Figure 6.3. Although it may vary from design to design, generally it comprises three levels: The station level includes the substation computer, the substation human machine interface (which displays the station layout and the status of station equipment) and the gateway to the control centre. The bay level includes all the controllers and intelligent electronic devices (which provide protection of various network components and a real-time assessment of the distribution network). The process level consists of switchgear control and monitoring, current transformers (CTs), voltage transformers (VTs) and other sensors.

In connection 1, analogue signals are received from CTs and VTs (1 A or 5 A and 110 V) as well as status information and are digitised at the bay controller and IEDs. In connection 2, analogue and digital signals1 received from CTs and VTs are digitised by the interfacing unit. The process bus and station bus take these digital signals to multiple receiving units, such as IEDs, displays, and the station computer that are connected to the Ethernet network. To increase reliability, normally two parallel process buses are used (only one process bus is shown in Figure 6.3) [5]. The station bus operates in a peer-to-peer mode. This bus is a LAN formed by connecting various Ethernet switches through a fibre-optic circuit. The data collected from the IEDs is processed for control and maintenance by SCADA software that resides in the station computer. The hard-wiring of traditional substations required several kilometres of secondary wiring in ducts and on cable trays. This not only increased the cost but also made the design inflexible. In modern substations as inter-device communications are through Ethernet and use the same communication protocol, IEC 61850, both the cost and physical footprint of the substation have been reduced.

Feeder Automation

Feeder Automation Solution reduces capital investment in the distribution network by limiting the replacement of legacy devices. It contributes to more direct cost savings by facilitating preventative maintenance. Arctic Control is also ideally suited to retrofitting into existing disconnectors. It enables remote control of these devices and further extends the life cycle of the disconnectors themselves.

Feeder Automation Solution provides means for the utilities to reduce the frequency of power outages and faster restoration time by remote monitoring and control of medium voltage network assets such as disconnectors, load break switches and ring main units in energy distribution networks. It provides an always-on wireless connectivity together with the intelligence needed for disconnector control and monitoring. Wireless connectivity is implemented via commercial mobile networks, thus reducing investment and operational costs. Used in conjunction with always-on communication from a SCADA system, this method achieves an ideal combination of local and centralized intelligence for real time systems in a cost-efficient way.

Devices & Features:

Ultra High-speed Automatic Transfer Scheme (ATS) for Critical Loads

Fault Location, Isolation and Service Restoration (FLISR)

Communication and Networking Technology

Remote Terminal Unit

Remotely Operable Switch

Application Specific Integrated Circuit (ASIC)

DA software

Distribution Network Simulator

Flexible configuration

Quick, automated restoration

Multiple communication options

Use of any standard recloser

Small footprint

Integrated automation controller for local control

Protects critical loads

Intelligent Electronic Devices (IED)

The name Intelligent Electronic Device (IED) describes a range of devices that perform one or more of functions of protection, measurement, fault recording and control. An IED consists of a signal processing unit, a microprocessor with input and output devices, and a communication interface.

IED configuration consist of

1. Analog/Digital Input from Power Equipment and Sensors

2. Analog to Digital Convertor (ADC)/Digital to Analog Converter (DAC)

3. Digital Signal Processing Unit (DSP)

4. Flex-logic unit

5. Virtual Input/ Output

6. Internal RAM/ROM

7. Display

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Relay IED: Modern relay IEDs combine a number of different protection functions with measurement, recording and monitoring. For example, the relay IED shown in Figure 6.12 has the following protection functions: three-phase instantaneous over-current: Type 50 (IEEE/ANSI designation); three-phase time-delayed over-current (IDMT): Type 51; three-phase voltage controlled or voltage restrained instantaneous or time-delayed overcurrent: Types 50V and 51V; earth fault instantaneous or time-delayed over-current: Types 50N and 51N. The local measurements are first processed and made

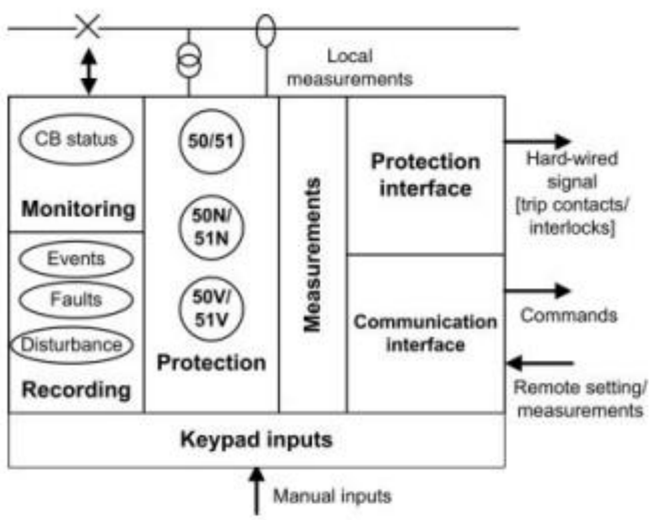


Figure 6.12 Typical configuration of a relay IED

available to all the processors within the protection IED. A user may be able to read these digitised measurements through a small LED display as shown in Figure 6.13. Furthermore, a keypad is available to input settings or override commands. Various algorithms for different protection functions are stored in a ROM. For example, the algorithm corresponding to Type 50 continuously checks the local current measurements against a set value (which can be set by the user or can be set remotely) to determine whether there is an over-current on the feeder to which the circuit breaker is connected. If the current is greater than the setting, a trip command is generated and communicated to the circuit Breaker (CB). IEDs have a relay contact that is hard-wired (in series) with the CB tripping coil and the tripping command completes the circuit, thus opening the CB.

Meter IED: A meter IED provides a comprehensive range of functions and features for measuring threephase and single-phase parameters. A typical meter IED measures voltage, current, power, power factor, energy over a period, maximum demand, maximum and minimum values, total harmonic distortion and harmonic components.

Recording IED :

Even though meter and protection IEDs provide different parameters (some also have a data storage capability), separate recording IEDs are used to monitor and record status changes in the substation and outgoing feeders. Continuous event recording up to a resolution of 1 ms is available in some IEDs. These records are sometimes interrogated by an expert to analyse a past event. This fault recorder records the pre-fault and fault values for currents and voltages. The disturbance records are used to understand the system behaviour and performance of related primary and secondary equipment during and after a disturbance.

Batteries:

Batteries store energy in chemical form during charging and discharge electrical energy when connected to a load. In its simplest form a battery consists of two electrodes,1 a positive and a negative placed in an electrolyte. The electrodes exchange ions with the electrolyte and electrons with the external circuit. Lead acid and Sodium Sulfur (NaS) batteries are used at present for large utility applications in comparable numbers. Lithium Ion (Li-ion), Nickel Cadmium (NiCd) and Nickel metal hydrides (NiMH) are also thought to be promising future options. Lead acid batteries have been used for many years in utility applications, providing excitation for synchronous machines and acting as back-up auxiliary power supplies. They are cheap but need significant maintenance. Their lifetime is comparatively short particularly if discharged deeply. NaS batteries operate at 300–400 ◦C and have a large energy capacity per unit volume and weight. They are used for electrical energy time shifting (for example, Citizens Substation, USA, 2 MW , 12 MWh), wind farm support (for example, East Busco Substation, USA, 1MW, 6 MWh) and to smooth the output of PV generators.

Superconducting magnetic energy storage systems:

In a SMES system, a magnetic field is created by direct current passing through a superconducting coil (Figure 12.12). In a superconducting coil, resistive losses are negligible and so the energy stored in the magnetic field (equal to $LI^2/2$ where L is the inductance of the coil and I is the current passing through the coil) does not reduce with time. However, in order to maintain the superconductivity of the SMES coil, a cryostat which can keep the temperature of the coil below the superconductor temperature limit is required. The optimum operating temperature of high temperature superconductors, that are favoured for energy storage applications, is around 50–70 K. Further, as the magnetic field produced by a SMES is large, a strong supporting structure is needed to contain the electromagnetic forces. The stored energy in the SMES is retrieved when required by a power conditioning system that is connected to the AC network as shown in Figure12.12.

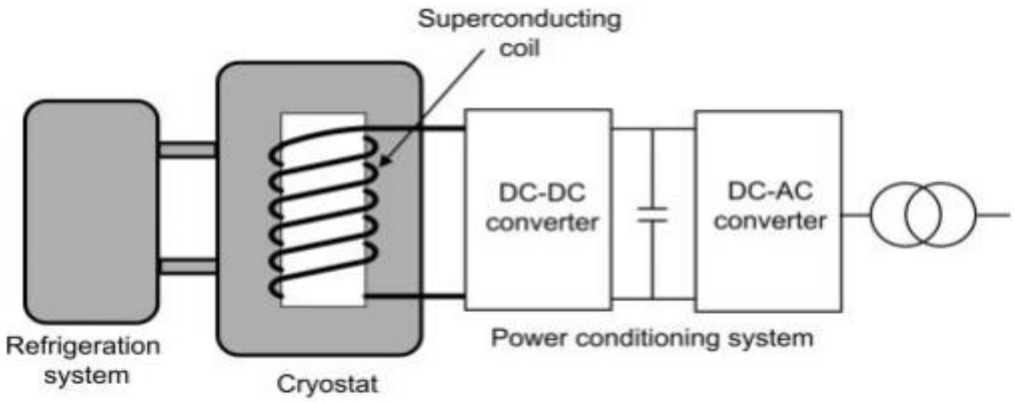


Figure 12.12 Component of a superconducting energy storage

Supercapacitors:

In a capacitor, energy is stored in an electrostatic field. The quantity of energy stored, E, is given by:

$$E = \frac{1}{2}CV^2$$

where C is the capacitance and V is the voltage across the capacitor.
In a parallel plate capacitor:

$$C = \frac{\varepsilon_r \varepsilon_o A}{d}$$

where ε_r is the relative permittivity of the dielectric material, ε_o is the permittivity of free space, A is the surface area of the plates and d is the distance between two plates.

Supercapacitors have a double layer structure that uses a porous electrolyte such as Polyethylene Terephathalate (PET). The double layer structure increases energy storage capability significantly due to a large increase in surface area, thus C. Further, the higher relative permittivity of PET (about 3.5 at 20 ◦C) compared to the electrolytes used in thin film capacitors also contributes to the increase in stored energy. Supercapacitors are constructed with a carbonised porous material as one electrode and a liquid chemical conductor as the other electrode.

5.4.3.2 Pumped Hydro Storage

The hydraulic turbine in a conventional pumped hydro station normally works as a pump when water is to be pumped to the upper reservoir and as a generator when power has to be generated. But such scheduled pumping and generation is impossible in this application as the schedule and the pumping rate are to be dynamically decided by the DEMS. The pump and the generator should be physically separate and are required to be operated in parallel. A variable speed drive is selected to operate the pump to control the power absorbed by PHS. This is modeled as 10 units of 250 kW induction motor running in parallel to pump the water.

The total capacity of PHS is chosen as 50% of that of the MHPP. The VSD operates based on a LUT containing the values of voltage (V) and frequency (f). The VSD uses the method of V/f control on the motor where V/f is kept constant while V and f are considered to vary the speed. In grid-connected mode, a single step change of V and f in the LUT (i.e., the adjacent higher or lower values) is enacted in order to increase or decrease the speed of the pump. This single step change would not suffice in islanded mode, as the PHS has to operate in synchronism with the variation in frequency. Therefore, a secondary controller is to be used to decide the number of steps of incrementing or decrementing the pumping rate when the DEMS instructs to adjust the speed of PHS. The operation of PHS aided by the LUT is carried out at a resolution of 0.2% (5 kW) of the total output delivery. For a motor power output of P_{op}, the water flow rate is computed as,

$$Q = \frac{1000 P_{op}}{\rho g h}, \mathrm{m}^3/\mathrm{s} \tag{5.15}$$

where:

h: Head (m),

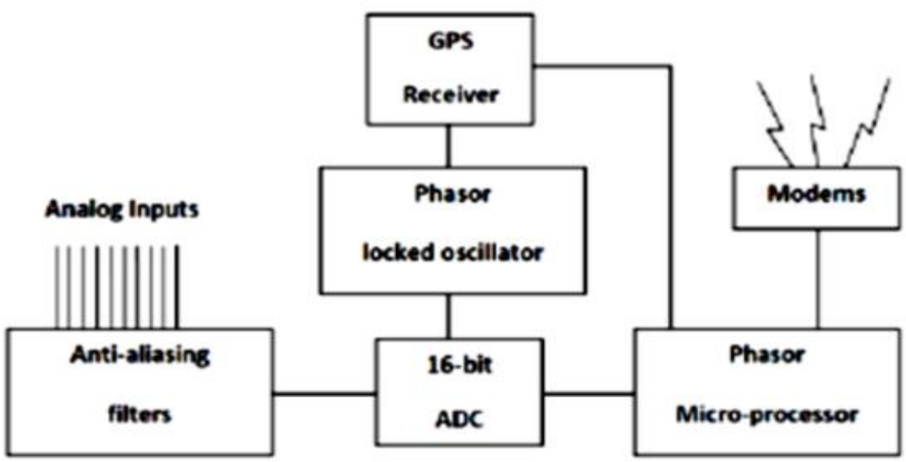
ρ: Density of water, 1000 kg/m^3, and

g: Acceleration due to gravity, 9.8 m/s^2.

Phase Measurement Unit (PMU)

Phasor Measurement Units (PMUs) are electronic devices that use digital signal-processing components to measure AC waveforms and convert them into phasors, according to the system frequency, and synchronize these measurements under the control of GPS reference sources.

The analog signals are sampled and processed by a recursive Phasor algorithm to generate Voltage and Current Phasor. Different components of a PMU are shown by a block diagram in below fig.



Components of a Phasor Measurement Unit

Synchrophasor technologies and systems use monitoring devices called phasor measurement units (PMUs) that measure the instantaneous voltage, current, and frequency at specific locations in an electric power transmission system.

COMPONENTS OF PMU:

1.PMUs, which calculate and time stamp phasors, and use the created synchrophasors to measure grid conditions. Other devices with PMU-like capabilities include upgraded relays and digital fault recorders (DFRs), which normally capture data during specific events such as system faults (or short-circuits such as when a tree falls against a transmission line), equipment failure, and generators tripping out of service.

2. Phasor Data Concentrators (PDCs), which are computers with software that receive data streams from PMUs and other PDCs, time-align synchrophasor data from multiple sources to create a system-wide set of linked measurements that are sent to computers for processing in applications software. PDCs also perform data-quality checks, monitor the performance of the PMUs and feed a data archive[3]. Increasingly, PDC functionality can be located within the grid at transmission substations, aggregating local PMU data and feeding it to local applications and actions, as well as passing the data upstream to multiple applications and operations centers.

3.Communications networks of varying technologies and speeds are used to deliver synchrophasor data between PMUs, PDCs, and operations centers.

4.Applications that use synchrophasor data for online and offline use. An example of an online application is real-time grid monitoring and control for use by reliability engineers and by operators in the operations center. Off-line applications include uses such as operations modeling, transmission planning and forensic analysis.

Most of the Recovery Act synchrophasor projects are developing Wide-Area Measurement Systems (WAMS) to collect synchrophasor measurements from PMUs that are on their power system or across the interconnection if they are a reliability coordinator.

A. Outlook of PMUs

PMUs facilitate innovative solutions to traditional utility problems and offer power system engineers a whole range of potential benefits,including:

• Precise estimates of the power system state can be obtained at frequent intervals, enabling dynamic phenomena to be observed from a central location, and appropriate control actions taken.

• To ensure acceptable quality of the power supplied to the consumers.

• Post-disturbance analyses are much improved because precise snapshots of the system states are obtained through GPS synchronization.

• To analyze the vulnerability of the system against any contingency. This is known as security assessment of the power system networks.Advanced protection based upon synchronized phasor measurements could be implemented, with options for improving overall system response to catastrophic events.

• Advanced control using remote feedback becomes possible, thereby improving controller performance.

A.Concepts Of Phasor Measurement

Although a constant phasor implies a stationary sinusoidal waveform, in practice it is necessary to deal with phasor measurements whichconsider the input signal over a finite data window. In many PMUs the data window in use is one period of the fundamental frequency of the input signal. If the power system frequency is not equal to its nominal value (it is seldom), the PMU uses a frequency-tracking step and thus estimates the period of the fundamental frequency component before the phasor is estimated. It is clear that the input signal may have harmonic or non-harmonic components. The task of the PMU is to separate the fundamental frequency component and find its phasor representation. The most common technique for determining the phasor representation of an input signal is to use data samples taken from the waveform, and apply the Discrete Fourier Transform (DFT) to compute the phasor. Since sampled data are used to represent the input signal, it is essential that antialiasing filters be applied to the signal before data samples are taken. The antialiasing filters are analog devices which limit the bandwidth of the pass band to less than half the data sampling frequency (Nyquist criterion).

The synchronization is achieved by using a sampling clock which is phase-locked to the one-pulse-per-second signal provided by a GPS receiver given in fig 3. The receiver may be built in the PMU, or may be installed in the substation and the synchronizing pulse distributed to the PMU and to any other device which requires it. The time tags are at intervals that are multiples of a period of the nominal power system frequency. It should also be noted that the normal output of the PMU is the positive sequence voltage and current phasors. In many instances the PMUs are also able to provide phasors for individual phase voltages and currents