WAMS and PMU :

- Need of Synchrophasor Technology
- History of PMU development
- Basic structure of phasor measurement units (PMUs)
- Application of PMUs in power system
- P-class and M-class PMUs
- Synchrophasor Meter Placement Initiative in India

Need of Synchrophasor Technology

Phasor measurement units have numerous advantages over conventional SCADA system.

- Faster data availability
- Measurements of voltage and current over wide area network
- Measurement of angle

Table 1. Comparison between SCADA and PMU data

SCADA data	PMU data
Scan rate: 2 s Magnitude of voltage, current, and frequency from the field Latency in the measurements due to the existing old communication Infrastructure Not fast enough to respond to the dynamic behavior of power system Time stamping for specific values and instances	Scan rate: 25-50 samples/s Angular difference between measured values from the field Latency is minimal due to the new communication technologies Fast enough to depict the system dynamic behavior Completely time tagged data with GPS synchronization

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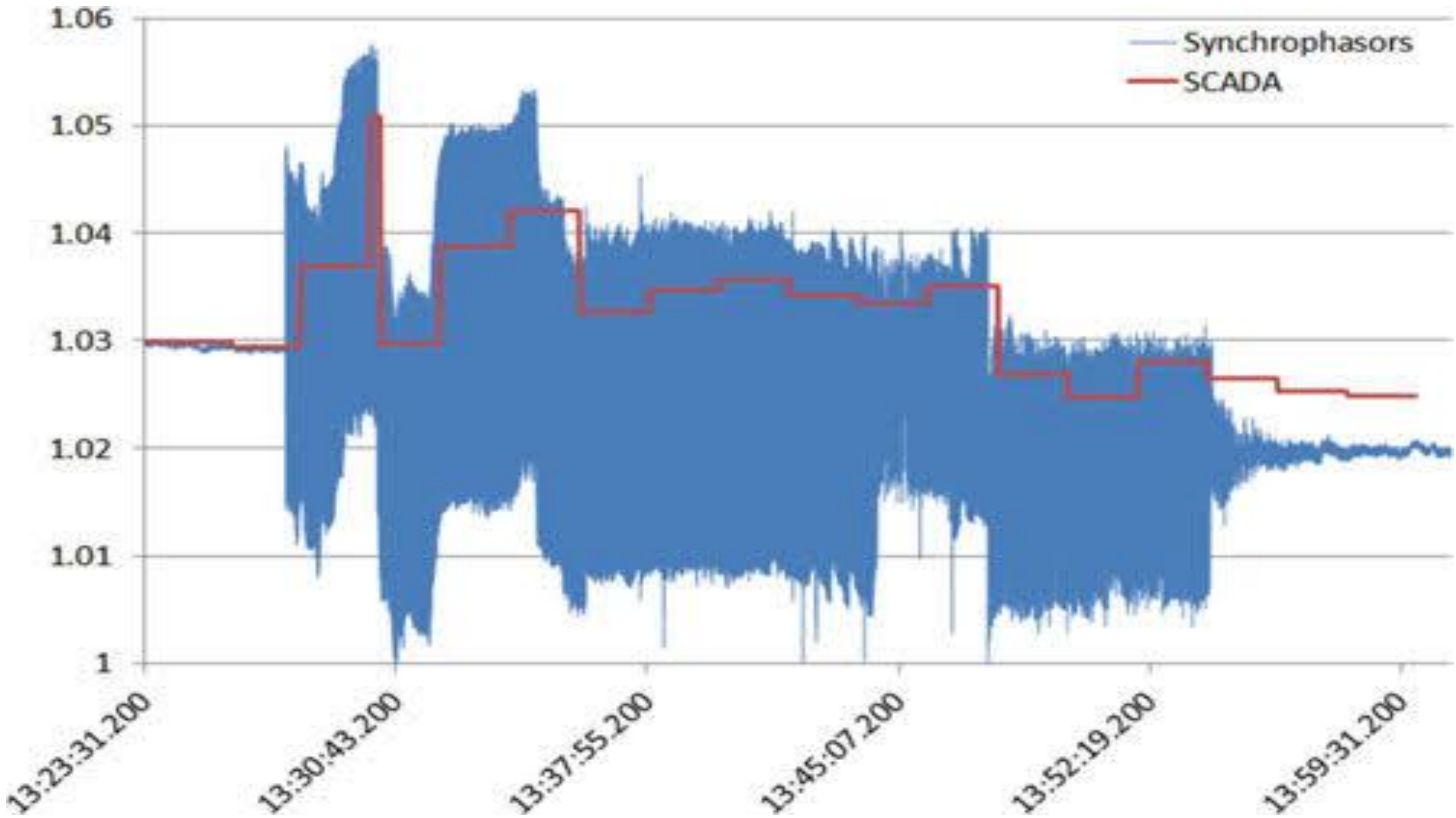
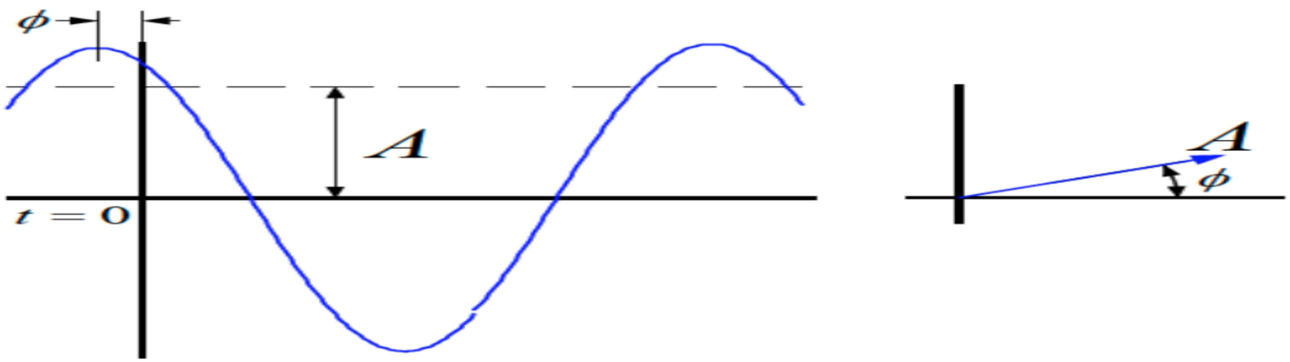


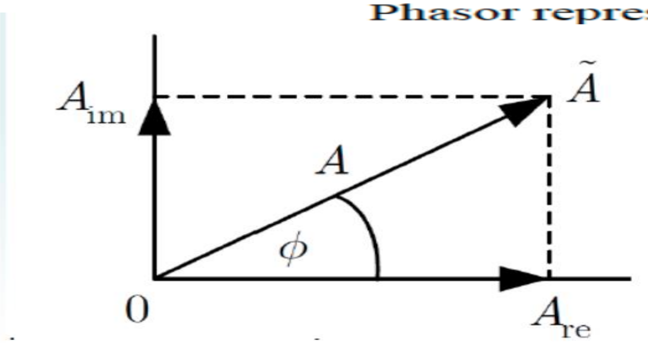
Fig. 1 Differences in SCADA and synchrophasor measurements [uploaded by Luigi Vanfretti, 2015]

History of PMU development

- In 1893, Charles Proteus Steinmetz presented a paper on simplified mathematical description of the waveforms of alternating current electricity. Steinmetz called his representation a 'phasor'.



Phasor representation of a sinusoidal wave form



$$\tilde{A} = A\varepsilon^{j\phi} = (A, \phi)$$

$$\tilde{A} = A_{re} + jA_{im} = (A_{re}, A_{im})$$

Fig. 2 Phasor representation

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- The invention of phasor measurement units (PMU) took place in 1988 by **Dr. Arun G. Phadke** and **Dr. James S. Thorp** at Virginia Tech.
- The invention of Phasor Measurement Units (PMU) in 1988 has changed the perspective of power system monitoring.
- Early prototypes of the PMU were built at Virginia Tech and Macrodyne built the first PMU (model 1690) in 1992. Today they are available commercially.

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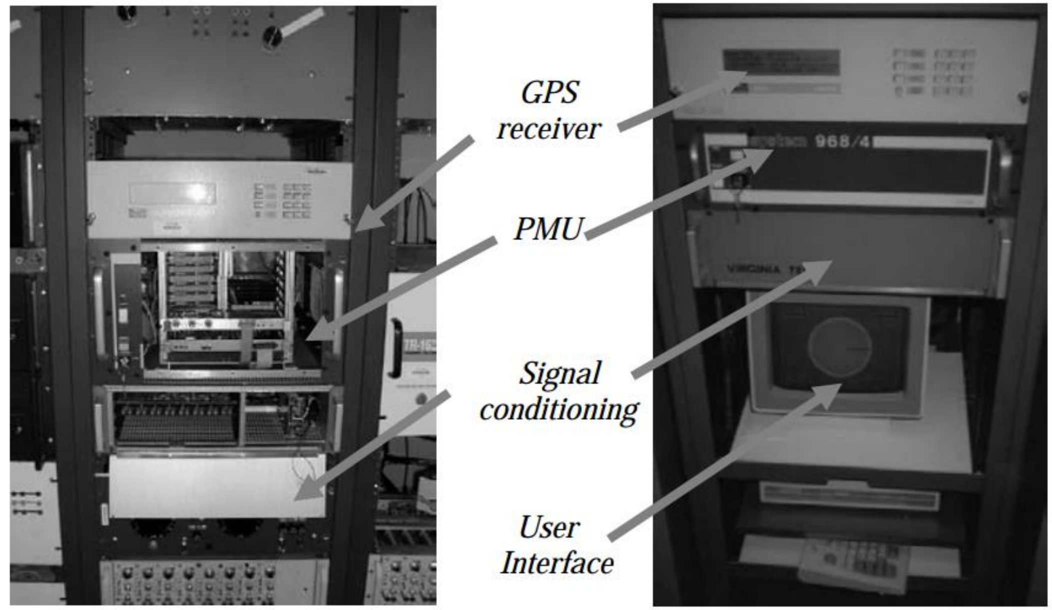
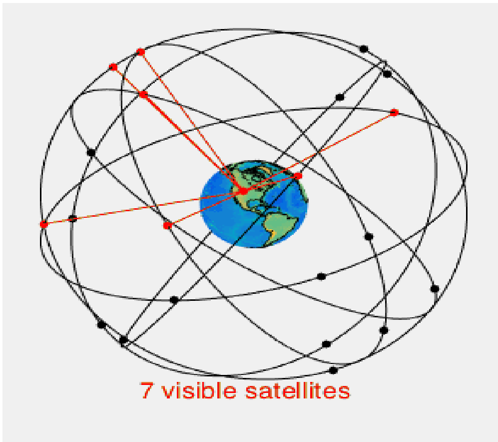
Macrodyne, Model 1690 [1]



Kontinuum, Model PMU 101

Fig. 3 First model and new generation PMUs

Basic structure of PMU

- 

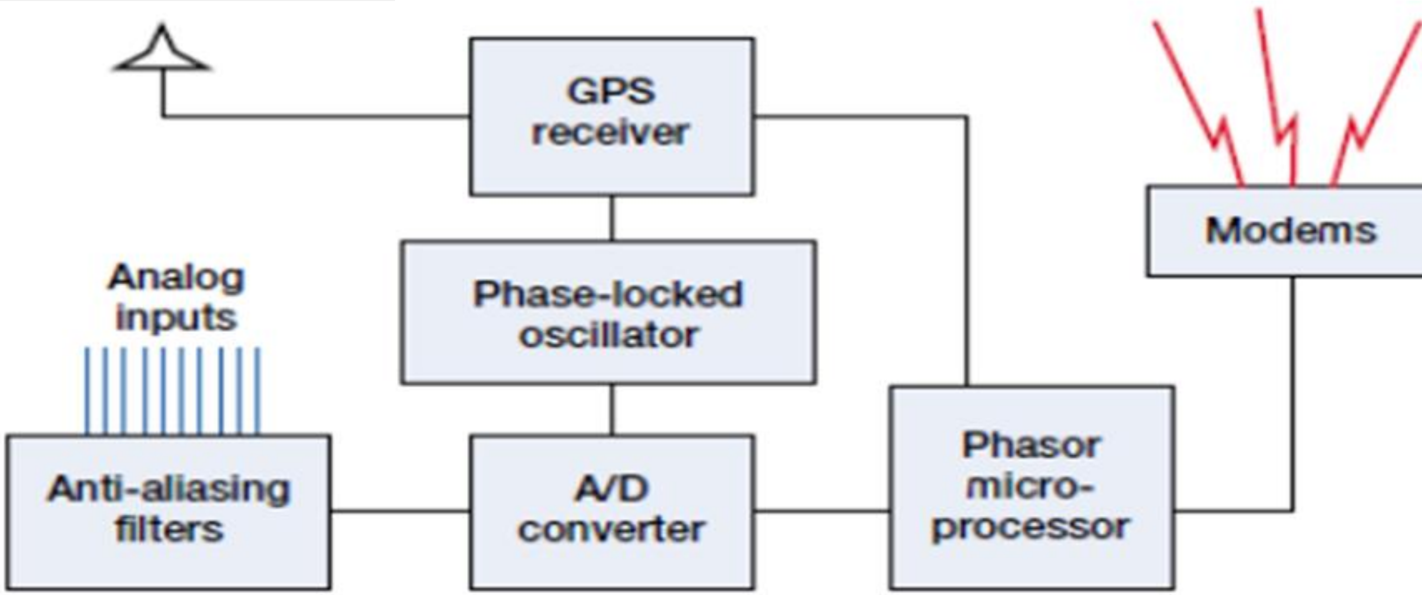


Fig. 4 Basic blocks of a PMU [1]

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Anti-aliasing filters: This is used to restrict the bandwidth of a signal to satisfy sampling theorem over the band of interest. In other words, the maximum frequency of the input signal should be less than or equal to half of the sampling rate.

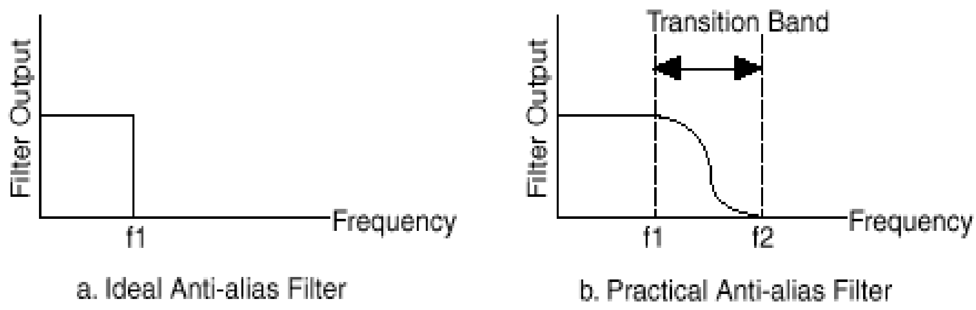

Fig. 5 Ideal and practical anti-aliasing filters

GPS receiver: GPS sends NMEA encoded data to each of the receiver in every seconds (1 Hz). Information available from this code are time, longitude, latitude, number of satellites seen and altitude.

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GPS reference time of 1μs corresponds to angle error of 0.005%, small enough from the point of view of phasor measurement.

Phase lock oscillator: The sampling clock is phase-locked with the GPS clock pulse. Sampling rates have been going up steadily over the years. Higher sampling rates do lead to improved estimation accuracy. It comprises of three basic blocks phase detector, low pass filter and voltage control oscillator.

A/D converter: Analog to digital converter samples the analog signal to process in microprocessor. Proper designing is required to avoid oversampling or under sampling.

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Phasor microprocessor: calculates phasor with DFT or FFT algorithm.

Modems: The goal is to produce a signal that can be transmitted easily and decoded to reproduce the original digital data. Modem helps to transmit the data to Phasor Data Concentrators (PDCs) or to a PMU.

Output: Phasor outputs in polar and rectangular form both are acceptable for data streaming.

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Data Transmitted: IEC standard 'COMTRADE' (**Com**mon format for **Tra**nsient **D**ata **E**xchange for power systems)is used by any PMU vendor. The numbers below the boxes show the word length in bytes.

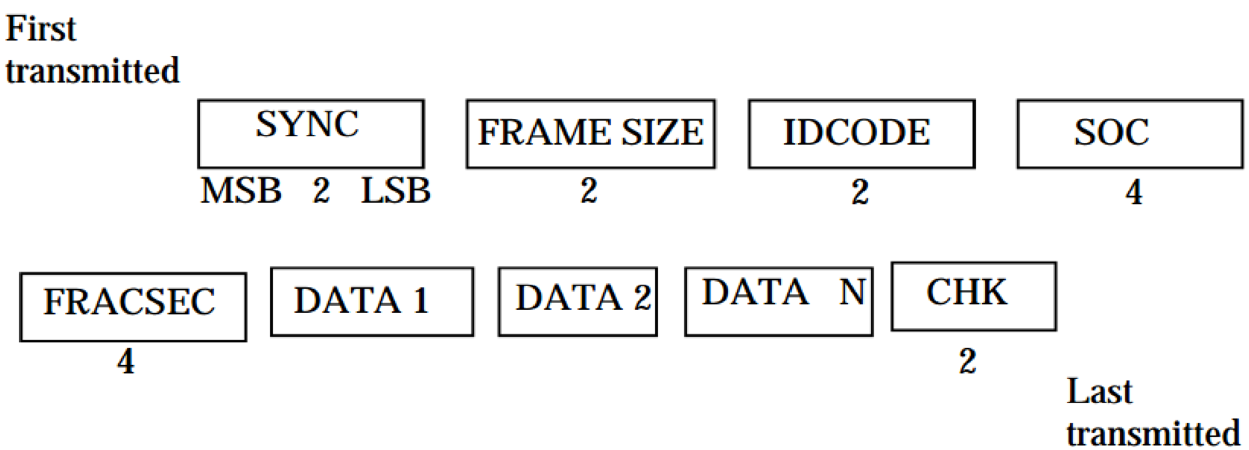
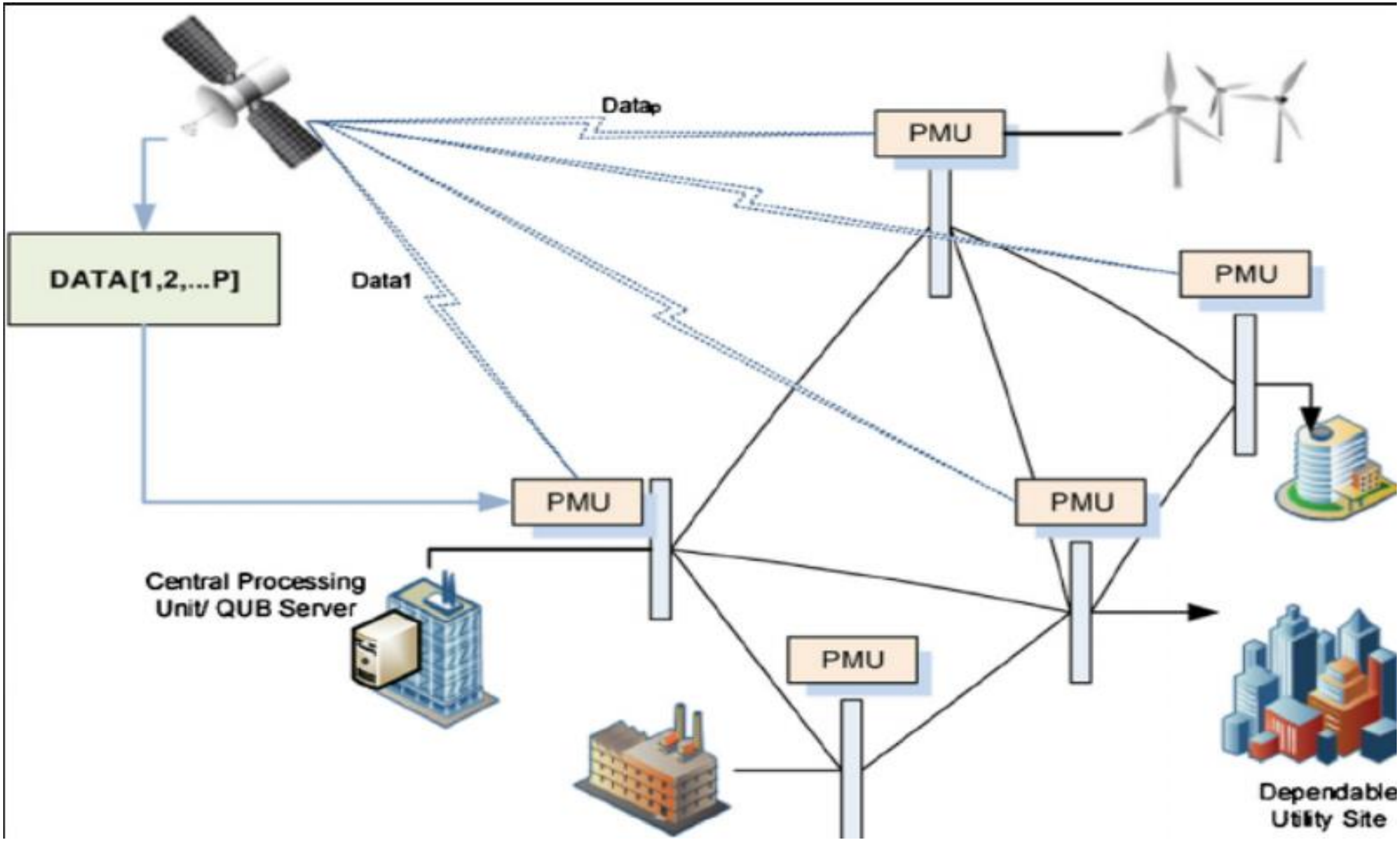


Fig. 6 Phasor data output for transmission

Application of PMUs in power system

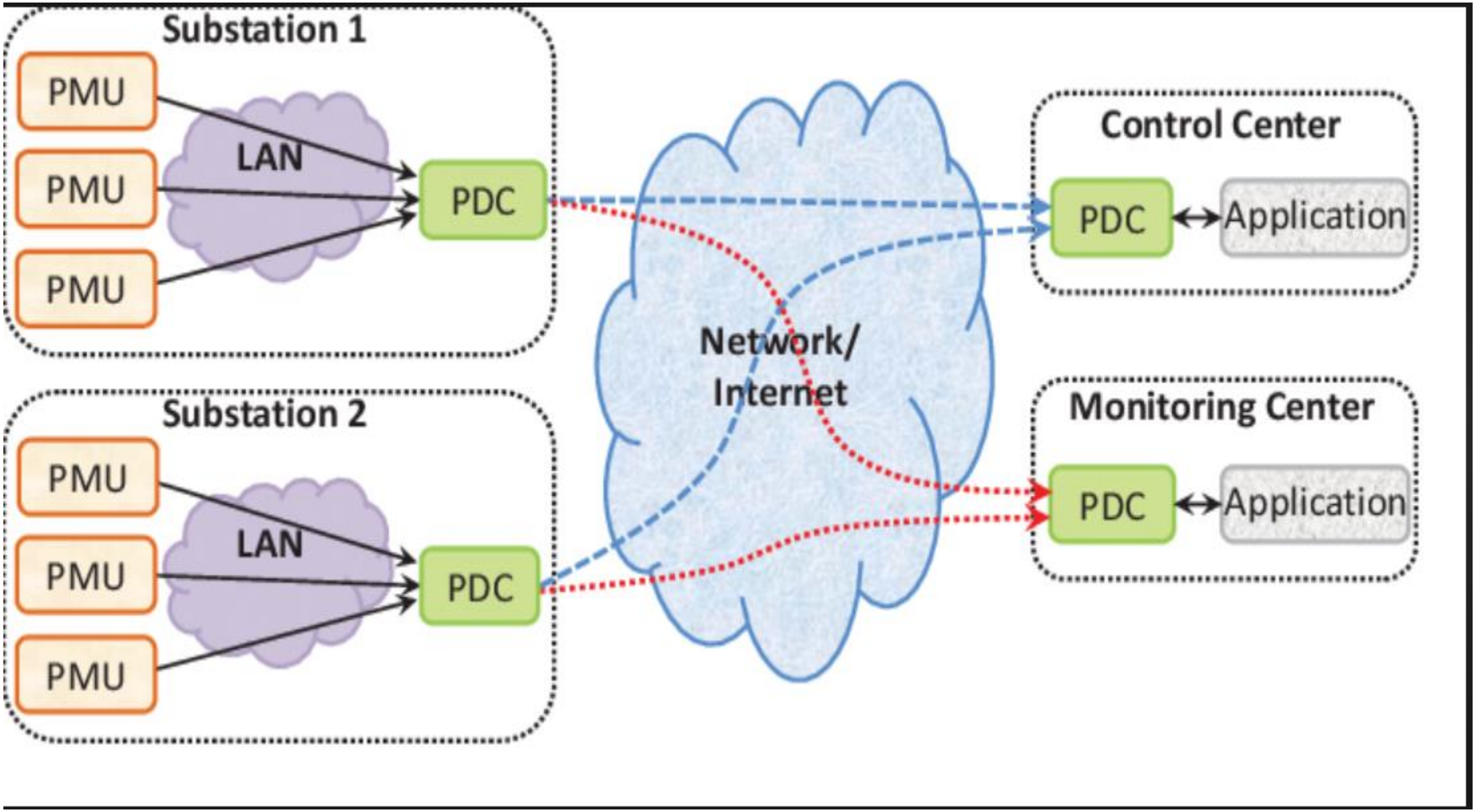
1. Model validation, calibration and extraction via PMU data [2-4].
2. Fault/event detection and location by PMU data [5,6] .
3. WAMS-based dynamics monitoring [7-10].
4. WAMS-based control strategies [11-13].
5. WAMS-based protection schemes [14-16].
6. PMU placement techniques [17-19].
7. State estimation (SE) consisting of or based on PMU data [20-23].

Synchrophasor architecture



[Ref: A novel radial basis function neural network principal component analysis scheme for PMU-based wide-area power system monitoring]

Synchrophasor architecture



[Ref: Analysis of IEEE C37.118 and IEC 61850-90-5 synchrophasor communication frameworks]

Standards for PMUs

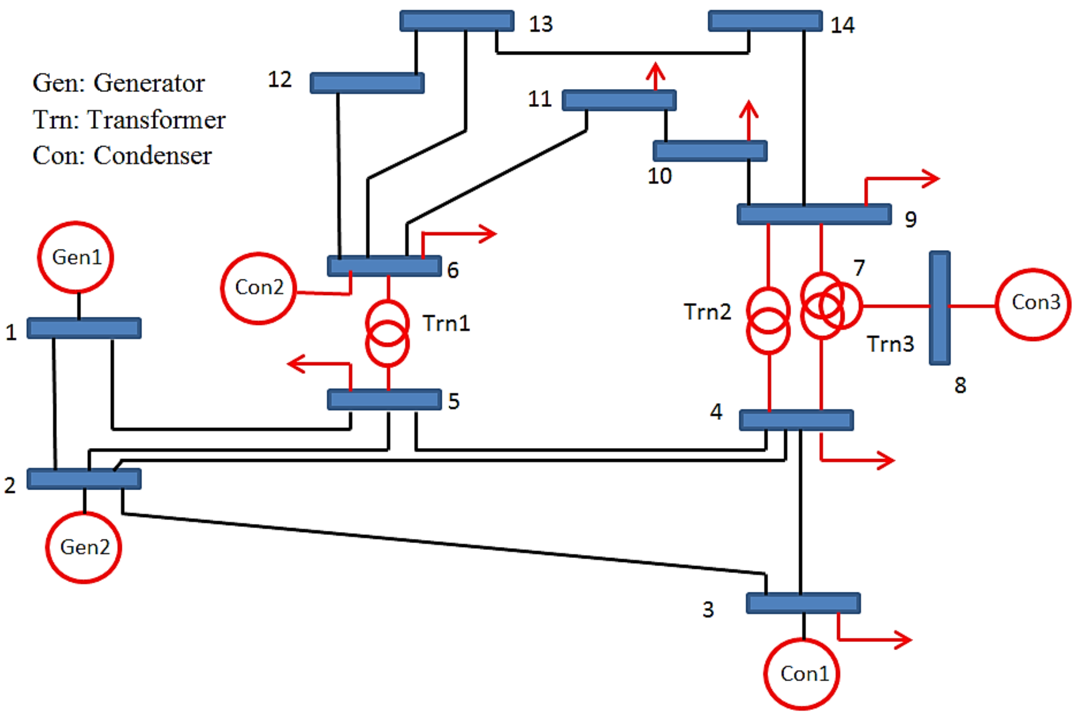
For synchrophasor technical specifications and communication frameworks

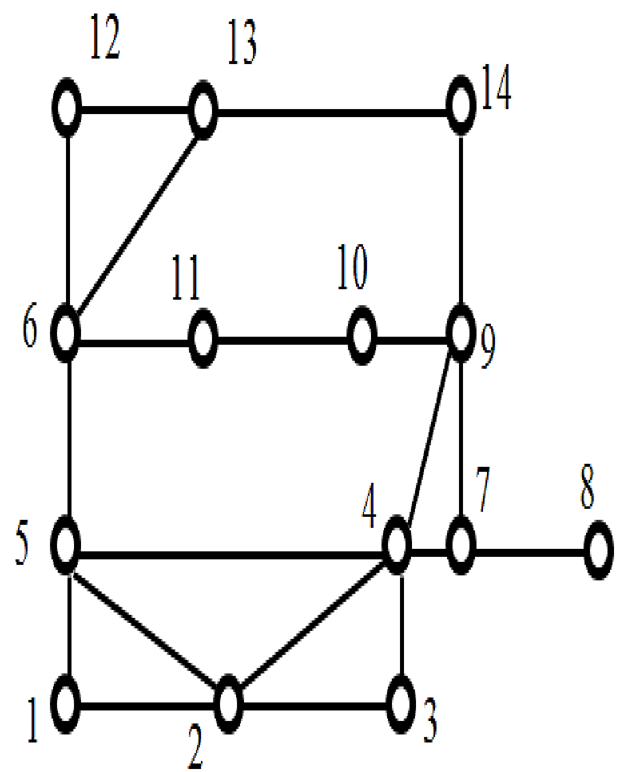
IEEE standard: IEEE C37.118

IEC standard: IEC 61850-90-5

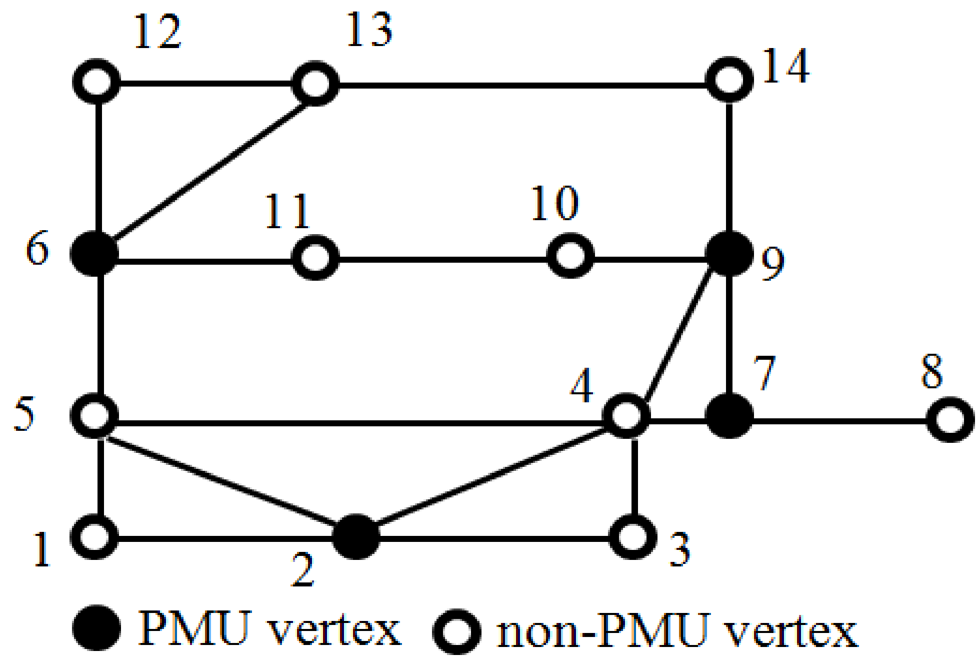
Optimum PMU placement

Optimal PMU Placement (OPP) problem is to determine a minimal set of PMUs such that the whole system is observable.

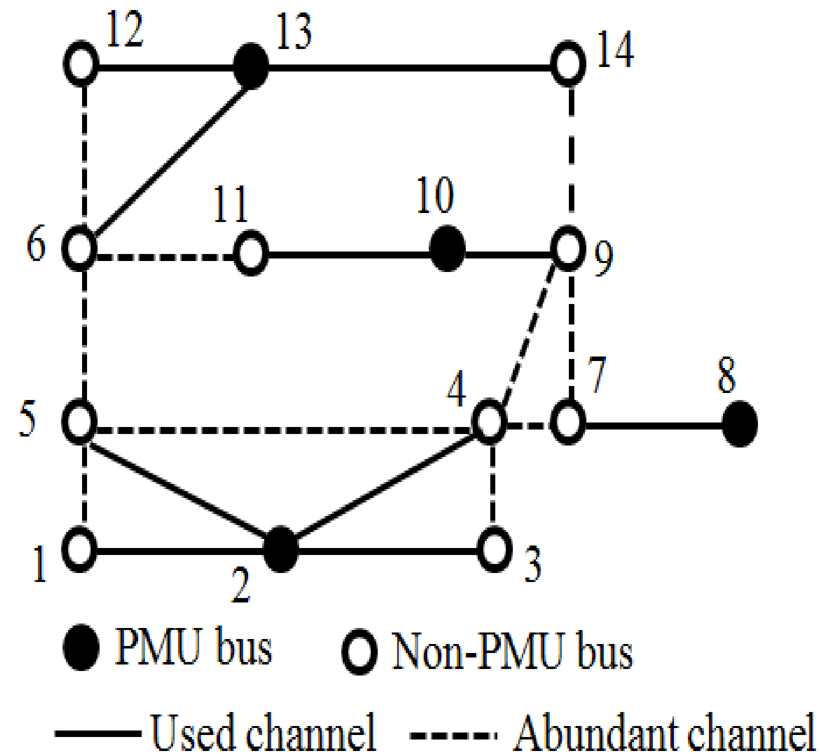




Optimum PMU placement solutions



Solution 1



Solution 2

P-class and M-class PMU

The IEEE Standard C37.118.1 defines two performance classes, P and M, for PMUs, respectively for **Protection and Measurement class** PMUs.

M class is close in performance requirements primarily for **steady state measurement**. **P-class** has relaxed some performance requirements and is intended to capture **dynamic system behaviour**.

M-class includes 20 dB anti-alias filtering which emphasizes accuracy. P-class no anti-alias filtering which emphasize low latency.

Amplitude scan tests- Voltage: 80 –120% (P) or 10 –120% (M); Current: 10 –200%

Performance is flat within total vector error(TVE) = 3%

M class: 0.1 to Fs/5 Hz with max 5 Hz

P class: 0.1 to Fs/10 Hz with max 2 Hz.

Current research trends with PMUs

- Power system automation, as in smart grids.
- Load shedding and other load control techniques such as demand response mechanisms to manage a power system. (i.e. Directing power where it is needed in real-time).
- Increase power quality by precise analysis and automated correction of sources of system degradation.
- Wide area measurement and control through state estimation, in very wide area super grids, regional transmission networks, and local distribution grids.
- Event Detection and Classification. Events such as various types of faults, tap changes, switching events, circuit protection devices. Machine learning and signal classification methods can be used to develop algorithms to identify these significant events.

Synchrophasor Meter Placement Initiative in India

India started its pilot project in 2010 with POSOCO by installing 4 PMUs in Northern Region [18].

After this pilot projects have been deployed in all 5 regions.

Table 2. Regional distribution of PMUs and PDCs

Description	Distributions					
	ER	NER	NR	SR	WR	NLDC
Project type	Pilot	Pilot	Pilot	Pilot	Pilot	Pilot
Num. of PMUs	8	6	8	6	11	18
PDCs	5	1	1	1	1+1	1

Under URTDSM scheme being implemented by POWERGRID, it is envisaged to deploy around 1700 PMUs throughout All India Grid with aim of enhanced visibility to the operator [18].

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Project at North Eastern Region (NER): M/s SEL has employed SEL 700G PMUs in eight selective locations in NER.

All PMUs are of measurement class, 12 phasors and 4 analog channels with a reporting rate of 25 frames/s. Bandwidth of communication link between PMU and PDC is of 2Mbps.

Received data is presented to NERLDC and visualization extended to RPC, SLDCs, and NLDC.

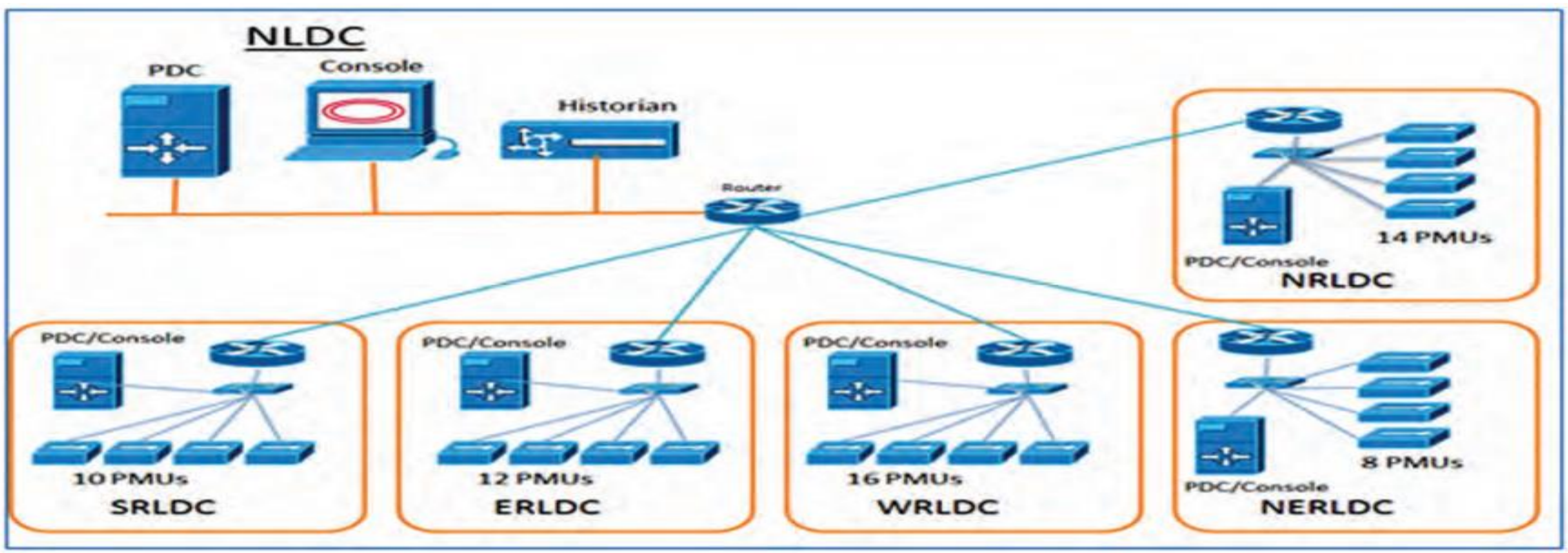

Fig. 11 National WAMS project architecture in India

Smart meters: *Advanced metering infrastructure*

AMI is defined as ‘‘an integration of many technologies that provides an intelligent connection between consumers and system operators.

Or

An alternative definition refers to AMI as ‘‘a measurement and collection system that includes smart meters, communication networks, and data management systems that make the information available to the service provider.’’

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Main components of the AMI:

1. Smart meters, 2. Communication network, 3. Data reception and management system.

Smart meters:

Smart meters are typically digital programmable devices that record customer consumption of electric energy in intervals of an hour or less and communicate that information, daily or more frequent, back to the energy supplier for monitoring and billing purposes.

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2. Communication network:

Communication network is the second mportant component of an AMI system. The aim of the communications network employed by AMI is to continuously support the interaction between the energy supplier, the consumer, and the controllable electrical load.

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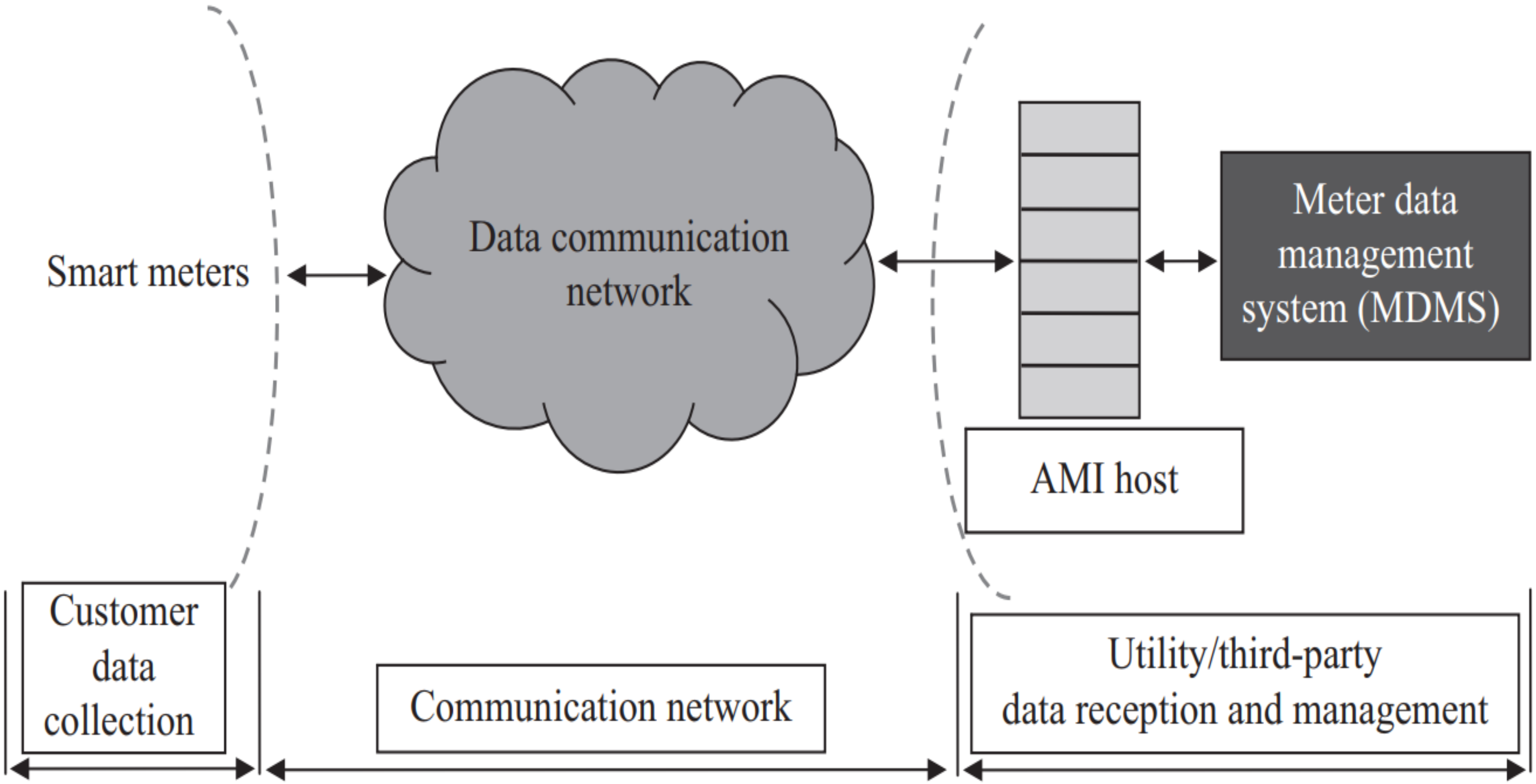

Figure 2.2 The three main components of an AMI system

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