INNOVATIVE SMART GRID TECHNOLOGIES
CONFERENCE

January 19-21, 2010

Sioe T. Mak Ph.D. EE
IEEE Fellow

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

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

Typical transients at the distribution network

Perturbation introduced at the 25 KV medium voltage substation bus

Cur. Mult. : 20.0
Sig. Mult. : 144.0

Transient current response captured at the neutral of a grounded Y substation transformer
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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

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

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

\[ a = |V_{ab}| \quad b = |V_{bc}| \quad c = |V_{ca}| \]
\[ x = b/a \quad y = c/a \]

\[
\frac{|V_2|}{|V_1|} = \frac{\sqrt{1+\frac{x^2+y^2}{6} - \sqrt{\frac{(1+x+y)(x+y-1)(1+y-x)(1+x-y)}}}}{\sqrt{1+\frac{x^2+y^2}{6} + \sqrt{\frac{(1+x+y)(x+y-1)(1+y-x)(1+x-y)}}}} \]

\[
(I_1 + I_2)^2 \cdot R \cdot T
\]
Assume \( I_1 = I_2 = I \)
\[
P_{\text{LOSS}1} = 4 \cdot I^2 \cdot R \cdot T
\]
\[
P_{\text{LOSS}2} = 2 \cdot I^2 \cdot R \cdot T
\]
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.**
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

- 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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.
Knowledge Based Architecture Serving As a Rigid Framework For Smart Grid Applications

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.