# Key Aspects of Substation Automation

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## Introduction

Consulting engineers are required to empower themselves with the various aspects of substation automation so that technical bids with adequate inputs can be sent to vendors, the bids can be judiciously evaluated & eventually to approve the vendor drawings of the successful bidder. As substation automation is a multi-disciplinary subject involving software / computer engineering, networking technologies & high-end electronic components, the article hopes to provide the reader with the basic tools necessary to achieve the goals set in the earlier part of the introduction.

The key aspects of substation automation are as follows.

**A. Network Topology**

**B. Network components**

**C. Network architecture**

**D. Serial communication protocols**

**E. Time synchronization protocols**

**F. Software Tools**

**G. Performance requirements**

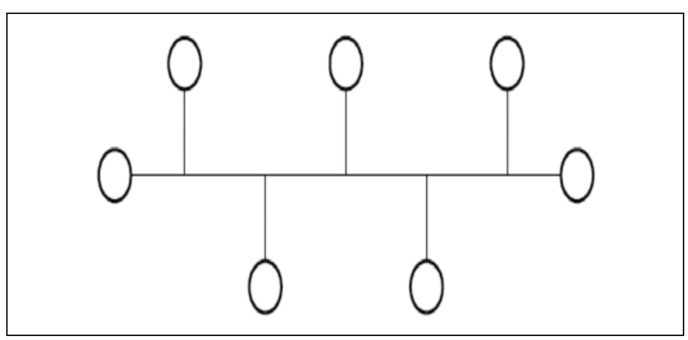
## A. Network Topology

Definition of the network topology at the conceptual stage is of paramount importance. There are various topologies which can be selected viz. bus, star, ring, tree, mesh, hybrid, free, etc, based upon factors such as reliability under abnormal conditions like network overload, component failure, expandability, latency, initial cost of investment, mean time to repair, etc.,

The network topology needs to be reflected at each level of automation i.e. process level, station level & grid level & also the choice of interconnection between the various levels. Choice is also available to provide communication with single channel or parallel channel / dual channel network structure for increased reliability. This means duplicating the network components & cabling thereby increasing initial investment cost.

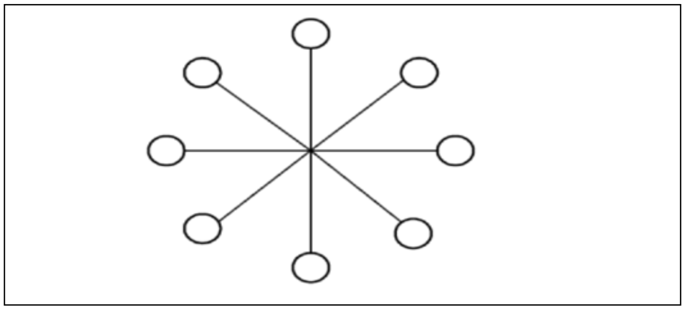
**Bus topology – characteristics**

- Easy to use.



- ❖ Lesser number of cabling required.
- ❖ Inexpensive & simple network
- ❖ Easy to extend
- ❖ Becomes slow by network traffic
- ❖ Difficult to trouble shoot a cable break or loose connector as reflection will bring down the whole network.

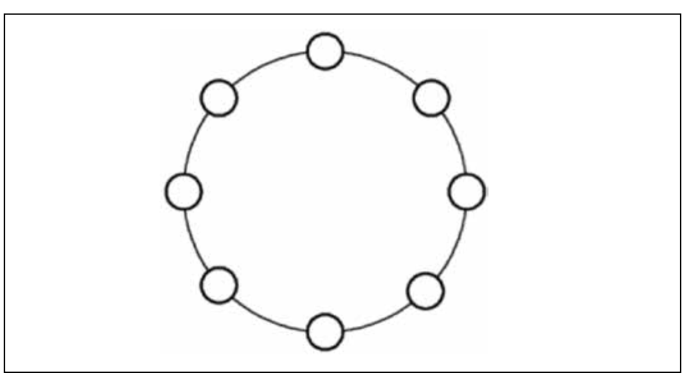
**Star topology – characteristics**



- ❖ Most widely used topology.
- ❖ The failure of a single device does not bring down the whole network.
- ❖ The centralized networking equipment can reduce costs
- ❖ Several cable types can be used on the same network with suitable hub.
- ❖ Failure of central device causes whole network failure.
- ❖ More expensive than bus topology.

**Ring topology – characteristics**

- ❖ One device cannot monopolize the entire network.
- ❖ Continue to function after capacity is exceeded but speed will be slow.

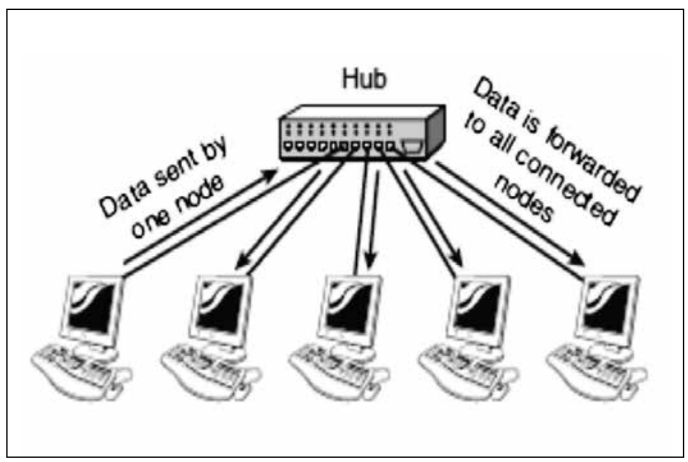


- ❖ Failure of one device can affect the whole network.
- ❖ Difficult to troubleshoot.
- ❖ Adding & removing devices disrupts the network.

## B. Network components

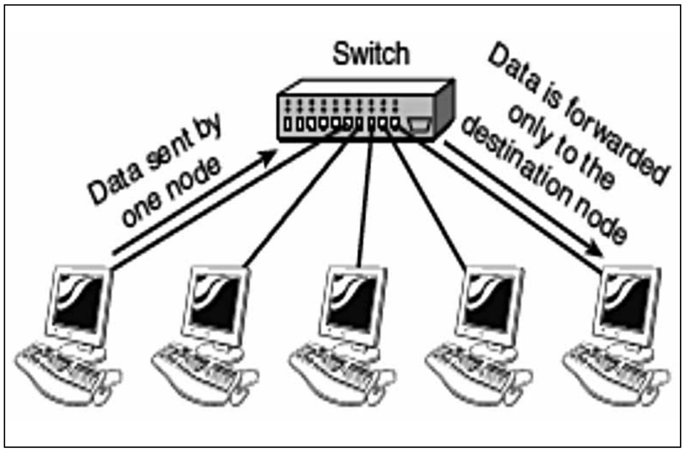
Network components form the main hardware devices necessary for automation. The various components, but not limited to the following are hub, repeater, switch, bridge, router, firewall, CSU/ DSU, gateway, modem, NIC, ISDN terminals, WAP, transceivers, Ethernet cables / connectors, fiber optic cables / connectors, etc. The components are divided into logical groups based upon the data transfer function performed as per OSI model of network architecture. Hubs are considered layer 1 device operating at physical layer (bits), switch is considered a layer 2 device operating at data link layer (frames) & router is considered a layer 3 device operating at network layer (packets). All the upper layers are logical in nature & functions are performed by the software protocol.

**Hub - characteristics**

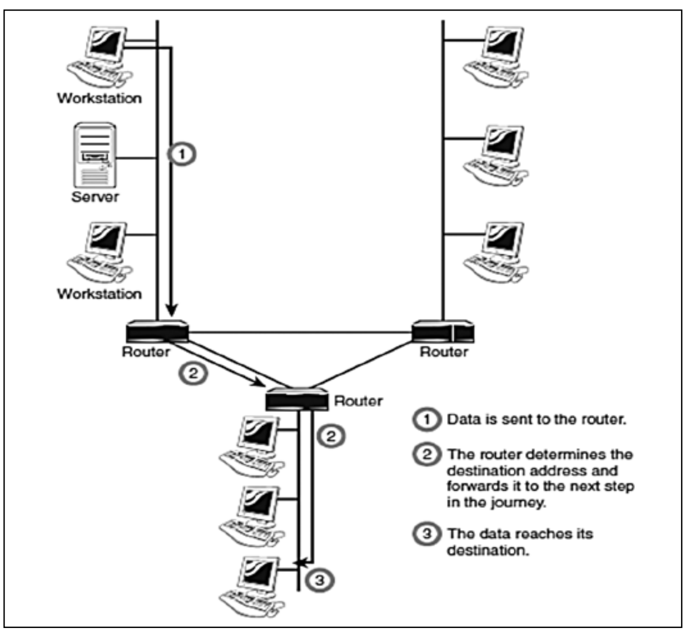



- ❖ Hubs are also known as multiport repeaters.
- ❖ They are plug & play devices
- ❖ A limited number of hubs can be cascaded.
- ❖ Devices interconnected by hubs are in the same collision domain & must operate at the same speed.

**Switch - characteristics**



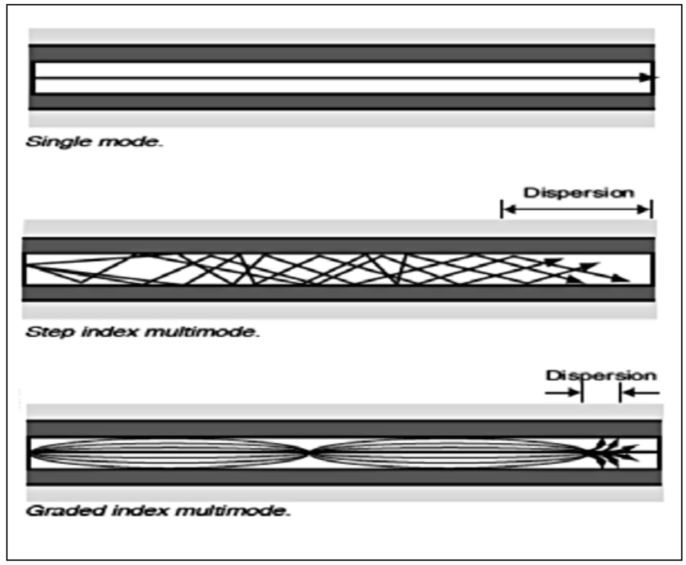

- ❖ Switches are active components operating at layer 2.
- ❖ Every port & its associated device is a separate collision domain, enabling full duplex (parallel sending & receiving) operating if the switch is suitably selected.
- ❖ Each port can operate at a separate speed & use different media.
- ❖ Switches can provide flow control.
- ❖ Unlimited number of switches can be cascaded.
- ❖ Store-and-forward type switches are preferred over cut-through switches as it checks for packet corruption & allows for improved switching features.




**Router - characteristics**

- ❖ Routers are layer 3 devices used to interconnect separate networks.
- ❖ They create & maintain a table of available networks & use this information to determine the best route for a given data packet from source to destination.
- ❖ Routers can be used to break up broadcast domains.

**Fiber Optic Cable – characteristics**




Single mode fiber has a small core diameter (about 9 $\mu$m) and transmits infrared laser light (wavelength = 1300 to 1550 nm). It provides only one optic mode that forces light along a linear path through the cable and causing much lower dispersion & attenuation than multimode. Single mode fiber are used when its higher bandwidth & longer distance are areas of concern.

Step index multimode has an abrupt change between core & cladding & graded index multimode has gradual change between core & cladding. Multimode fibers have large core diameters (typically 50, 62.5, 100 $\mu$m) and transmits infrared laser light (wavelength = 850 to 1300 nm). The cladding diameter is usually 125 $\mu$m for all types of fiber optic cables.

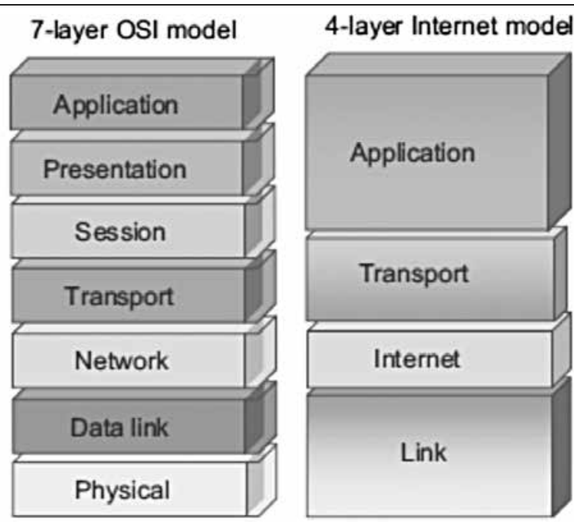
## C. Network architecture

Open Systems Interconnection (OSI) model is maintained by ISO & is a conceptual model that characterizes the internal functions of a communication protocol by dividing the same into seven logical layers. A layer serves the layer above it & is in turn served by the layer below it.

**The OSI Model**

| | Layer | Data unit | Function |
|---|---|---|---|
| Host layers | 7. Application | Data | Network process to application |
| | 6. Presentation | | Data representation and encryption |
| | 5. Session | | Interhost communication |
| | 4. Transport | Segment | End-to-end connections and reliability |
| Media layers | 3. Network | Packet | Path determination and logical addressing |
| | 2. Data Link | Frame | Physical addressing |
| | 1. Physical | Bit | Media, signal, and binary transmission |

The 4 layer internet model or the TCP/IP protocol suite is a set of communication protocol used for the internet & other similar networks. Each layer solves a set of problems involving transmission of data, and provides a well defined service to the upper layer protocol based on using services from some lower layers. The internet layer works on IPv4 & IPv6. Protocols like ICMP & IGMP are associated with this layer. The transport layer contains 2 protocols viz. TCP & UDP. The application layer contains various protocols like FTP, HTTP, SNMP, SMTP, NTP, RSTP, POP, DHCP, DNS, etc.




## D. Serial communication protocols

Communication protocols like Ethernet, Modbus, CANopen, IEC 60870-5-103, IEC 61850, etc are been used extensively for communication between the various layers set up under network topology & via the various network components.

### Ethernet

| Field | Field size (in octets) | Cumulated field size (in octets) |
|---|---|---|
| Preamble | 7 | 72...1530 |
| Start-of-Frame delimiter | 1 | |
| MAC destination | 6 | |
| MAC source | 6 | |
| 802.1Q header (optional) | 4 | 64...1522 |
| Ethertype/Length | 2 | |
| Payload (Data and padding) | 46...1500 | |
| CRC32 | 4 | |
| Interframe gap | 12 | 84...1542 |

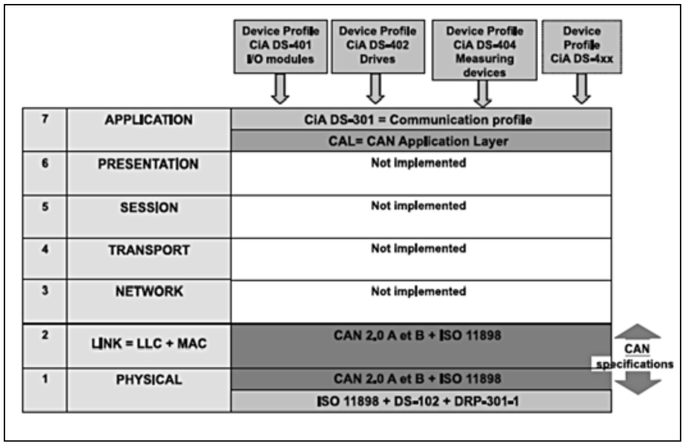
*Frame structure.*

Ethernet is a communication protocol for LAN & WAN networks. It is part of IEEE 802.3 standard & is part of international standard ISO/IEC 8802-3. Ethernet works on the CSMA principle & further upgrades like CSMA/CD & CSMA/CA has helped the protocol gain prominence. The only drawback compared to the IBM token ring & token bus systems was that of collisions. With the advent of switching technology, Ethernet now has a new lease of life which creates collision-less & full duplex network operation. Ethernet can be mapped onto the TCP/IP protocol stack to make it more versatile over the large internetworks & can be implemented with co-axial cable or twisted pair cable (CAT 5, CAT6, etc).

Ethernet is generally specified using <data rate> <modulation> <additional parameter> method. The data rate is in Mbps, the modulation is either BASE or BROAD & additional parameter like T for twisted pair, S for short wavelength optics & X for block PCS coding. Thus 100BASE-TX means as speed of 100 Mbps, modulation is BASE type & implemented using twisted pair cable & PCS coding.

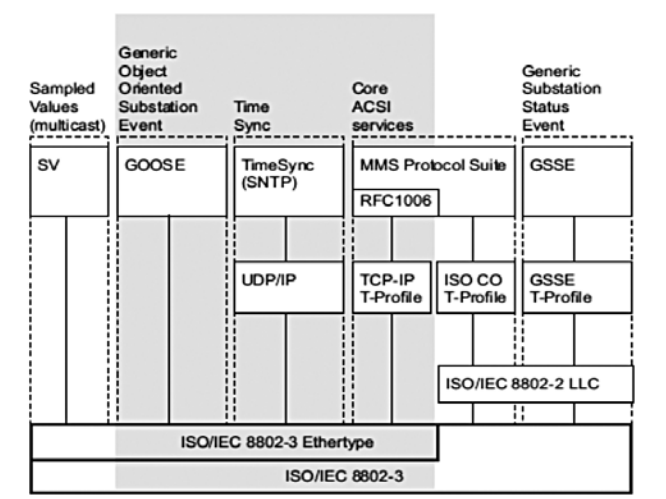
### CANopen

Controller Area Network (CAN) is an important protocol used to interface directly with intelligent




machines, tools, jigs & controllers. Because of its high immunity to electro-magnetic interference(EMI), CANopen enables a plant & machine to work with very high precision.

### IEC 61850



*IEC 61850 mapping to Ethernet.*

This protocol is meant for seamless communication between substation components. IEC 61850 is an ACSI i.e. Abstract Communication System Interface & hence it needs to be mapped to a physical network. At present this mapping is only available with Ethernet. The colored portion indicates the part of the mapping & functions provided by numerical protection relays which has facility for communication using IEC 61850.

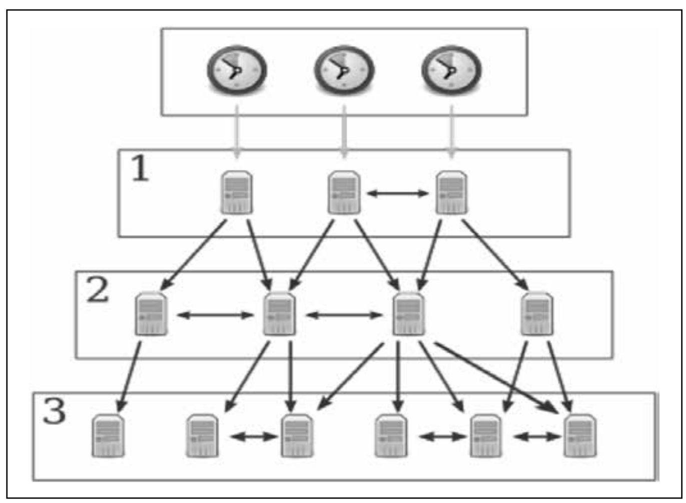
The client-server part of the IEC 61850 is mapped to Manufacturing Message Specifications (MMS – ISO 9506). MMS is designed to operate on top of an ISO communication stack. In case of TCP/IP communication stack, which is generally the case, an intermediate RFC1006 layer is used which provides the necessary mapping between OSI reference model & TCP/IP reference model.

To allow fast real time communication, GOOSE (Generic Object Oriented Substation Event) messages do not make use of any protocol stack. GOOSE messages are directly encoded into the Ethernet frame & these messages are multicast at MAC level.

## E. Time synchronization protocols

Time synchronization is a very important aspect as it is necessary to have time stamping of all events under normal & under fault conditions. Also as now-a-days commands can be provided & feedback received over the network or internet with the present technology, it will be only prudent to have credible time stamping system for normal as well as abnormal circumstances. The need for precision time stamping having nano-second level accuracy have become even more necessary with the advent of latest technologies for monitoring the system parameters like synchro-phasors & also for in-depth fault analysis.

### Network Time Protocol (NTP)




Network Time Protocol (NTP) is a networking protocol for clock synchronization between components over packet-switched, variable-latency data networks. NTP is intended to synchronize all components to within a few milliseconds of Coordinated Universal Time (UTC). NTP uses a hierarchical, semi-layered system of time sources. Each level of this hierarchy is termed a "stratum" and is assigned a number starting with zero at the top. The number represents the distance from the reference clock and is used to prevent cyclical dependencies in the hierarchy. Only strata 0 to 15 are valid; stratum 16 is used to indicate that a device is unsynchronized. A less complex implementation of NTP, using the same protocol but without requiring the storage of state over extended periods of time is known as the Simple Network Time Protocol (SNTP). It is used in some embedded devices and in applications where high accuracy timing is not required. Standard computers operating on standard commercial operating systems can maintain time stamping accuracy in the range of 1 to 2 seconds. If higher accuracy is desired, then it calls for a different implementation of NTP using dedicated servers & high end computers. The NTP/SNTP synchronization is possible over the networks using Ethernet & no dedicated cabling is required.

### IRIG-B Time synchronization

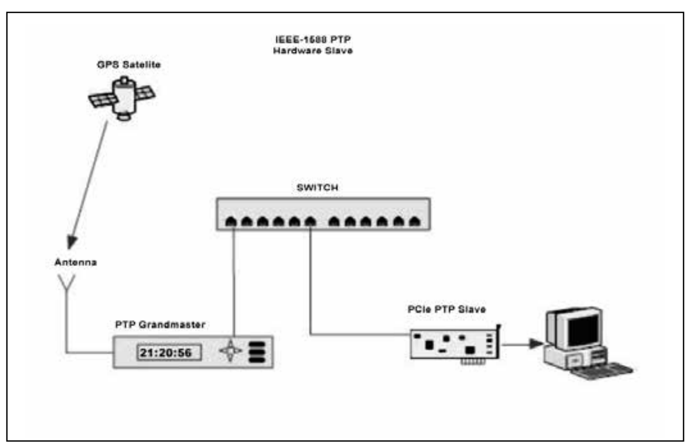
Inter-range instrumentation group time codes, commonly known as IRIG timecodes, are standard formats for transferring timing information. The different timecodes defined in the Standard have alphabetic designations. A, B, D, E, G, and H. The main difference between codes is their rate, which varies between one pulse per second and 10,000 pulses per second. Atomic frequency standards and GPS receivers designed for precision timing are often equipped with an IRIG output. For example, one of the most common formats, IRIG B122: IRIG B122 transmits one hundred pulses per second on an amplitude modulated 1 kHz sine wave carrier, encoding information in BCD. This means that 100 bits of information are transmitted every second. The time frame for the IRIG B standard is 1 second, meaning that one data frame of time information is transmitted every second. This data frame contains information about the day of the year (1–366), hours, minutes, and seconds. Although information is transmitted only once per second, a device can synchronize its time very accurately with the transmitting device by using a phase locked loop to synchronize to the carrier. Typical commercial devices will synchronize to within 1 microsecond using IRIG B time codes. Separate co-axial cable is required to interconnect all network devices to be synchronized through IRIG-B.

### Precision Time Protocol (PTP v2)

Precision time protocol (PTP v2) as defined in IEEE 1588 standard provides a method to precisely synchronize multiple clocks over a LAN within an accuracy range of less than 100 nanosecond.

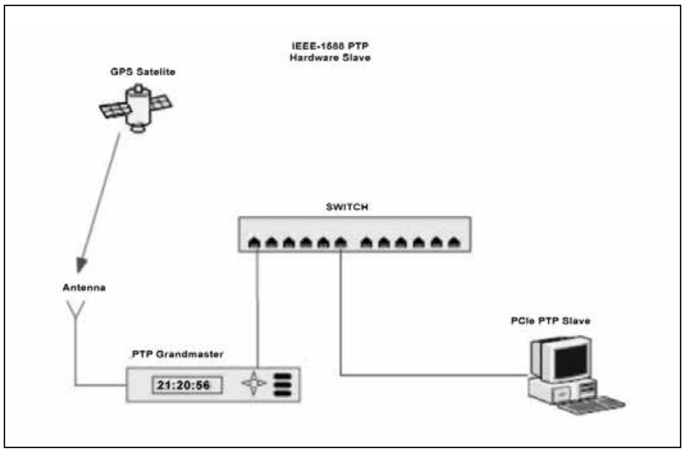
While locked to GPS, the PTP v2 grandmaster clock can provide timestamp resolution & accuracy better than 30 nanoseconds. A grandmaster clock incorporates a local reference oscillator that is disciplined to the GPS. The oscillator is the reference clock use with dedicated hardware for the precise timestamp.

Hardware timestamps with a PTP v2 software Daemon provide precision nanosecond timestamp resolution better than 100 nanosecond using IEEE 1588 compliant Ethernet switch. To eliminate the variability in the delay of timing packets between devices, PTP v2 compliant Ethernet devices records the time that PTP v2 packets enter & exit the device and makes the timestamp available to PTP v2 software. This enables the PTP v2 application to use timing packets to accurately synchronise clocks without the inconsistent variability introduced by delays in the operating system and software stacks.



Software-only implementations utilize existing computer hardware & a PTP v2 Daemon. The slave software solution must compensate for the internal oscillator on the computer motherboard using software timestamping. The local oscillator on the motherboard is typically of poor quality & the software timepstamping is affected by operating system latency. Time stamp resolution of 10 micro second is achievable with a software slave.

The synchronization using PTP v2 is possible over the Ethernet network and no dedicated cabling is necessary.




## F. Software Tools

System software shall encompass all the control, diagnostics & monitoring functions so as to provide the operator with all the means to allow a continuous and simple operation of the system. The software application program shall perform diagnostics, define procedure for network data exchange, define procedure for I/O card configuration & parameters, define procedure for preparing the data like reports, trends, logs, etc, for supervisory system, define procedure for event & alarm detection & management, define procedure for processing the system functions,

Identification of the program with clear & easily interpretable commands.

The HMI shall have the following as minimum.

- graphic pages
- real time & historical records of events & logs
- equipment control
- alarm & measurement trends
- real time recording of faulty & abnormal operations
- event disturbance records
- energy & power consumption
- balance reports
- equipment operating counter & operating time
- easily configurable
- possibility of relay parameterization over the network

## G. Performance requirements

The consulting engineer is required to amalgamate all the various aspects to create specifications which broadly define the performance requirements of substation automation system. One of the major aspects to be defined is the response time of a command under maximum network loading conditions, which enables the vendor to adjust any of the parameters already identified during the bid. Any interface with a network beyond the scope is also of particular interest for compatibility issues, especially any using utilizing legacy protocols.

The primary performance evaluation parameters of substation automation system are as follows.

- Integrity
- Accuracy
- Response time
- Electromagnetic compatibility (EMC)
- Availability & Reliability
- Auto-test & diagnostics
- Safety
- Ergonomics of HMI
- Expandability
- Noise level of the equipment
- Mean Time Between Failure (MTBF)
- Mean Time To Repair (MTTR)
- Capability of backward integration with legacy systems
- Compliance with international norms viz, IEEE 999, IEEE 1046, IEEE 1379, IEEE C37.1, IEC 61131, IEC 61000, IEC 61850, etc.