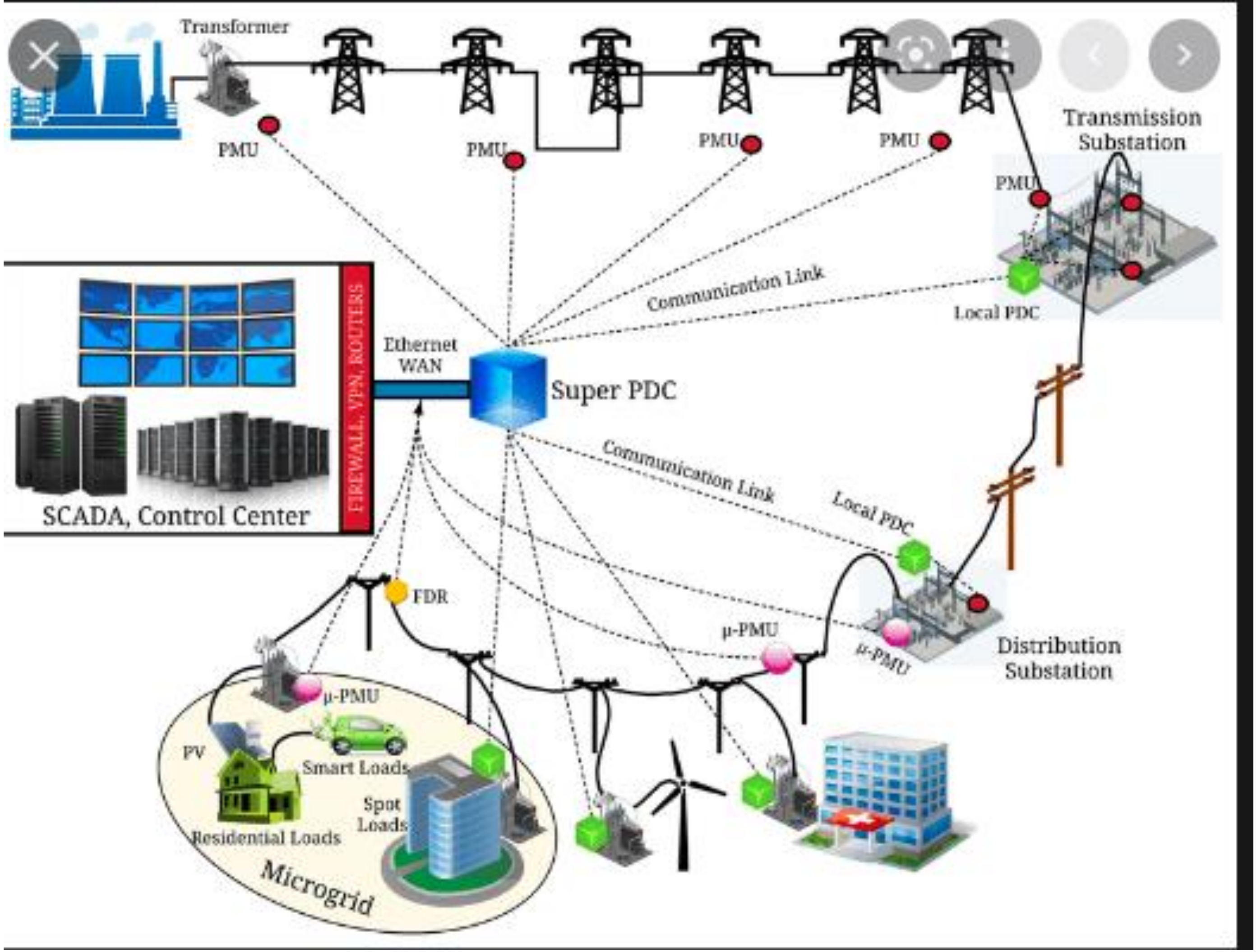
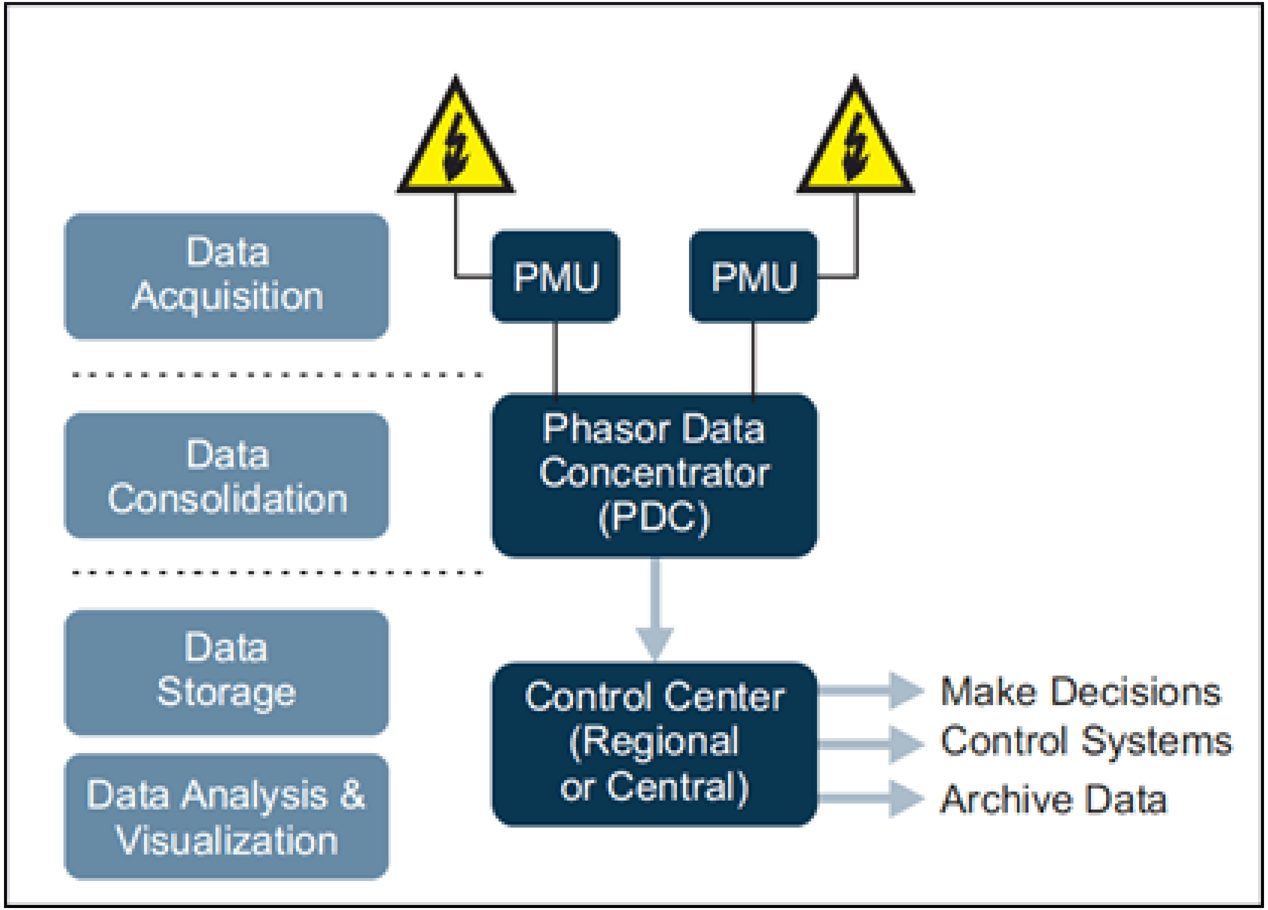
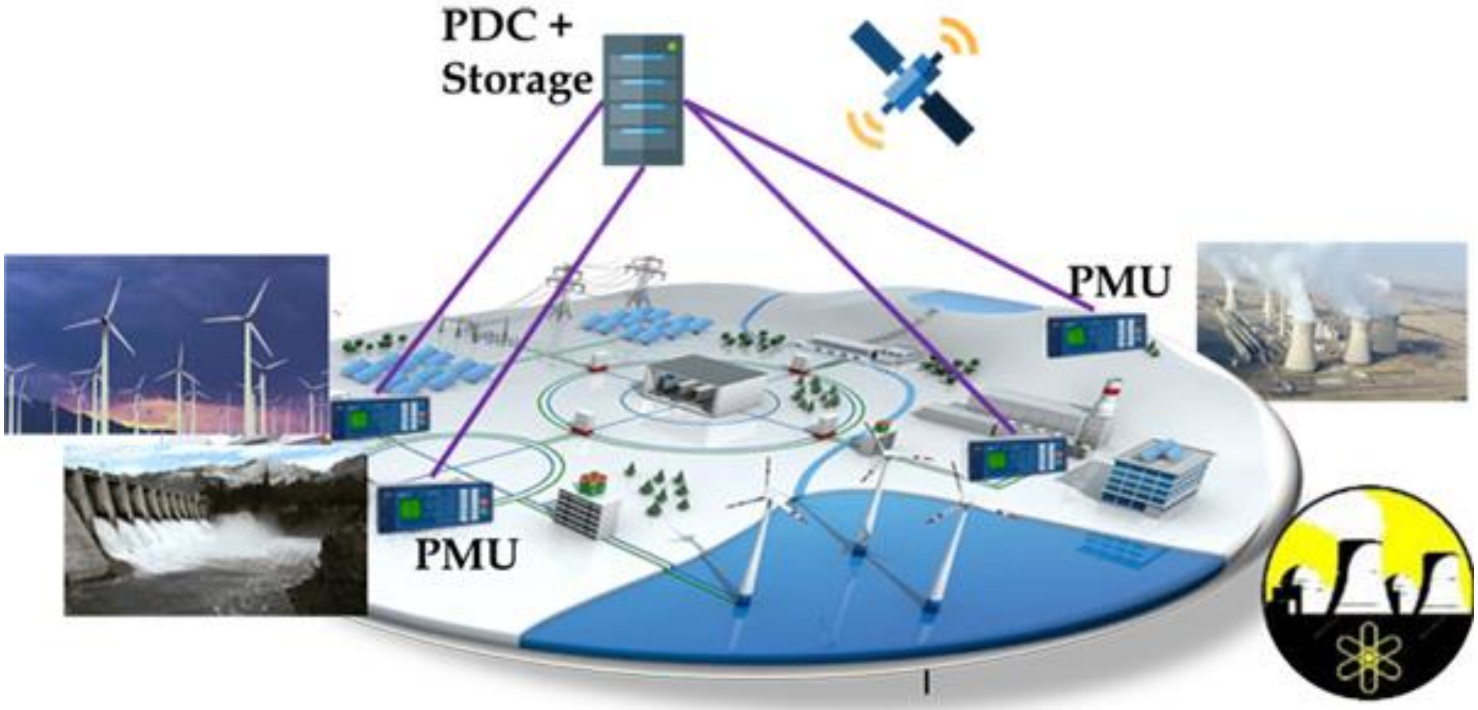
Phasor measurement Unit (PMU)

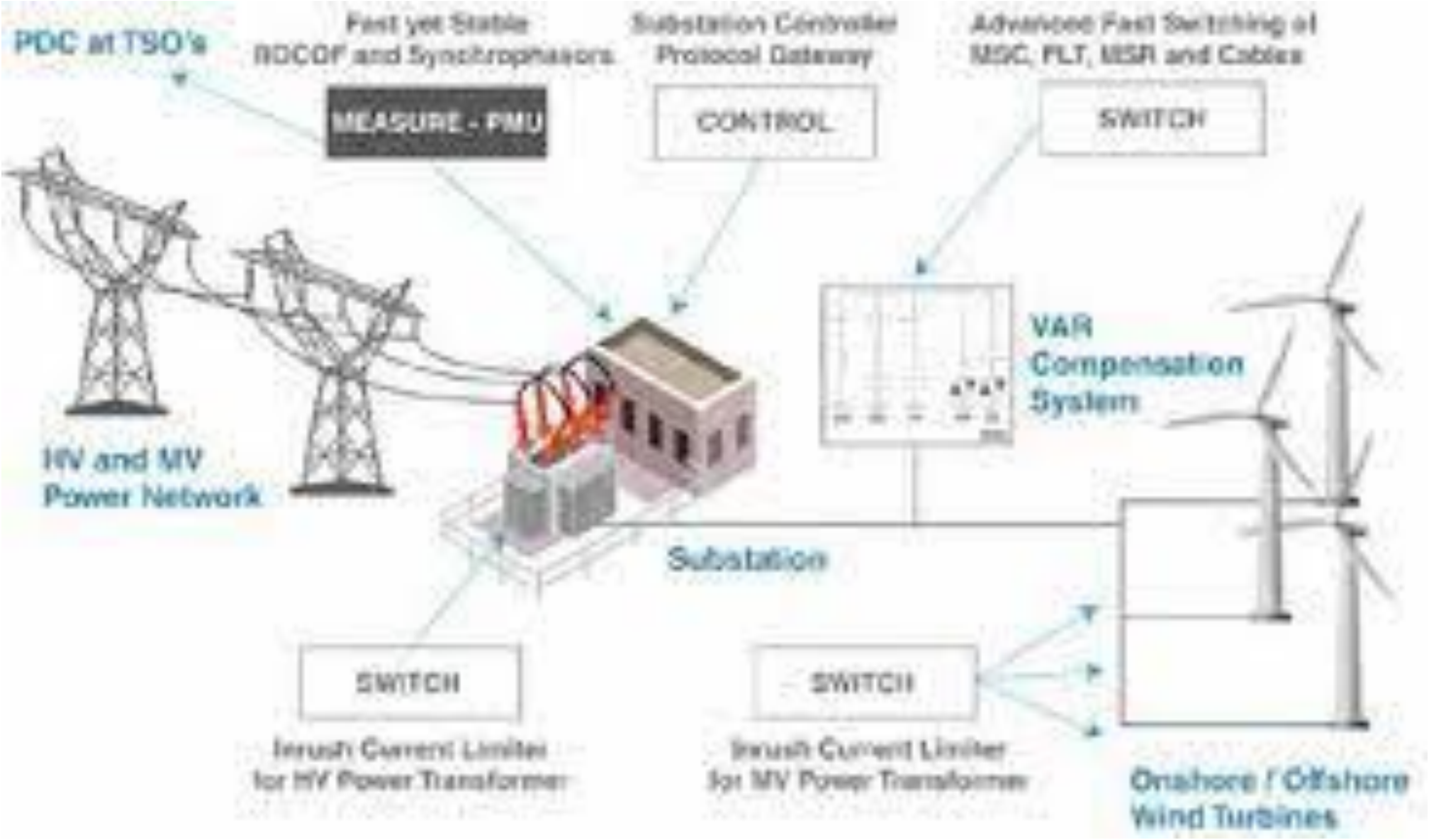


Transformer
PMU
PMU
PMU
PMU
Transmission Substation
PMU
Local PDC
Communication Link
FIREWALL, VPN, ROUTERS
Ethernet WAN
Super PDC
SCADA, Control Center
Communication Link
Local PDC
FDR
μ-PMU
μ-PMU
Distribution Substation
μ-PMU
PV
Smart Loads
Spot Loads
Residential Loads
Microgrid



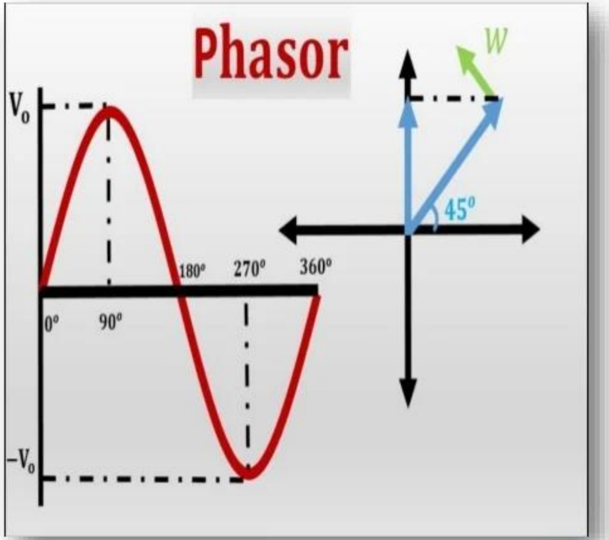
Data Acquisition
Data Consolidation
Data Storage
Data Analysis & Visualization
PMU
PMU
Phasor Data Concentrator (PDC)
Control Center (Regional or Central)
Make Decisions
Control Systems
Archive Data


PDC +
Storage
PMU
PMU


PDC at TSO's
Fast yet Stable
ROCOF and Synchrophasors
MEASURE - PMU
Substation Controller
Protocol Gateway
CONTROL
Advanced Fast Switching of
MSC, FLT, MSR and Cables
SWITCH
VAR
Compensation
System
HV and MV
Power Network
Substation
SWITCH
Inrush Current Limiter
for HV Power Transformer
SWITCH
Inrush Current Limiter
for MV Power Transformer
Onshore / Offshore
Wind Turbines

WHAT IS PHASOR?

- **Phasor is a quantity with magnitude and phase (with respect to a reference)** that is used to represent a sinusoidal signal.
- Here the **phase or phase angle is the distance between the signal's sinusoidal peak and a specified reference and is expressed using an angular measure.**
- Here, the **reference is a fixed point in time (such as time = 0).**
- The phasor magnitude is related to the **amplitude of the sinusoidal signal**.



WHAT IS PHASOR MEASUREMENT UNIT?

- A **phasor measurement unit** (PMU) is a device used **to estimate the magnitude and phase angle of an electrical phasor quantity** (such as voltage or current) in the electric grid using a common time source for synchronization.
- **Time synchronization is usually provided by GPS** and allows synchronized real-time measurements of multiple remote points on the grid.
- **PMUs are capable of capturing samples from a waveform in quick succession** and reconstructing the phasor quantity, made up of an angle measurement and a magnitude measurement.
- The resulting measurement is known as a ***synchrophasor***. These time synchronized measurements are important because if the grid's supply and demand are not perfectly matched, frequency imbalances can cause stress on the grid, which is a potential cause for power outages.

Continue...

- PMUs can also be **used to measure the frequency** in the power grid.
- A typical commercial PMU can report measurements with very high temporal resolution in the order of **30-60 measurements per second**. This helps engineers in analyzing dynamic events in the grid which is not possible with traditional **SCADA measurements** that generate one measurement every **2 or 4 seconds.**
- Therefore, PMUs equip utilities **with enhanced monitoring and control capabilities** and are considered to be one of the most important measuring devices in the future of power systems.
- A PMU can be a dedicated device, or the PMU **function can be incorporated into a protective relay** or other device.

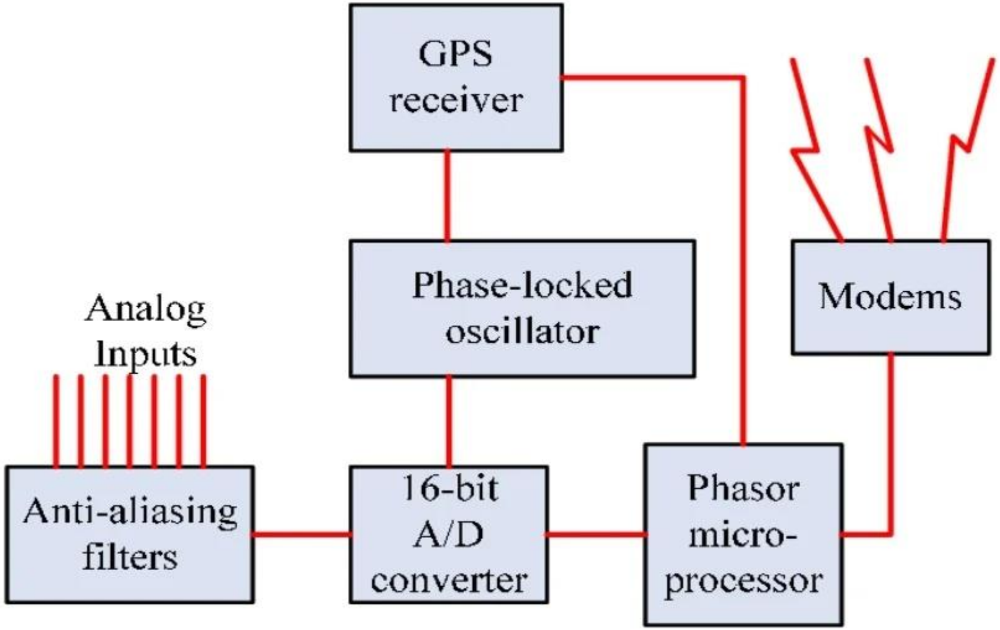
WHY PMU?

- PMU an essential component of Smart Grids.
- It **provides Synchrophasor data**
- **Reports Magnitude, Phase and Frequency** of an AC waveform
- **Makes the grid observable** due to high reporting rates
- **Preventive actions** can be taken such as black outs

The main components of PMU

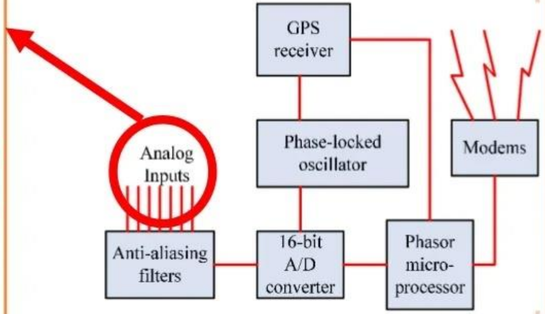
- Analog Inputs
- GPS receiver
- Phase locked oscillator
- A/D converter
- Anti-aliasing filters
- Phasor micro-processor
- Modem

Block diagram of PMU



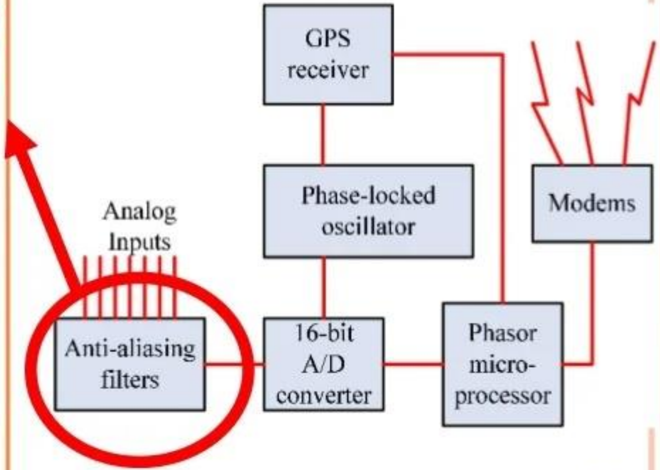
ANALOG INPUTS

- **Current and potential transformers** are employed at substation for measurement of voltage and current.
- **The analog inputs to the PMU are the voltages and currents** obtained from the secondary winding of potential and current transformers.



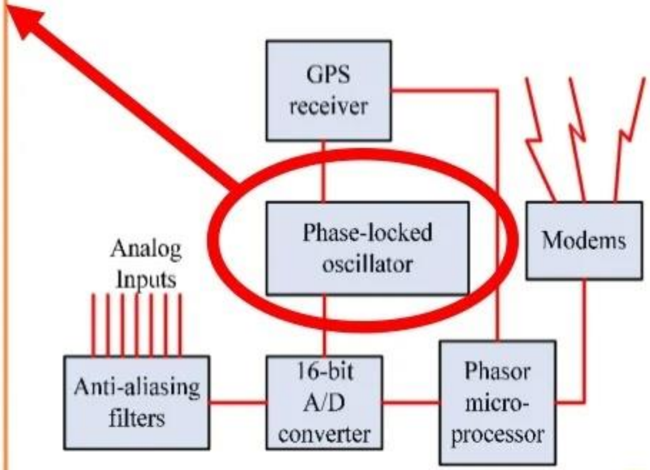
Anti-aliasing filters

- Anti-aliasing filter is an analog low pass filter which is **used to filter out those components from the actual signal whose frequencies are greater than or equal to half of nyquist rate to get the sampled waveform.**
- Nyquist rate is equal to twice the highest frequency component of input analog signal.
- If anti aliasing filters are not used, **error will be introduced in the estimated phasor**



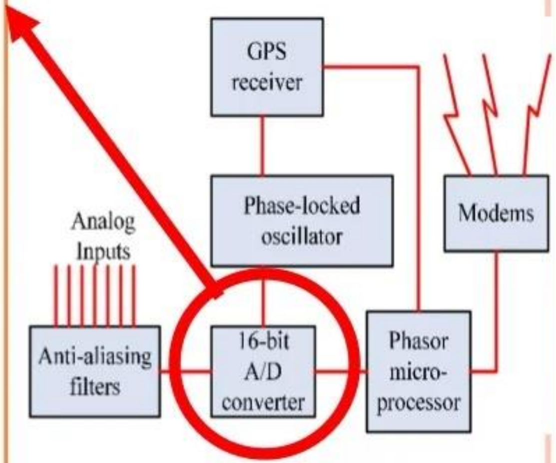
PHASE LOCK OSCILLATOR

- Phase lock oscillator along with Global Positioning System reference source **provides the needed high speed synchronized sampling.**
- Global Positioning System (GPS) is a satellite-based system for **providing position and time.**



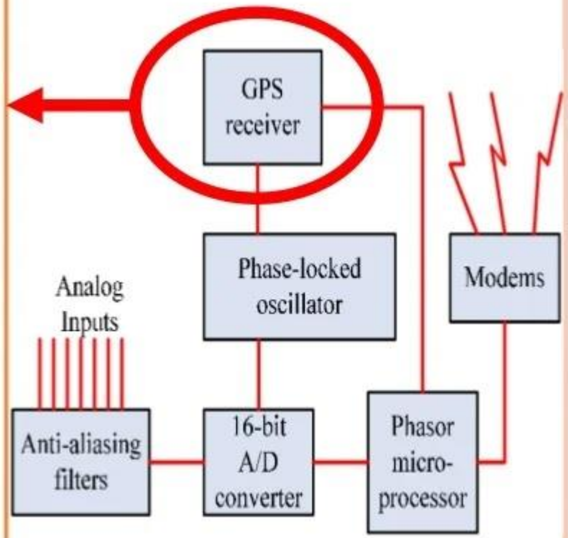
A/D CONVERTER

- It **converts the analog signal to the digital signal.**
- Quantization of the input involves in ADC that introduces a small amount of error.
- The output of ADC is a sequence of digital values that convert a continuous time and amplitude analog signal to a discrete time and discrete amplitude signal.
- It is therefore required to define the rate at which new digital values are sampled from the analog signal.
- The rate of new values at which digital values are sampled is called the sampling rate of the converter.



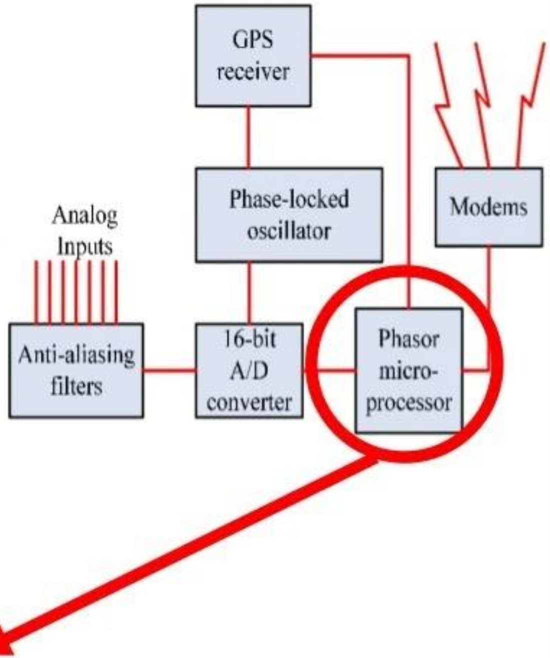
GLOBAL POSITIONING SYSTEM

- The synchronized time is given by GPS **uses the high accuracy clock from satellite technology.**
- Without GPS **providing the synchronized time**, it is hard to monitor whole grid at the same time.
- The GPS satellites **provide a very accurate time synchronization signal**, available, via an antenna input, throughout the power system. This means that that voltage and current recordings from different substations can be directly displayed on the same time axis and in the same phasor diagram.



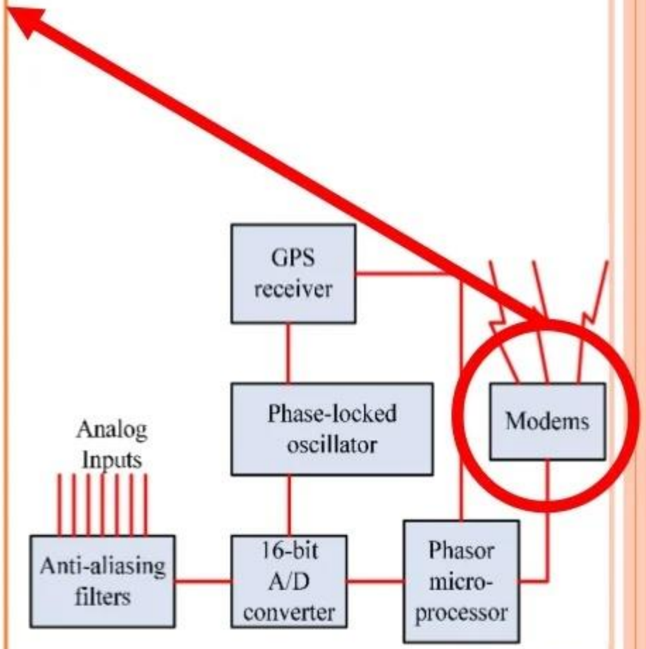
Processor

- The microprocessor **calculates positive-sequence estimates of all the current and voltage signals using the DFT techniques.**
- **Certain other estimates of interest are frequency and rate of change of frequency measured** locally, and these also are included in the output of the PMU.
- The timestamp is created from two of the signals derived from the GPS receiver.
- The time-stamp identifies the identity of the "universal time coordinated (UTC) second and the instant defining the boundary of one of the power frequency periods.



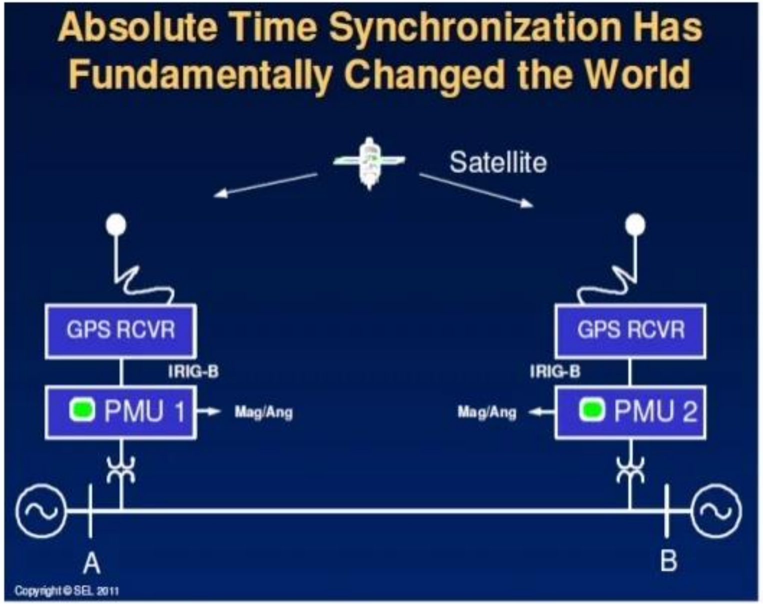
MODEM

- A device that **modulates an analog carrier signal and encodes digital information from the signal and can also demodulate the signal to decode the transmitted information from signal** is called modem.
- The objective of modem is to **produce a signal that can be transmitted and decoded to make a replica of the original digital data.**
- Modem can be used with no means of transmitting analog signals



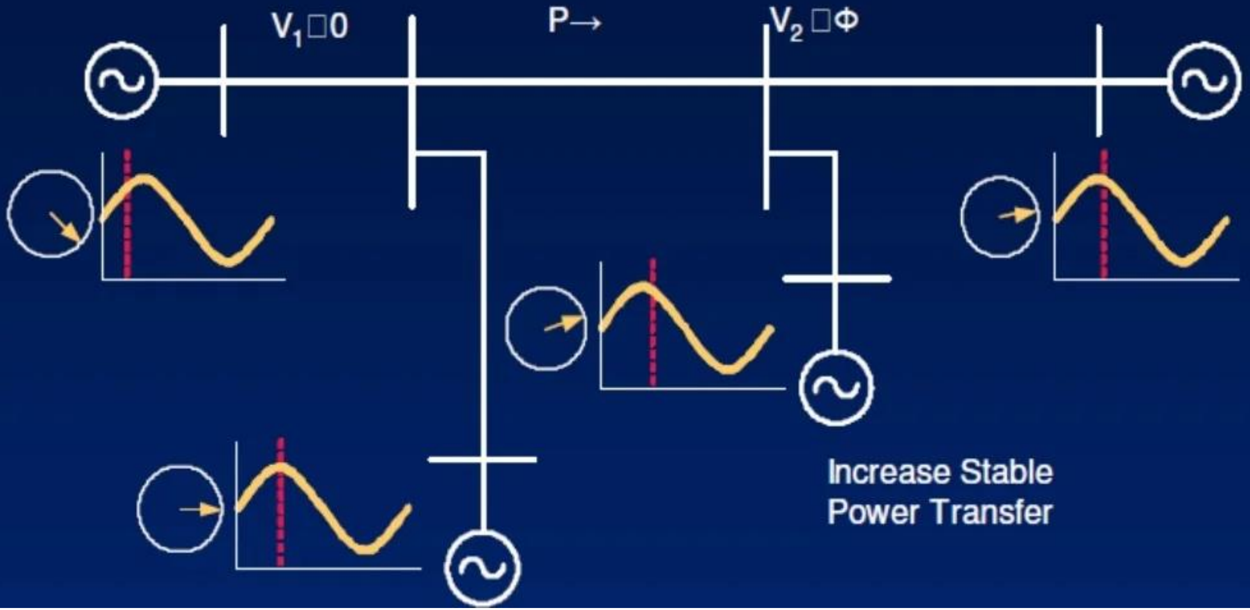
SYNCHROPHASOR

- A synchrophasor is a phasor measurement with respect to an absolute time reference.
- With this measurement we can determine the absolute phase relationship between phase quantities at different locations on the power system.



Synchrophasors Provide a “Snapshot” of the Power System

$P = |V_1|\ |V_2| \sin\Phi\ /\ X$ $\Phi = \sin^{-1}(PX\ /\ |V_1|\ |V_2|)$



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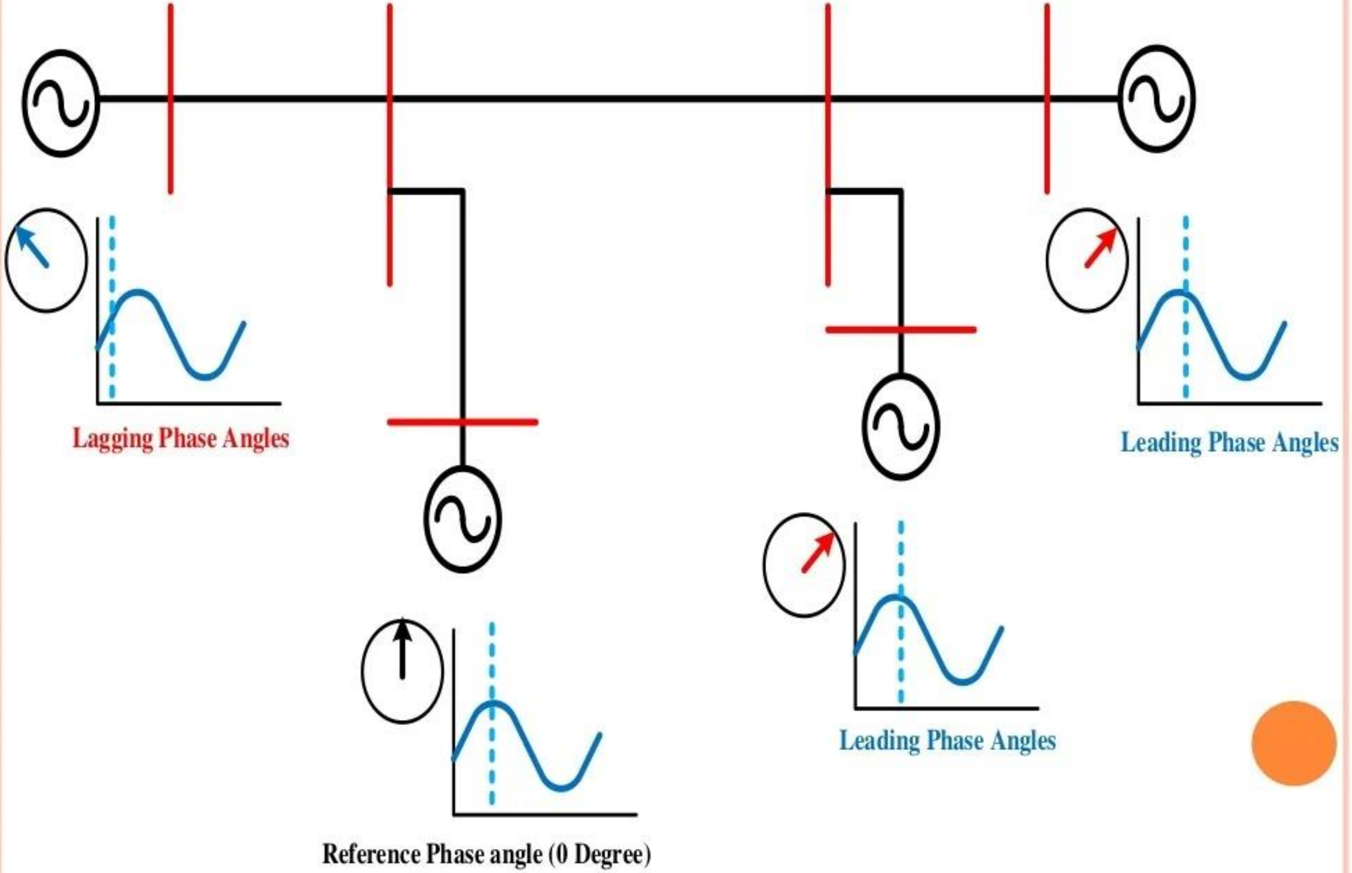


Lagging Phase Angles
Leading Phase Angles
Leading Phase Angles
Reference Phase angle (0 Degree)

Features of PMUs

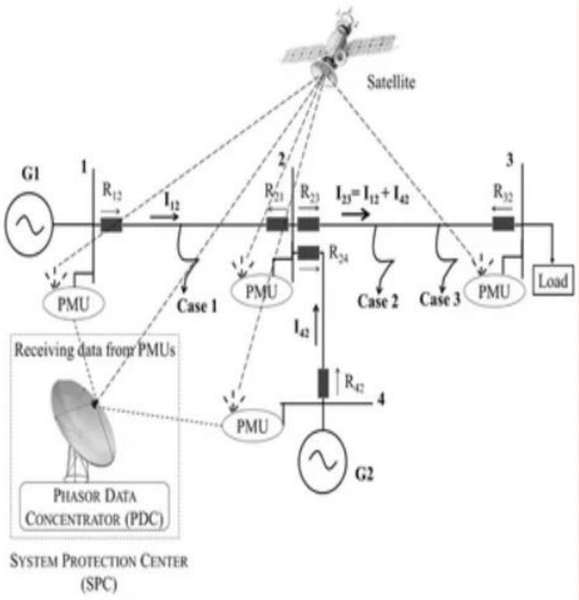
- PMUs are Measures 50/60 Hz AC waveforms (voltage and current) typically at a rate of 48 samples per cycle.
- PMUs are then computed using DFT-like algorithms, and time stamped with a GPS.
- The resultant time tagged PMUs can be transmitted to a local or remote receiver at rates up to 60 samples per cycle.

Application of PMU in Power System

1. Adaptive relaying
2. Instability prediction
3. State estimation
4. Improved control
5. Fault recording
6. Disturbance recording
7. Transmission and generation modeling verification
8. Wide area Protection
9. Fault location

Adaptive Relaying

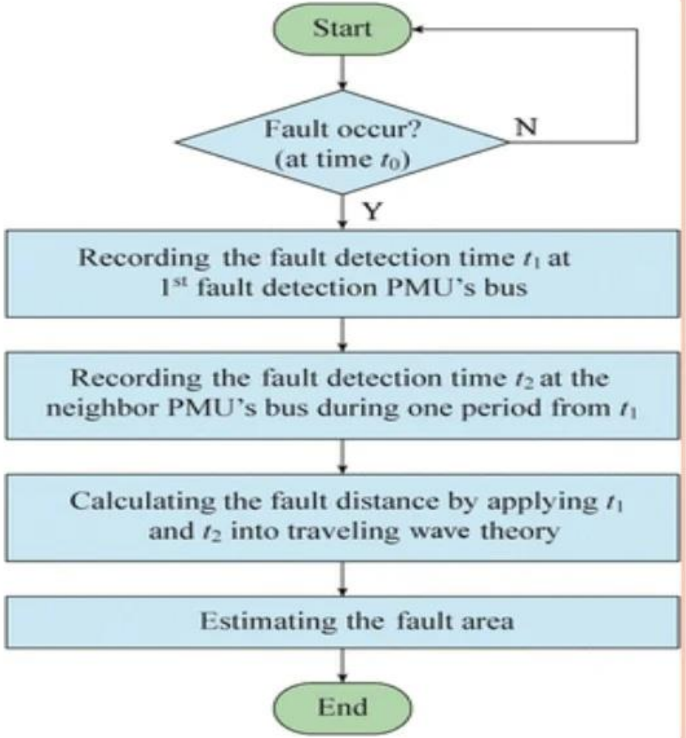
Adaptive relaying is a protection philosophy which permits and seeks to make adjustments in various protection functions in order to make them more tuned to prevailing power system conditions



Instability prediction

The instability prediction can be used to adapt load shedding and/or out of step relays.

We can actually monitor the progress of the transient in real time by the technique of synchronized phasor measurements.

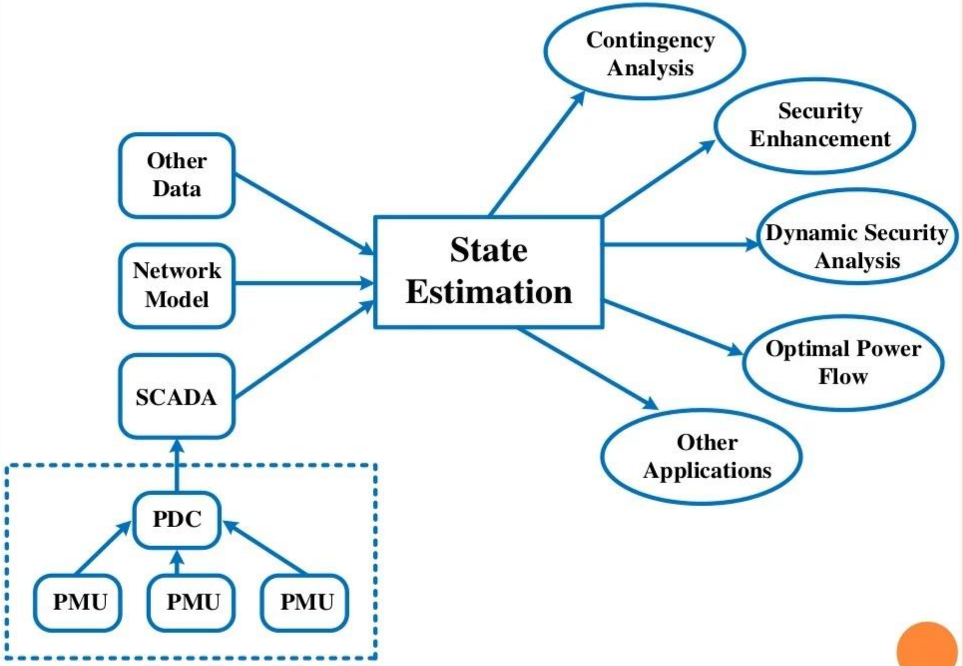


State estimation

- The state estimator uses various measurements received from different substations, and, through an iterative nonlinear estimation procedure, **calculates the power system state.**

- By maintaining a continuous stream of phasor data from the substations to the control center, a state vector that can follow the system dynamics can be constructed.

- For the first time in history, synchronized phasor measurements have made possible the **direct observation of system oscillations** following system disturbances.



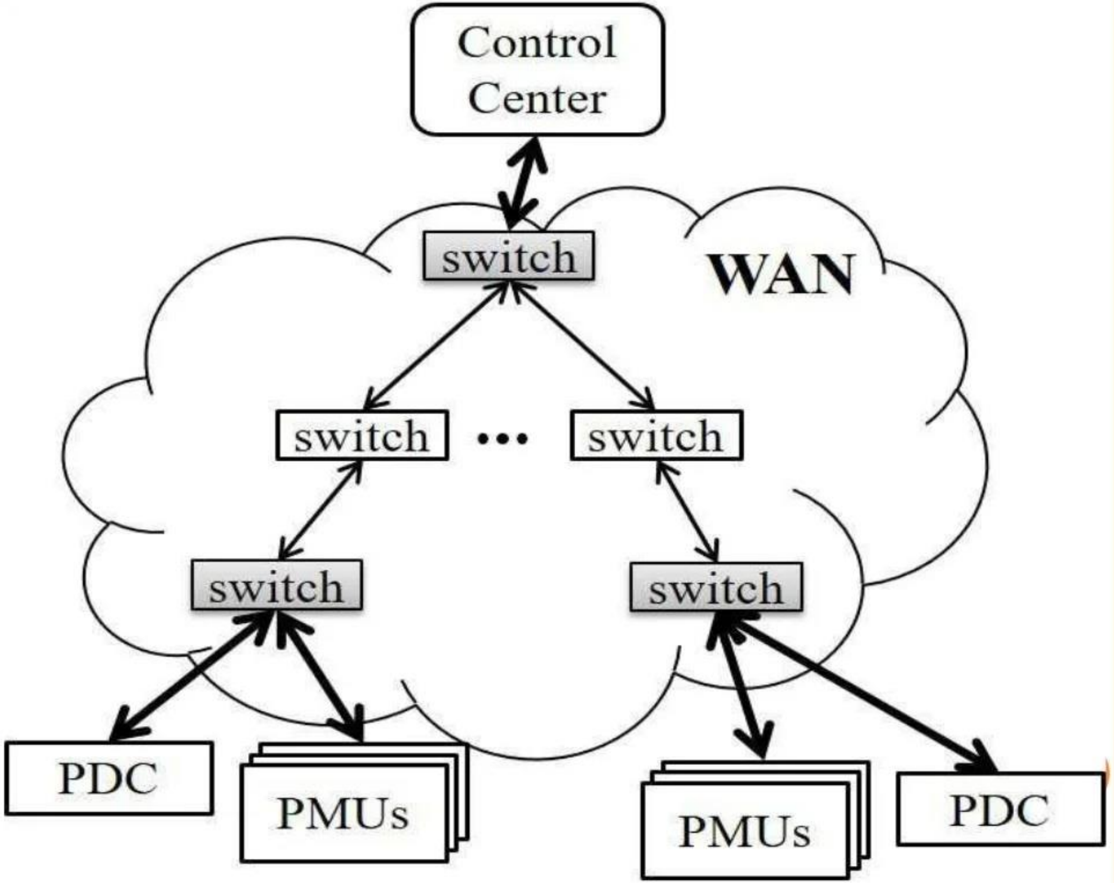
The role of state estimation in power system operation

Improved control

- Power system control elements use local feedback to achieve the control objective.

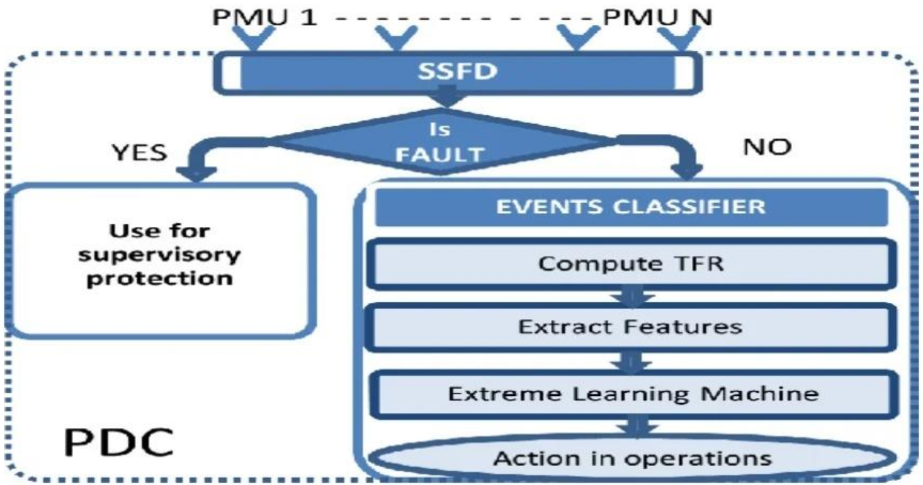
- The PMU was necessary to capture data during the staged testing and accurately display this data and provide comparisons to the system model.

- The shown figure shows a typical example of one of the output plots from the PMU data


Control Center
switch
WAN
switch
•••
switch
switch
switch
PDC
PMUs
PMUs
PDC

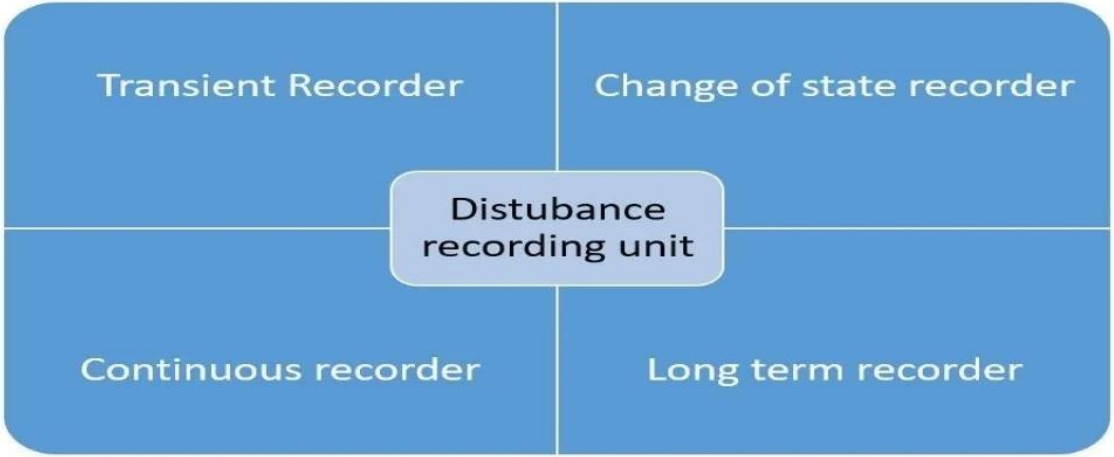
Fault Recording

- They can capture and display actual 60/50 Hz wave form and magnitude data on individual channels during power system fault conditions.



Disturbance Recording

- Loss of generation, loss of load, or loss of major transmission lines may lead to a power system disturbance, possibly affecting customers and power system operations.



Transmission and Generation Modeling Verification

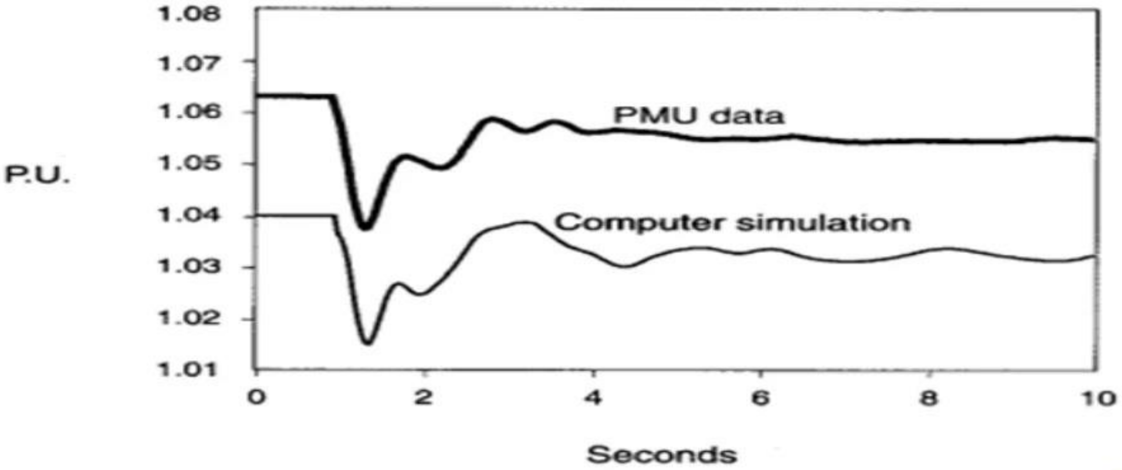
- Computerized power system modeling and studies are now the normal and accepted ways of ensuring that power system parameters have been reviewed before large capital expenditures on major system changes.

- In years past, **actual verification of computer models via field tests** would have been either impractical or even impossible

- The PMU class of monitoring equipment can now **provide the field verification** required.

Continue ...

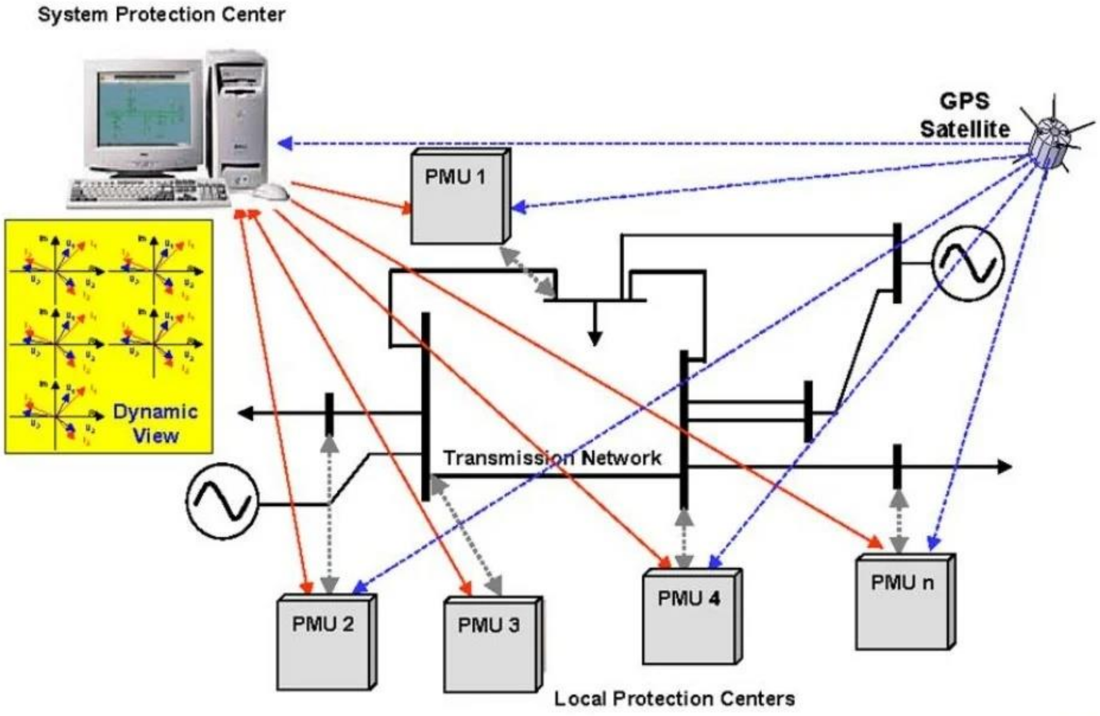
• The shown figure compares a remote substation 500 kV bus voltage captured by the PMU to the stability program results



Positive sequence voltage phasor on a 500 kv bus vs computer model simulation of switching test

Wide – Area protection

The introduction of the Phasor Measurement Unit (PMU) has greatly improved the **observability of the power system dynamics**. Based on PMUs, different kinds of wide area protection, emergency control and optimization systems can be designed

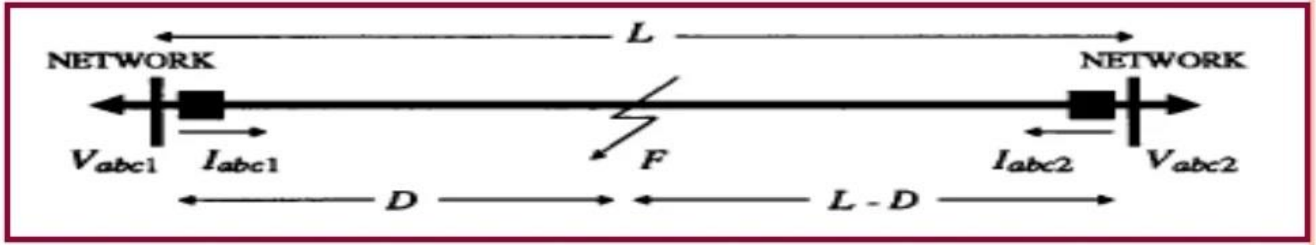


Multilayered wide area protection architecture

Fault Location

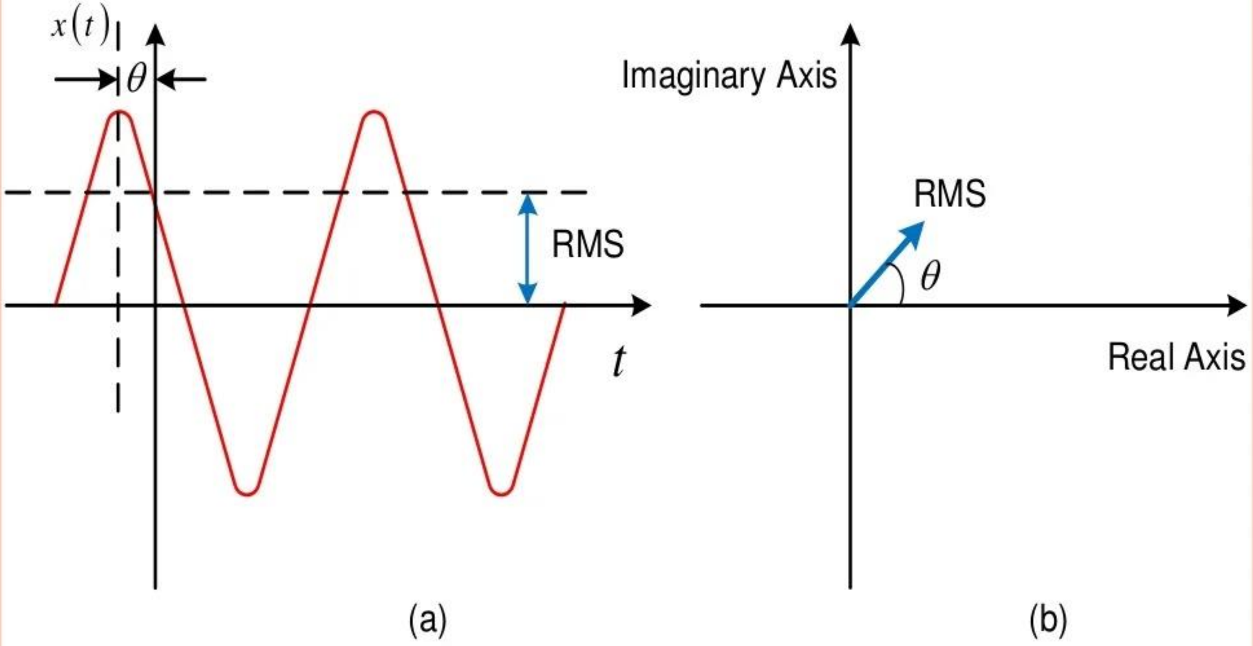
A **fault location algorithm** based on synchronized sampling. A time domain model of a transmission line is used as a basis for the algorithm development. **Samples of voltages and currents at the ends of a transmission line** are taken simultaneously (synchronized) and used to calculate fault location.

Phasor measurement units are installed at both ends of the transmission line. The three phase voltages and three phase currents are measured by PMUs located at both ends of line simultaneously



Phasor Measuremnet Techniques

- A pure sinusoid quantity given by $x(t) = X_m \cos(\omega t + \theta)$ and its phasor representation $X = (X_m/\sqrt{2})e^{j\theta} = (X_m/\sqrt{2})(cos\theta + jsin\theta)$ are illustrated in Figure. The aim of phasor estimation technique is just to **acquire the phasor representation**.
- Samples of waveform data are collected over a data window which is normally one period of the fundamental frequency of the power system. In early days a sampling rate of 12 times a cycle (720 Hz for the 60 Hz system) was commonly used. Much higher sampling rates are currently used in commercial PMUs.



A sinusoid and its representation as a phasor

Comparison

SCADA	PMU
Analogue measurement	Digital measurement
2-4 samples per cycle (resolution)	60 samples per cycle (resolution)
Steady state (Observability)	Dynamic (Observability)
Local monitoring	Wide area monitoring
Phasor angle measurement: No	Phasor angle measurement: Yes

References

- Phadke, A. G., & Thorp, J. S. (2006, October). History and applications of phasor measurements. In *2006 IEEE PES Power Systems Conference and Exposition* (pp. 331-335). IEEE.
- Tholomier, D., Kang, H., & Cvorovic, B. (2009, March). Phasor measurement units: Functionality and applications. In *2009 Power Systems Conference* (pp. 1-12). IEEE.
- Phadke, A. G., & Tianshu, B. I. (2018). Phasor measurement units, WAMS, and their applications in protection and control of power systems. *Journal of Modern Power Systems and Clean Energy*, *6*(4), 619-629.

QUESTIONS

- How does a Phasor Measurement Unit (PMU) work?
- What are the main components of PMU? Explain briefly with PMU Block Diagram.
- What is use of PMU in Smart Grid?
- Explain the application of PMU in power system.
- What is synchrophasor?
- What is phasor measurement techniques?