EE 555 CCN

Bandwidth and Latency Requirements for Smart Transmission Grid Applications

Authors: Prashant Kansal, Anjan Bose

Reviewed by
Ceeman B. Vellaithurai
WSU ID: 11253840

Topics

- Introduction
- Smart Grid Communication
  - Infrastructure/Communication Architecture
  - Data Assumptions
  - Simulation Assumptions
- Good contributions
- Drawbacks
- Research Project

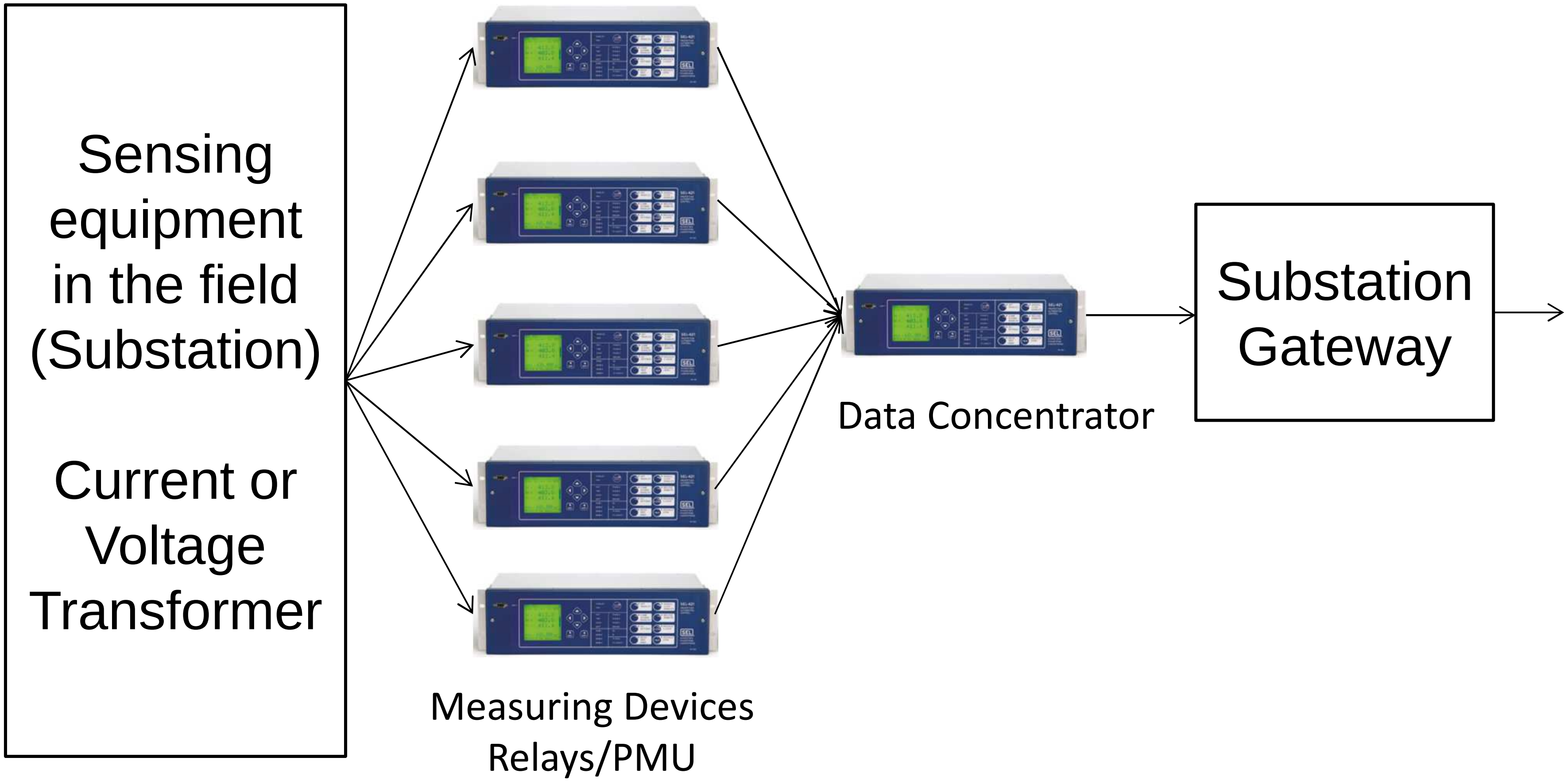
Introduction

- Power delivery levels
  - Transmission
  - Distribution
- Why Transmission over Distribution level ?
  - Distribution level is not very well represented. This is changing with increase in smart meters
  - More power being dealt with at transmission level
  - Fast action needed to prevent damage of equipment incase of faults
  - Applications at transmission level are time critical and need fast communication to support required actions.

Introduction

- Substation
  - Substations transform voltage from high to low, or the reverse, or perform any of several other important functions
  - Measurements are taken at substations and sent to control centers

Introduction



Sensing equipment in the field (Substation)

Current or Voltage Transformer

Measuring Devices
Relays/PMU

Data Concentrator

Substation Gateway

Introduction

- Phasor Measurement Units (PMU)
  - Measurement sampling rate is very high. Ranges between 30 to 120 samples per second
  - Time synchronized through GPS. Hence, time stamped data is available
  - Provides better time resolution due to higher sampling rate

Introduction

- Before PMUs ?
  - Measurement devices in the field were polled (Refers to request for data from a device) at some interval of time
  - This interval of time used to range from a few seconds to a few minutes
  - Polling requests reach different devices at different points of time, meaning the snapshot obtained about the system is not at a particular instant of time
  - Data is not time stamped

Introduction

- So what is the problem ?
  - An application called “State Estimator” is used at control centers to estimate the state of the system
  - Takes measurements from the system as input and estimate unknown parameters. Usually bus angle
  - Also used to eliminate any erroneous measurements
  - The filtered data is then used by various other applications

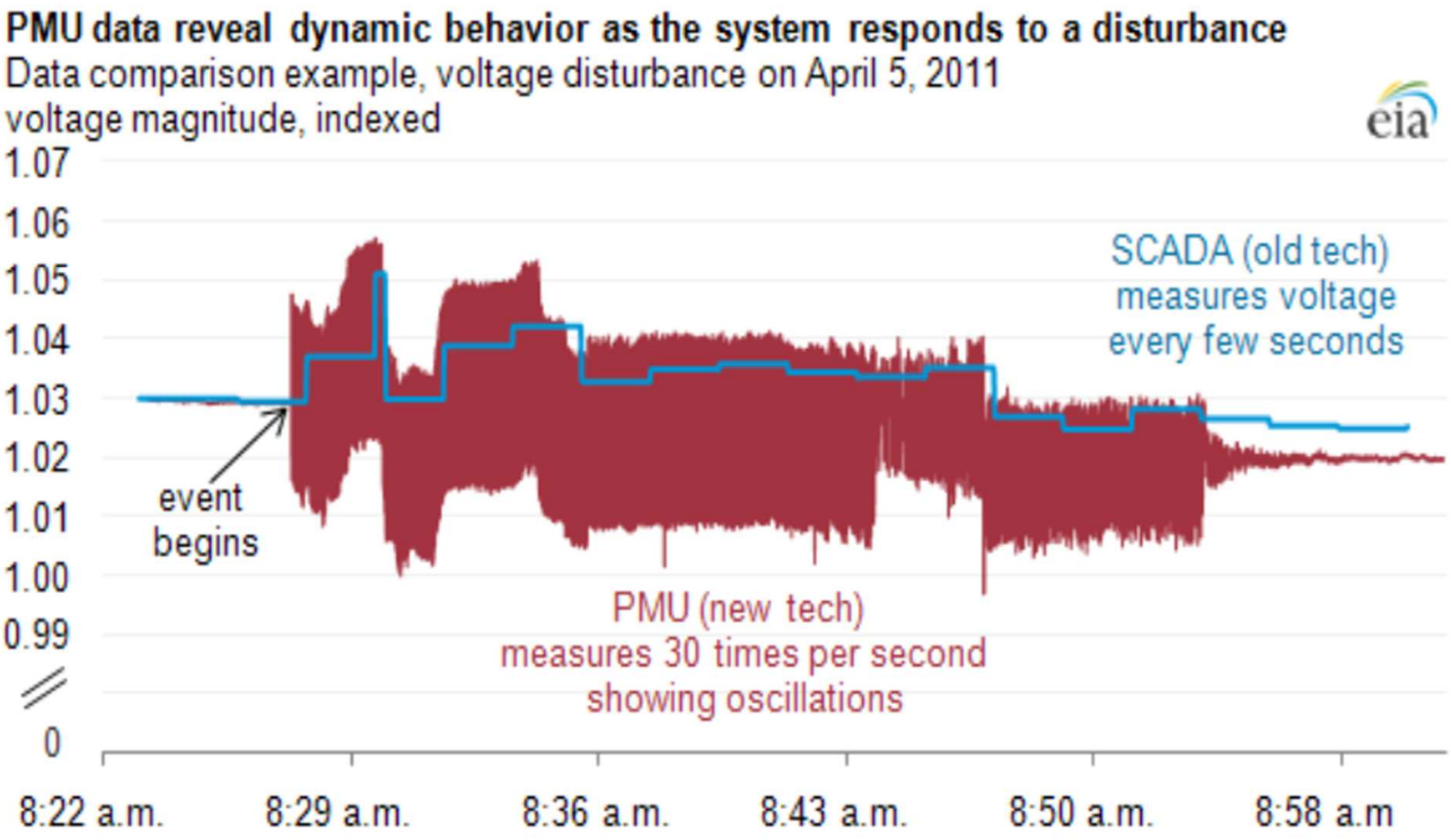
Introduction

- So what is the problem ?
  - Since most applications use State Estimator (SE) results, they are delayed by the computation time and frequency of running of the SE
  - Since polling is not time synchronized, and data is not time stamped. Hence, it does not reflect the state of the system at a particular instant of time
  - This makes it inaccurate
  - Becomes a bottle neck in the system

Introduction

- PMU Advantage
  - Since Voltage and angle are available directly from PMU, the SE problem changes from solving a set of non linear equations to solving linear equations. This greatly reduces the time required for computation.
  - Better time resolution.
  - Accurate snapshot of the system, due to availability of time stamped data.
  - Data is accurate and reliable.

Introduction



Taken from EE 581 Advanced Topics in Power System course taught by Dr. Anurag K Srivastava

Introduction

- PMU Advantage
    - Computation time of SE is greatly reduced.
    - Better time resolution.
    - Accurate snapshot of the system, due to availability of time stamped data.
    - Data is accurate and reliable.

PMU data facilitates real time monitoring and control of power system. Provides better view of “state” of the system.

Key Assumption: In this paper, it is assumed that all measurements are taken by PMUs only

Terms

- Latency Requirement
  - The Latency Requirement for an application is defined as the time between when the state was measured and when it was acted up by the application.
- Data Window
  - It is the time period for which data needs to be collected before it can be used by an application.

Application Requirements

- Smart Grid Application Requirements

Application	Origin of Data/Place data is required	Latency requirement	Data Time Window
State Estimation	All Substations/Control Center	1 second	Instant
Transient Stability	Generating Substations/ Application Server	100 ms	10 – 50 cycles (167 ms – 830 ms)
Small Signal Stability	Some Key Locations/ Application Server	1 second	Minutes
Voltage Stability	Some Key Locations/ Application Server	1-5 second	Minutes
Post Mortem Analysis	All PMU and Digital Fault Recorder Data/ Historian	NA	Instant and Event Data

Smart Grid Communications

- Simulations in the paper are done using Network Simulator 2 Version 2.34
- The simulation is carried out for two different systems
  - IEEE 14 bus system
  - Polish 2383 bus system. This system has 6 different zones and provides complex topology which facilitates deeper analysis.

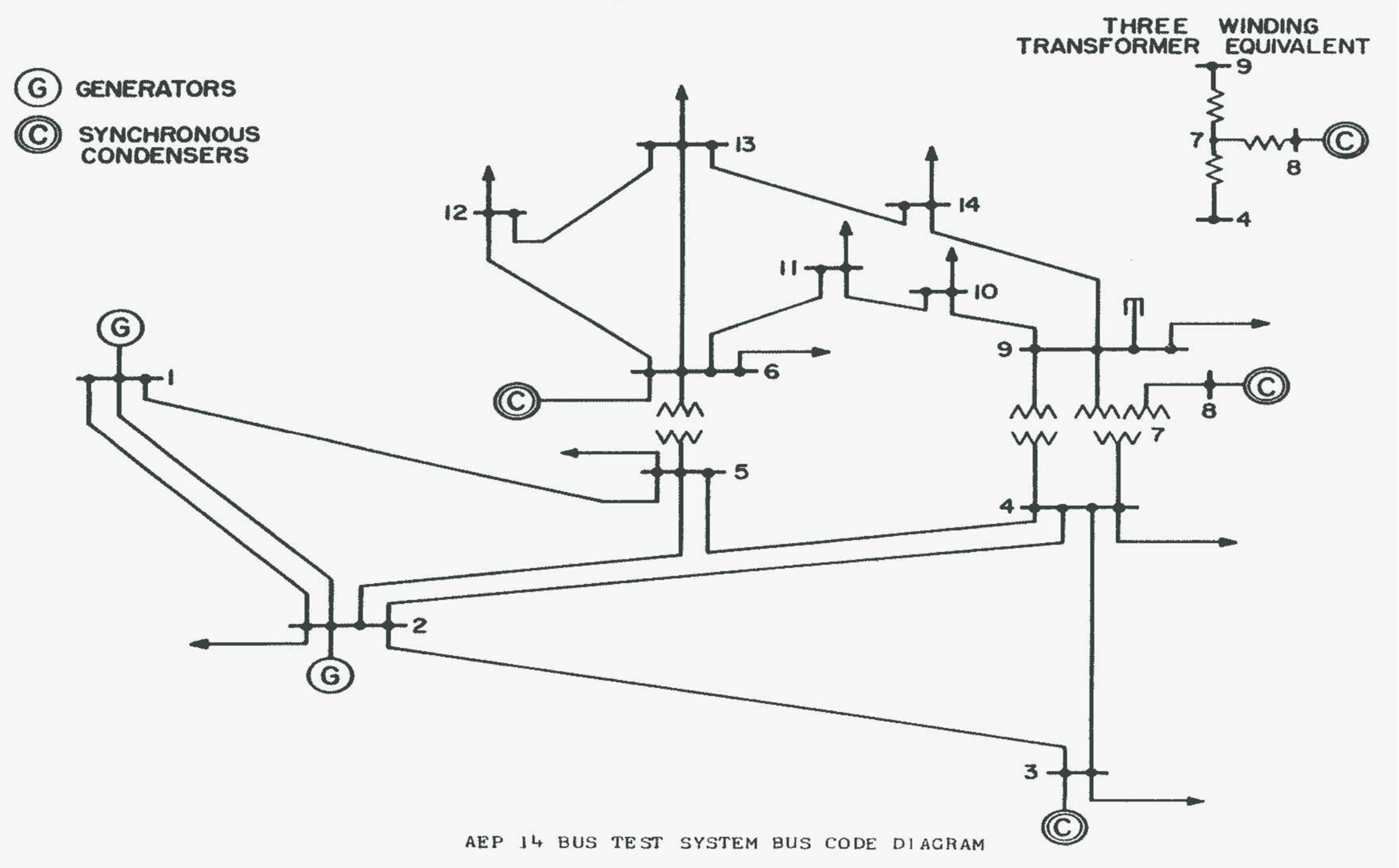
Terms

- Control Center
  - Location where smart grid applications are generally run.
  - All Substations send data to control center.
- Special Protection Scheme (SPS) Substation
  - Implementing protection schemes for special equipment like generators, which might require quick control.

Smart Grid Communications

Standard Power System

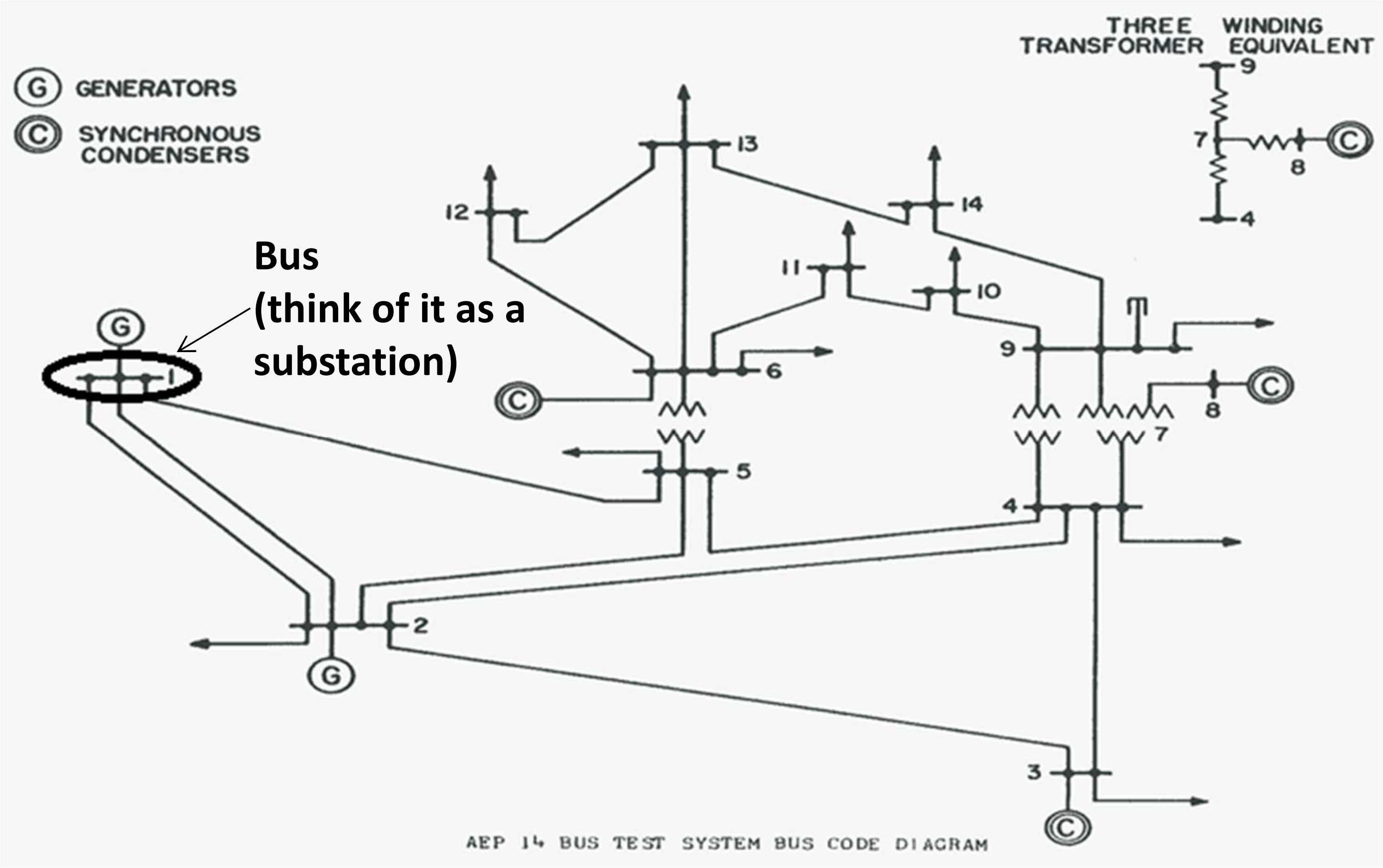
- IEEE 14 bus Power System



AEP 14 BUS TEST SYSTEM BUS CODE DIAGRAM

Smart Grid Communications

Standard Power System

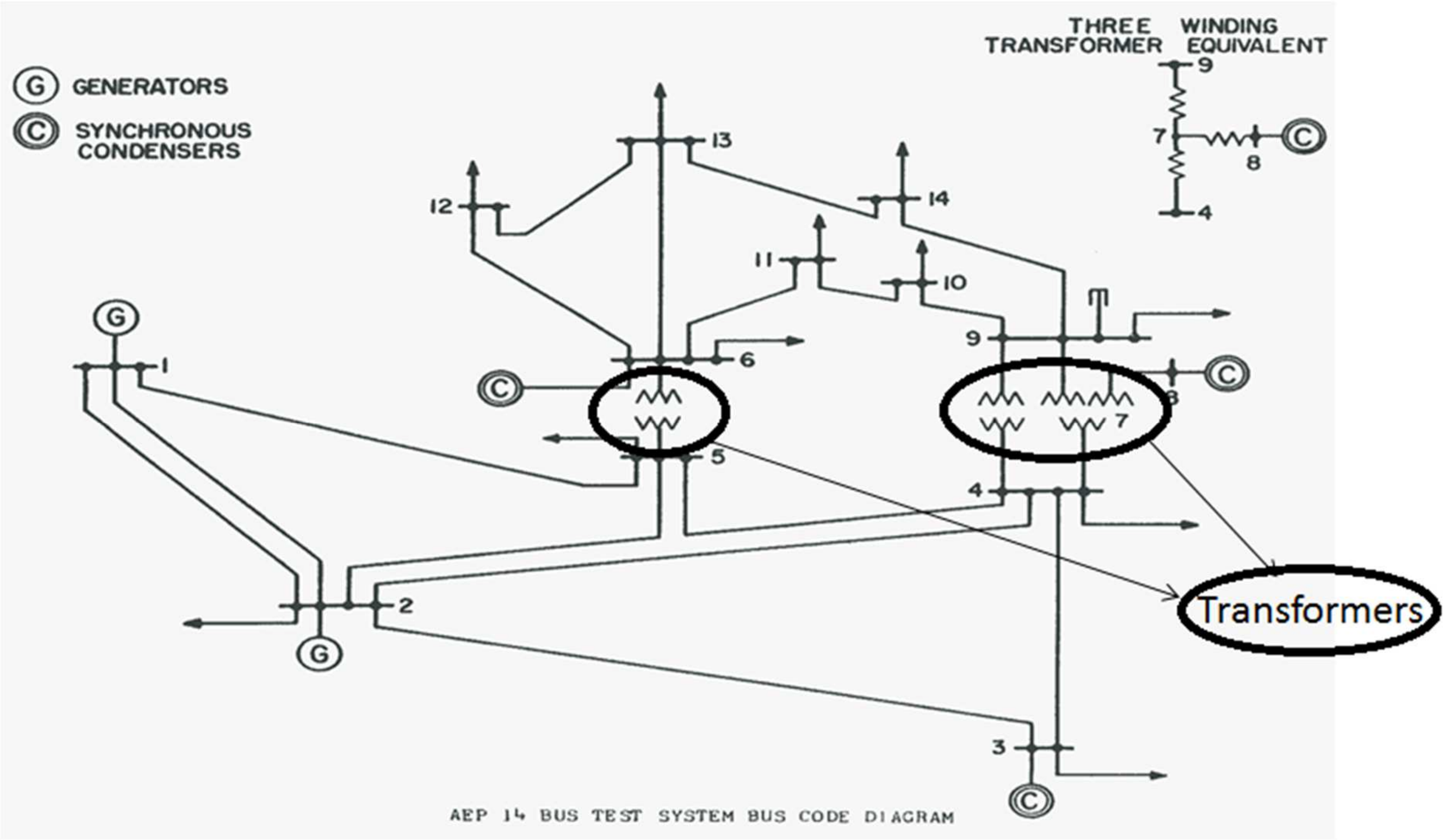


Bus
(think of it as a substation)

AEP 14 BUS TEST SYSTEM BUS CODE DIAGRAM

Smart Grid Communications

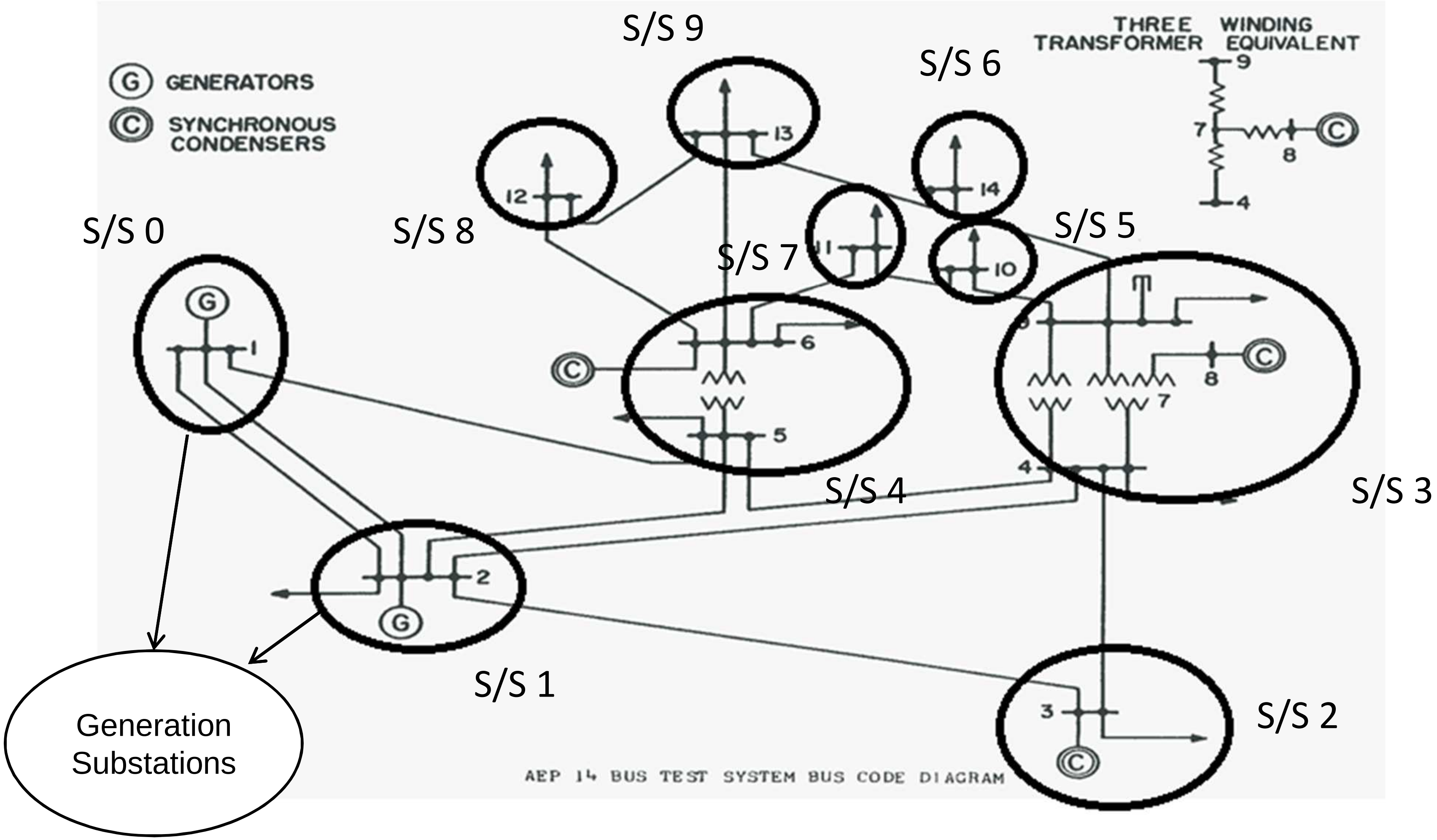
Standard Power System



AEP 14 BUS TEST SYSTEM BUS CODE DIAGRAM

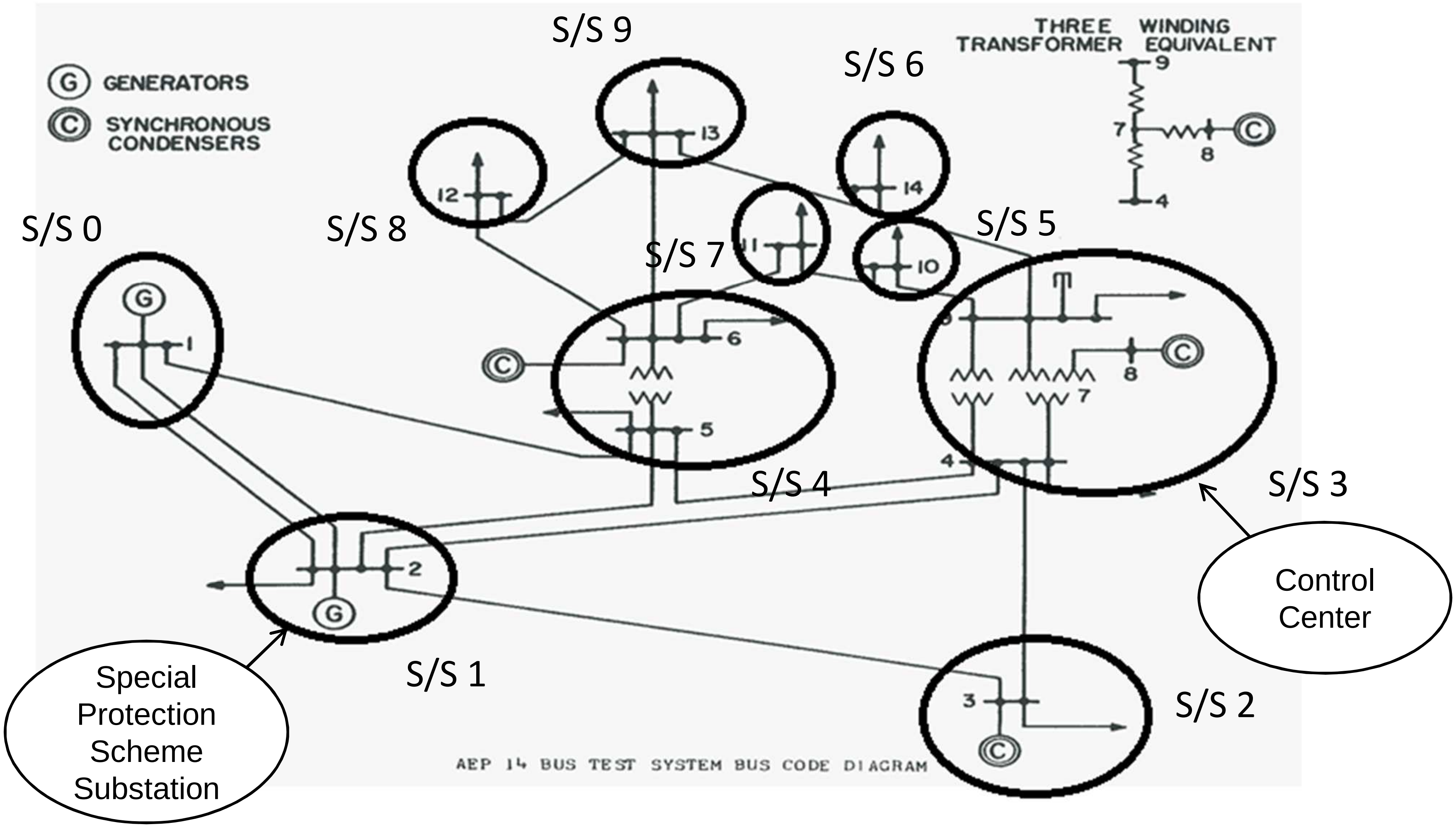
Smart Grid Communications

Communication Architecture



Smart Grid Communications

Communication Architecture



S/S 0

S/S 1

S/S 2

S/S 3

S/S 4

S/S 5

S/S 6

S/S 7

S/S 8

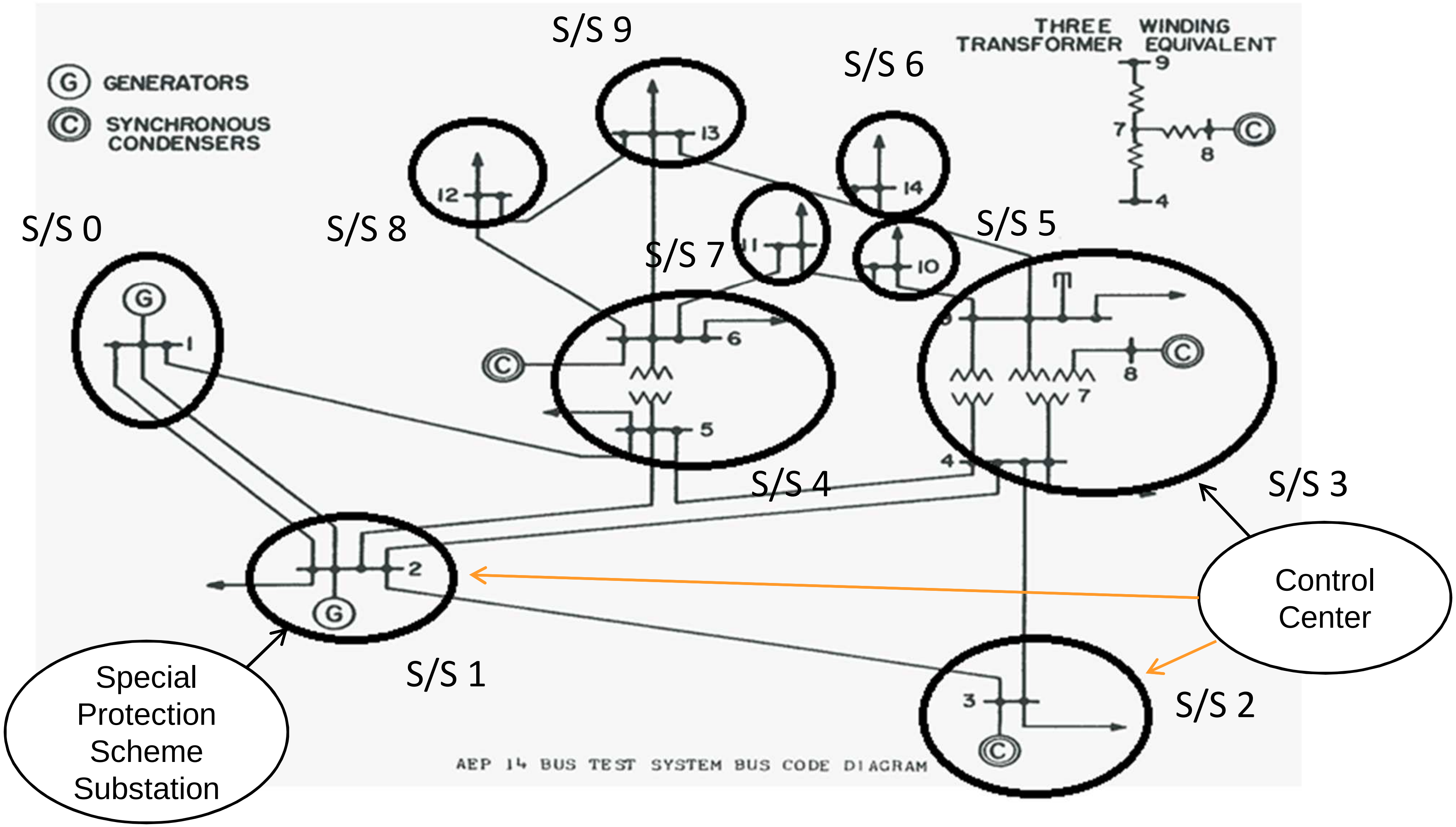
S/S 9

Control Center

Special Protection Scheme Substation

Smart Grid Communications

Communication Architecture



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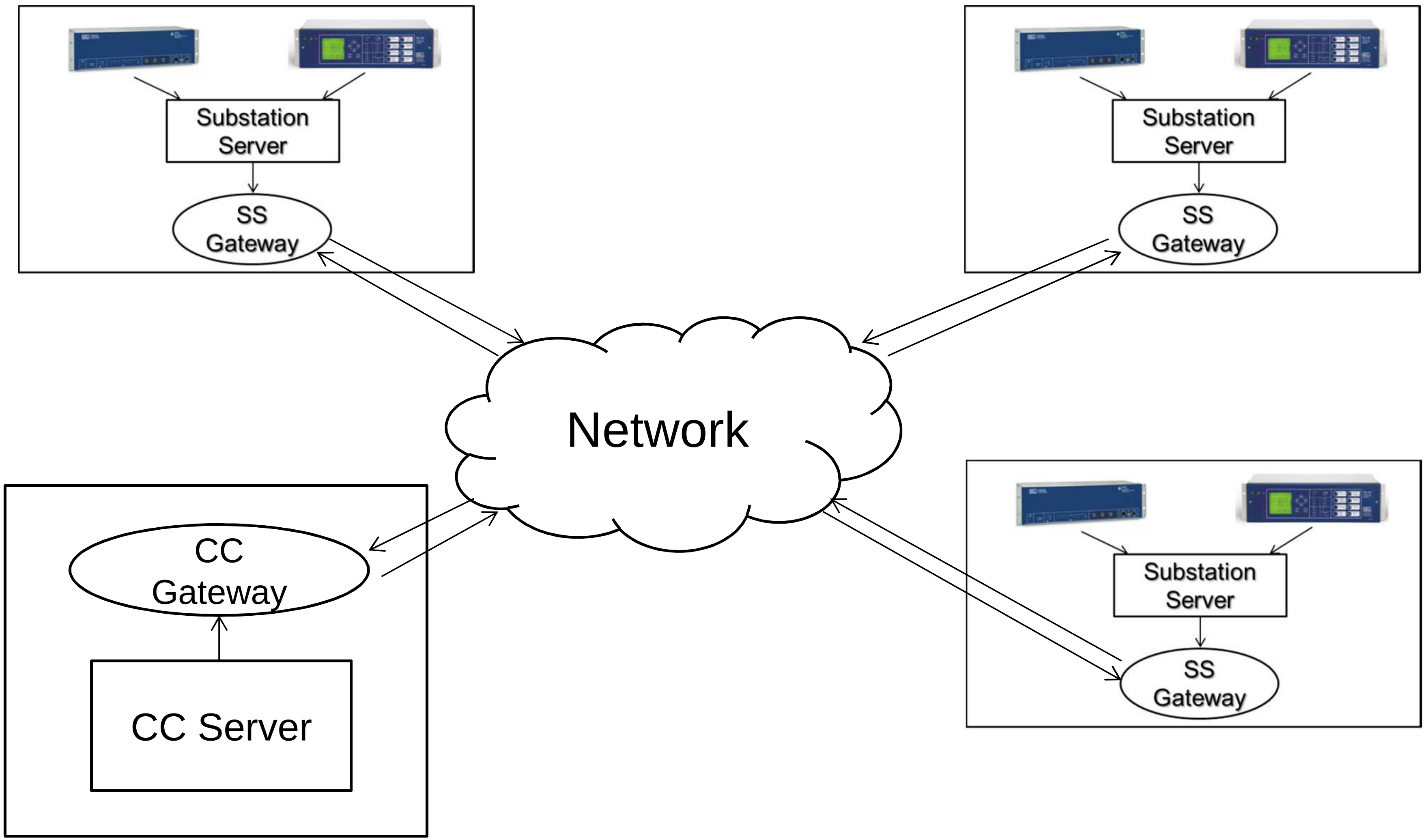
S/S 9

Special Protection Scheme Substation

Control Center

Smart Grid Communications

Communication Architecture



Smart Grid Communications

Protocol Layers

- The parameters used for the different layers is given in the table.

Layer	**Protocol**
Application	Constant Bit Rate (CBR)
Transportation	User Datagram Protocol (UDP)
Network	Internet Protocol (IP)
Data	Ethernet
Link Layer	Optic Fiber

Smart Grid Communications

Protocol Layers

- Why CBR and UDP ?
  - CBR over UDP is used to simulate traffic in the system
    - PMUs have constant rate of transmission. CBR accurately simulates this behavior
    - UDP is chosen over TCP. This is because TCP requires pre allocation of resources.
    - Also, in the case of data loss, retransmission of data might cause additional delays in transmission of subsequent data frames
  - Maximum Transmission Unit (MTU) is assumed to be 1500 bytes. This is reasonable for ethernet communications.

Smart Grid Communications

Power System Data Assumptions

- Data exchange levels
  - All Substation to Control Center (I)
  - Control Center to Control Substation (II)
  - Generating Substation to Generating Substation (III)
  - SPS to SPS (IV)
  - SPS to Control Center (V)
  - Control Center to Control Center (VI)

  It is assumed that these are the types of traffic present in the system. They are referred to as type 1 to type 6 traffic in the paper.

Smart Grid Communications

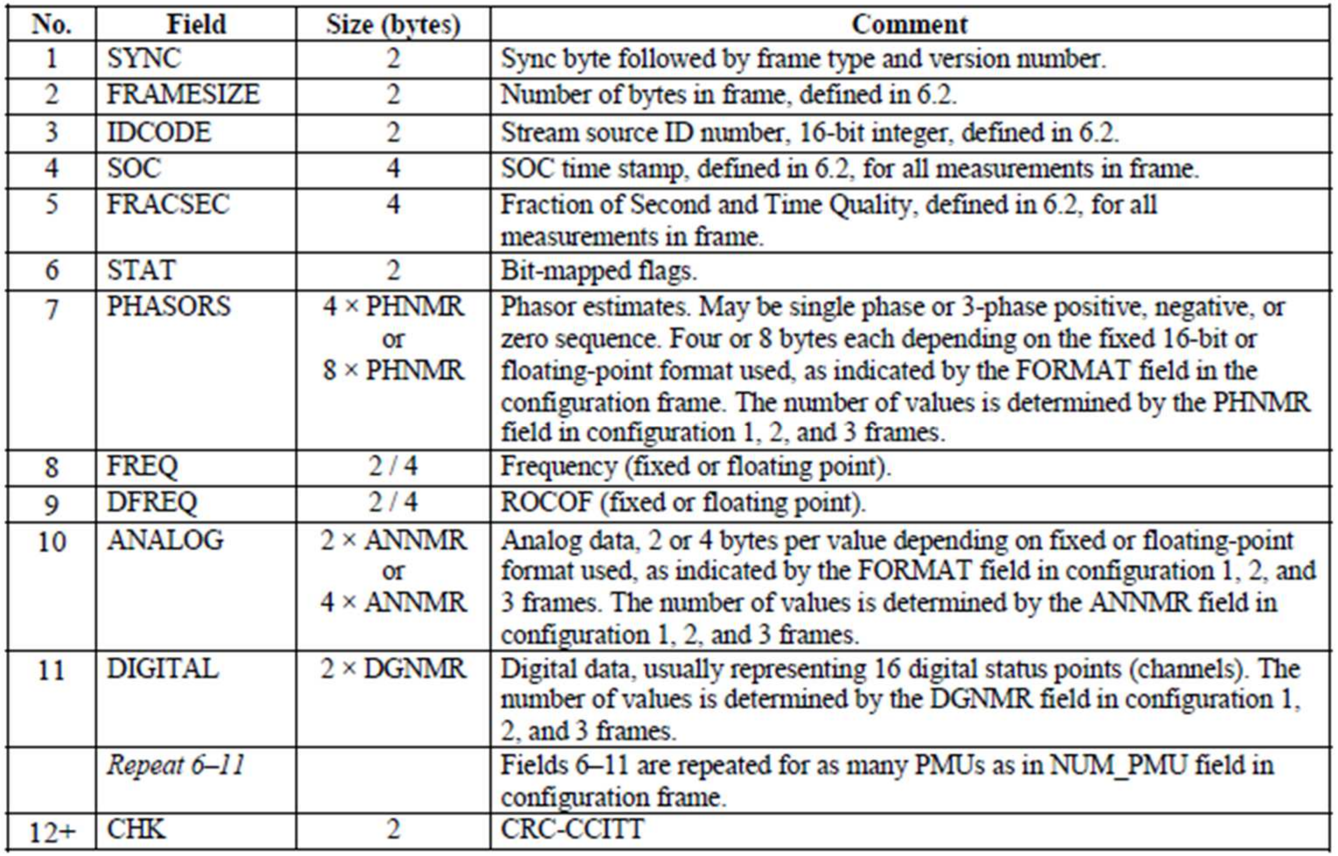
Power System Data Assumptions

- Information required
  - Substation configuration
    - Usually Known
    - If not known, can assume generic breaker and a half scheme
  - Connected equipment (generators, transformers etc. and associated measurement devices)
  - The amount of PMU data to be sent can be calculated from the number of phasors to be sent.
  - IEEE C37.118.2 standard provides for calculating the data frame size to be sent from each substation.

Smart Grid Communications

Power System Data Assumptions

- Data Frame



No.	Field	Size (bytes)	Comment
1	SYNC	2	Sync byte followed by frame type and version number.
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	Stream source ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2, for all measurements in frame.
5	FRACSEC	4	Fraction of Second and Time Quality, defined in 6.2, for all measurements in frame.
6	STAT	2	Bit-mapped flags.
7	PHASORS	4 × PHNMR or 8 × PHNMR	Phasor estimates. May be single phase or 3-phase positive, negative, or zero sequence. Four or 8 bytes each depending on the fixed 16-bit or floating-point format used, as indicated by the FORMAT field in the configuration frame. The number of values is determined by the PHNMR field in configuration 1, 2, and 3 frames.
8	FREQ	2 / 4	Frequency (fixed or floating point).
9	DFREQ	2 / 4	ROCOF (fixed or floating point).
10	ANALOG	2 × ANNMR or 4 × ANNMR	Analog data, 2 or 4 bytes per value depending on fixed or floating-point format used, as indicated by the FORMAT field in configuration 1, 2, and 3 frames. The number of values is determined by the ANNMR field in configuration 1, 2, and 3 frames.
11	DIGITAL	2 × DGNMR	Digital data, usually representing 16 digital status points (channels). The number of values is determined by the DGNMR field in configuration 1, 2, and 3 frames.
	Repeat 6–11		Fields 6–11 are repeated for as many PMUs as in NUM_PMU field in configuration frame.
12+	CHK	2	CRC-CCITT

Reference: IEEE C37.118.2 Standard for Synchrophasor Data Transfer for Power System

Smart Grid Communications

Simulation Assumptions

- Assumptions
  - It is assumed that all communication links are optic fiber with sufficiently high bandwidth to support PMU data transfer. OC-3 i.e. 155 Mbps is assumed
  - Queue Size is set to 5000
  - Time to Live value is set at 64 hops

Smart Grid Communications

Simulation Assumptions

- Assumptions
  - It is assumed that all communication links are optic fiber with sufficiently high bandwidth to support PMU data transfer. OC-3 i.e. 155 Mbps is assumed
  - Queue Size is set to 5000
  - Time to Live value is set at 64 hops
  - Number of CC and SPS depends on size of network
  - Shortest Path routing algorithm is used
  - No control frames are being sent in the network. Meaning that there is one way communication, from substation to control center and not vice versa.

Smart Grid Communications

Simulation Assumptions

- Assumptions
  - Static Routing is assumed; i.e., no changes in network topology during simulation.
  - PMU sampling rate is assumed to be set at 60 samples/second
  - Processing delay in gateways is assumed to be zero

Smart Grid Communications

Simulation Assumptions

- Assumptions
  - Static Routing is assumed; i.e., no changes in network topology during simulation
  - PMU sampling rate is assumed to be set at 60 samples/second
  - Processing delay in gateways is assumed to be zero
  - Propagation delay
    - Network communication lines are assumed to be present along the transmission lines
    - Power network reactance is converted to miles to calculate propagation delay
    - Propagation delay within a substation network is assumed to be in the order of microseconds.

Smart Grid Communications

Metrics

- Metrics calculated from simulation
    - Average Link Usage
    - Maximum Delays for different traffic types
    - Queuing Delays
    - Number of hops

Good Contributions

- Derives communication architecture from a power system stand point
  - This is important because, communication requirements of a power system are unique and different compared to other systems.
- Attempts to quantify bandwidth and latency requirements for the emerging smart grid
- Has been shown that the simulation is scalable (simulation is done for a 2383 bus system)

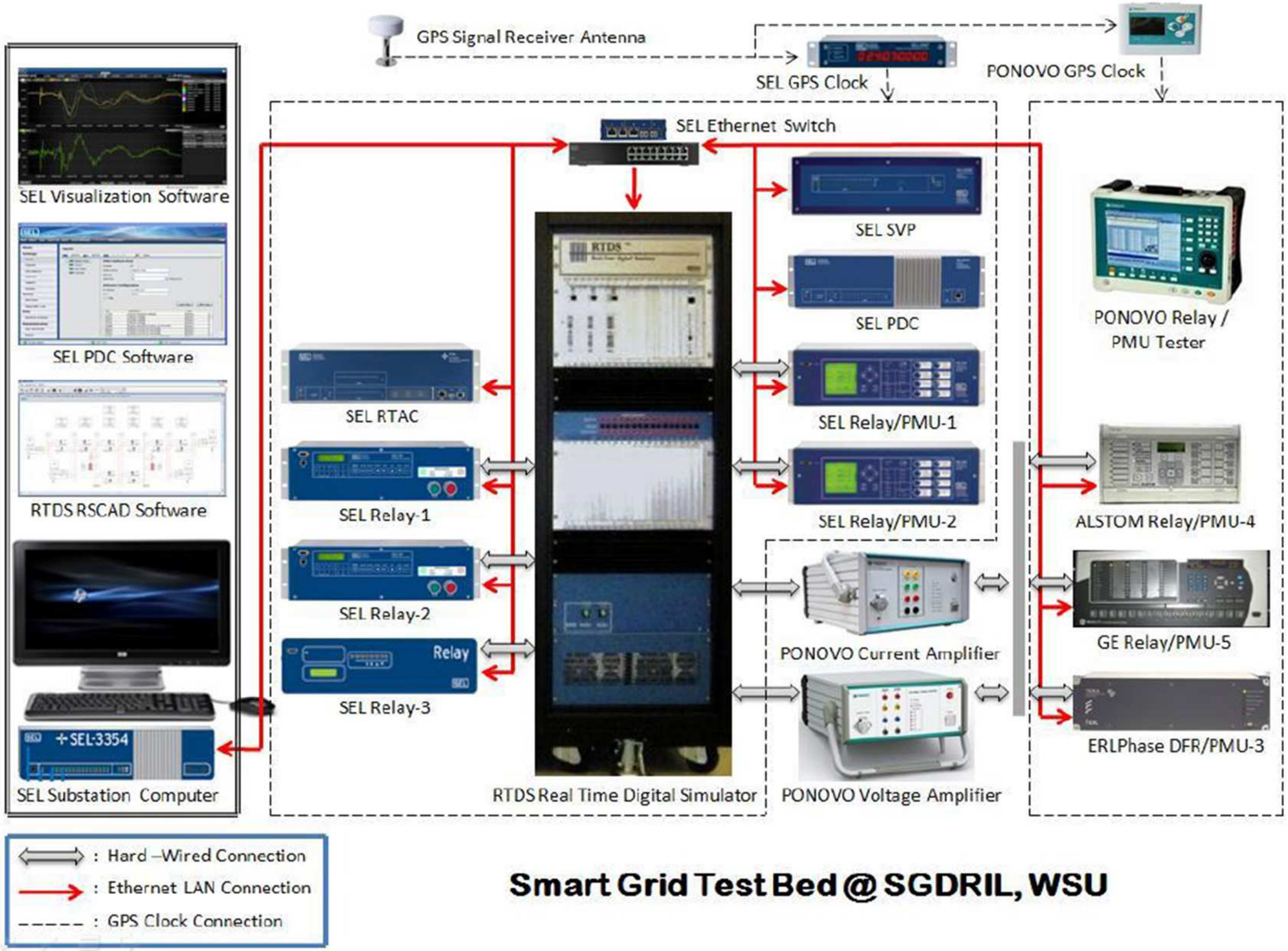
Drawbacks

- Considers only PMUs to be present throughout the system
  - This is not true for a real system. The age of using only PMUs is still far away.
- Considers a static system (uses static routing)
  - Doesn’t include control frames.
  - Assumes no disturbance or link failures.
- Uses NS2. This open source software came about in the early 2000s
  - Development and support have been discontinued.

Research Project

- The authors have explored offline simulation using NS2 for a static case.
- Network Simulator 3 is a open source network simulator with emulation functionality. Meaning it can integrate with real devices to provide communication backbone.

SGDRIL Lab Setup



Smart Grid Test Bed @ SGDRIL, WSU

Research Project

- The paper explores offline simulation.
- Network Simulator 3 is a open source network simulator with emulation functionality. Meaning it can integrate with real devices to provide communication backbone.
- SGDRIL lab setup can be used to include real data in the simulation.
- Simulation will have both real/simulated nodes.

I am done!!

Any

Questions/Comments/Concerns/Objections ?

or anything else you want to ask