INNOVATIVE SMART GRID TECHNOLOGIES CONFERENCE

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Knowledge Based Architecture Serving As a Rigid Framework for Smart Grid Applications

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Many utilities have already implemented Advanced Metering Infrastructure (AMI) and are ready to install Smart Meters.

This is made possible because of :

1. Advances in micro-electronics, communication and computer technologies

2. Smart meters are coming down in price, have increased their life and reliability, can generate more information and can be interfaced with different communication technologies.

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The Smart Grid Concept

1. ***To implement the ability to monitor the state of the electric energy delivery system.***
2. ***Develop and implement control applications to optimize and to improve the operation and reliability of the energy delivery system.***
3. ***And last but not least, enhance customer services.***

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The Energy Delivery Infrastructure

a. Generation. Capacities ranges between a few hundred MW to a few thousand MW.

b. Transmission. Voltage range between 34.5 to 765 KV.

c. Distribution. Voltages range between 4 KV to 34.5 KV.

d. Service voltage network. Voltages range between 120 to 480 V.

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Unique properties of the energy delivery infrastructure

1. ***Three phase 4-wires or 3-wires and transitions through step-down transformers can be Y-Y, Y-D and D-Y, grounded or ungrounded at the Y side.***
2. ***Under steady state conditions, the 3-phase voltages V_{an} , V_{bn} and V_{cn} can be defined as 3-phase phasors.***
3. ***For any of the phasors defined at the distribution substation bus, there is a remote corresponding phasor, slightly phase shifted from the phasor at the bus with a magnitude dependent on the intervening step-down transformer ratio and the voltage drop in the circuit due to circuit loading.***

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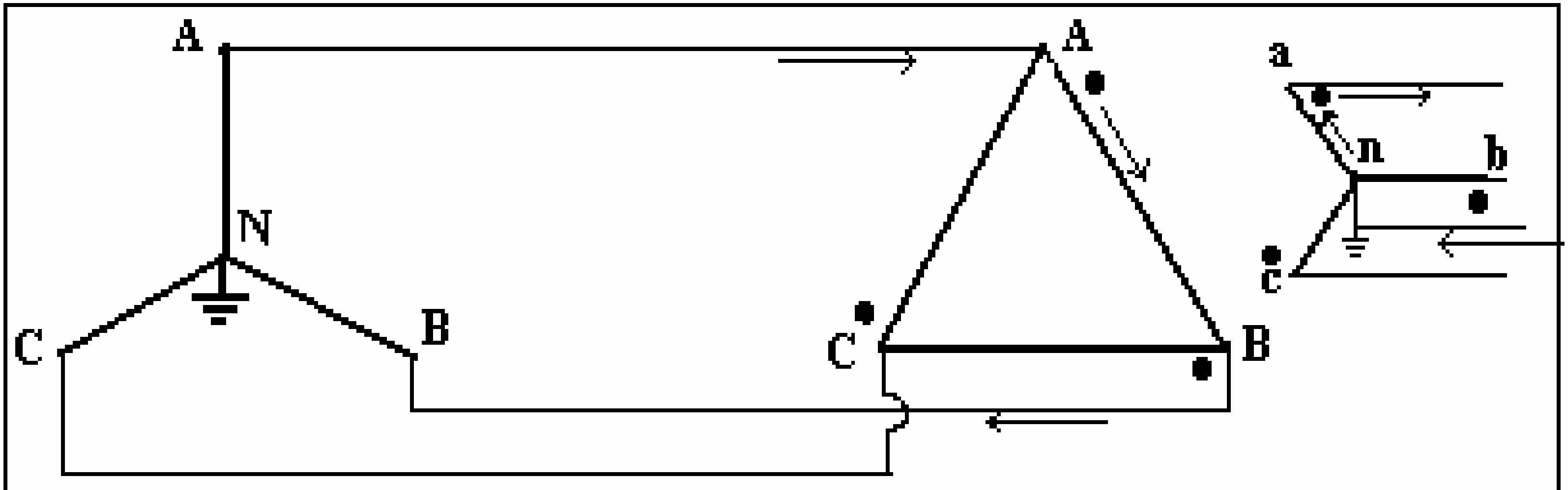

Corresponding phasors :

$V_{AB} \leftrightarrow V_{an}$ $\quad$ $V_{AN} \leftrightarrow V_{ac}$

$V_{BC} \leftrightarrow V_{bn}$ $\quad$ $V_{BN} \leftrightarrow V_{ba}$

$V_{CA} \leftrightarrow V_{cn}$ $\quad$ $V_{CN} \leftrightarrow V_{cb}$

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The transient and steady state behavior

1. ***The transient response due to a perturbation at the distribution network is transient oscillatory and ranges between 200 Hz to 600 Hz and its time constant is less than half a cycle of the 50 Hz or 60 Hz power frequency.***
2. ***Energy conversion devices (motors) have relatively longer transient time constants (mechanical inertia) and typically lasts for several cycles of the power frequency.***

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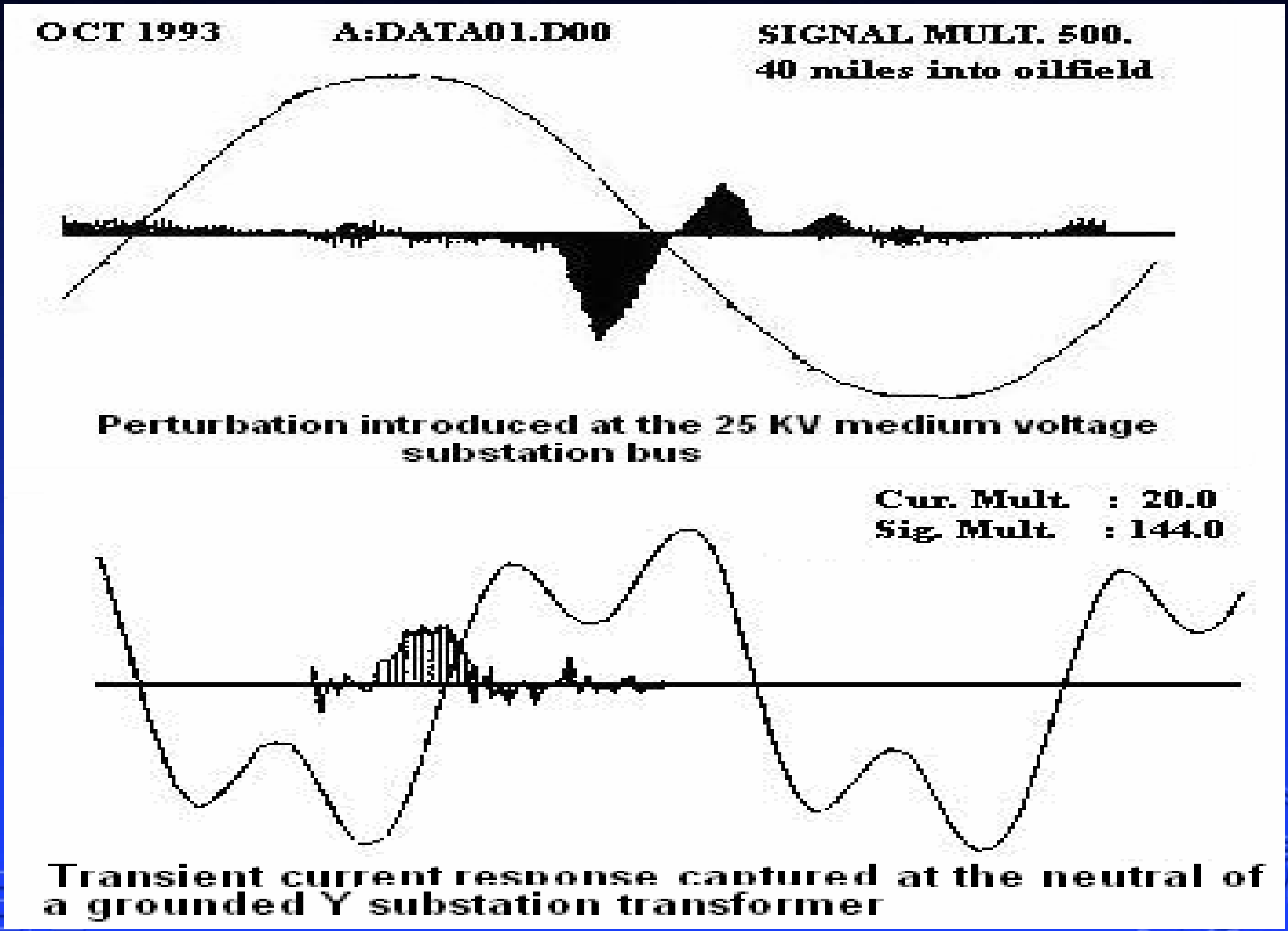
Typical transients at the distribution network



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Degrees of complexity of the energy delivery network for implementing control applications

1. ***Generation***
   Sparse and separated geographically over large distances. Circuits are balanced and very stiff.
2. ***Transmission***
   Circuits are long with few interconnections and each circuit is practically physically balanced.
3. ***Medium and Service level distribution***
   Spread over large geographical area with a multitude of balanced and unbalanced circuits and numerous phase rotations

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WHAT CONSTITUTE GOOD DATA?

1. *Time interval data of loads or voltage are averaged instantaneous values over a specified time interval longer than the duration of transients.*
2. *Time stamped interval duration and synchronized over the whole delivery system.*
3. *Attached circuit information to the monitored data.*
4. *Essentially each interval data point can be defined by the following Grid Parameter expression :*

Q(s, b, f, p, d, t)

s : substation name   b : bus number   f : feeder number
p : phasor number   d : protective device at supply side
t : time   Q : Data

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POSSIBLE APPLICATIONS

1. CUSTOMER REVENUE METERING :
   - Standard Billing
   - Pre-Pay Metering
   - Time-of –Use Rates (Demand Response Application)
2. DEMAND RESPONSE :
   - Customer load profiling to determine candidates for direct load control / time-of-use rates, participation and customer education
   - Reducing the impact of coal load pick-up.

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3. *ASSETT MANAGEMENT :*

   – *Distribution Transformer Overload Determination*
   – *Improving Feeder Load Factor to Reduce Circuit Losses*
   – *Improve Feeder Load and Voltage Balance (Reduce Circuit Losses, Improve Motor Life, Reduce Neutral and Ground Stray Current, etc.). ANSI C84.1 Annex 1 requires de-rating of motors if unbalance is in excess of 1%.*
   – *Integrated VOLT-VAR Control Improvements by Correlating Line Voltages with Load Distribution along the Feeder as a Function of Time.*

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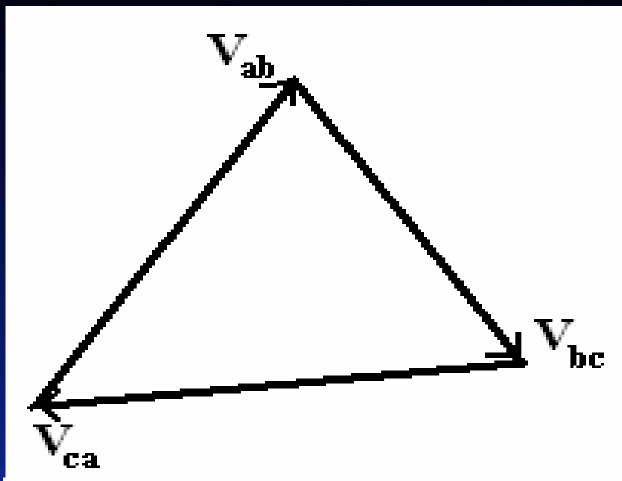
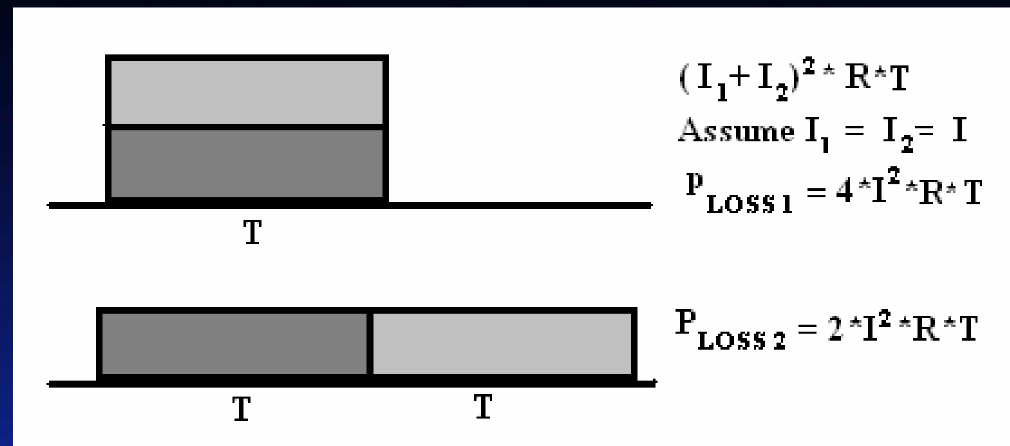


$a = |V_{ab}|$ $b = |V_{bc}|$ $c = |V_{ca}|$

$x = b/a$ $y = c/a$



$$\left|\frac{V_2}{V_1}\right| = \frac{\sqrt{\frac{1+x^2+y^2}{6} - \sqrt{\frac{(1+x+y)(x+y-1)(1+y-x)(1+x-y)}{12}}}}{\sqrt{\frac{1+x^2+y^2}{6} + \sqrt{\frac{(1+x+y)(x+y-1)(1+y-x)(1+x-y)}{12}}}}$$

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4. Network Outage Management

- ***Selective Coordination of Protective Devices is implemented***
- ***Fault on a feeder detected by SCADA or intelligent relay at the distribution substation.***
- ***Alarm signal trigger a polling sequence of remote devices using the utility communication system to determine which devices are de-energized.***
- ***By inference, the protective device serving part of the circuit supplying power to the devices is open.***
- ***Relate location of protective device and the de-energized part of the feeder to geographical map.***

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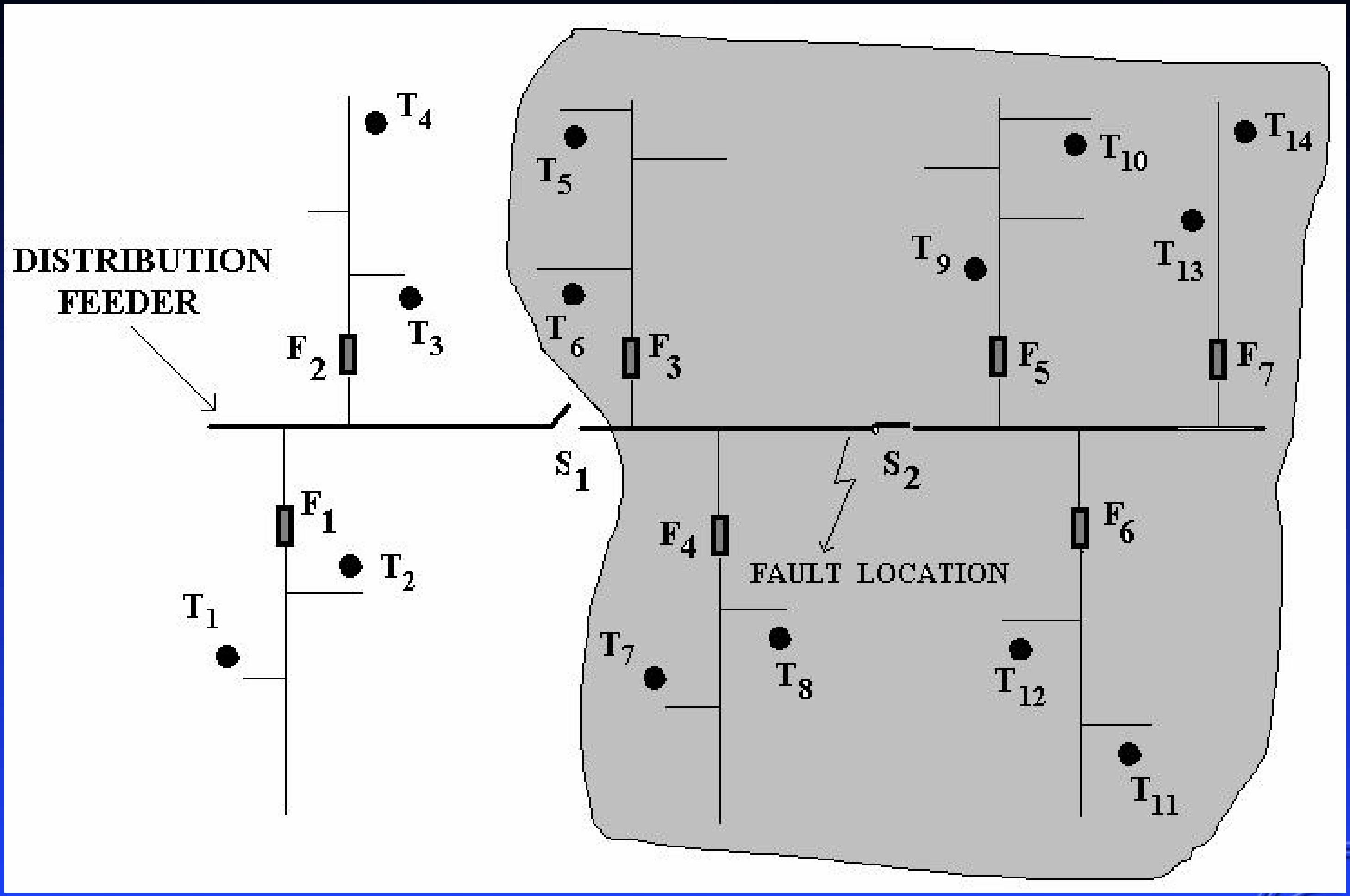

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SYSTEM ARCHITECTURE BUILDING BLOCKS

1. ***SMART METERS AND INTELLIGENT REMOTE DEVICES:***
   - ***Programmable Interval and maintain Real Time clock***
   - ***Multilevel data gathering with local processing capability,***
   - ***Local storage capability,***
   - ***Multilevel addressability.***
   - ***Digital communication interface***
   - ***Switching capability***
   - ***Etc.***

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2. The Utility Communication System

- ***Two-way Communication Network connecting the Net-Server Computer to the Main Nodes, Sub-nodes and Remote Devices.***
- ***The Communication System retrieves data from the remote devices and also serves as a control link to the remote devices.***
- ***Detecting non-functional parts of the communication network to reduce the Cost of Not-Knowing and improve the Cost of Reliability.***
- ***Maintains connectivity and provides rerouting if part of the communication network is not functioning.***
- ***The Net-Server Computer maintains addresses of remote devices and performs traffic control.***

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- ***The Net-Server transfers collected data from the remote devices to the Data Repository System and minimizes loss of data***
- ***Accepts commands from other Computers for Remote Control***
- ***Performs queuing of commands based on priorities.***
- ***Reduce wasteful communication due to distribution circuit power outage or physical transfer of part of a circuit to another feeder or substation network.***
- ***Adjust communication strategies to optimize communication under noisy propagation conditions.***
- ***Broadcast real time to all remote devices***
- ***Maintain communication Path-Maps Data Base to all remote devices***

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3. Data Repository and Data Base Management

- Store collected data to be made available for mining by different users
  - Customer Billing
  - Assets and Outage Management
  - Etc.
- Organize collected data for easy access by different users to design control algorithms
- Maintain data security and back-up plans
- Cross-link data with the Grid Parameters and the Communication Path-Maps
- Maintain controlled links to other users computers.

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CONCLUSIONS

1. ***Do not start choosing a communication without knowing what applications one plans to implement now and in the future.***
2. ***Determine what types of information are needed to design control algorithms for the intended applications.***
3. ***Explore potential commercial systems and evaluate the anticipated complexities and added costs to expand the system capabilities for future applications.***
4. ***This paper is intended to provide the necessary insights and ideas for implementing many of the Smart Grid functional requirements.***

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