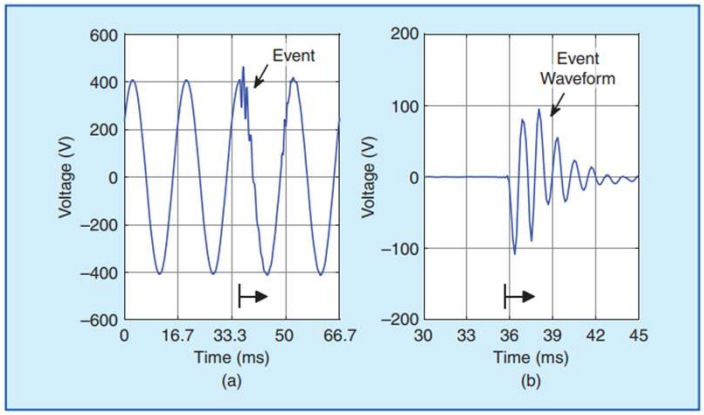
Synchro-waveforms

- Data saved as waveform data with time stamps
- Capture information that synchrophasors are not designed to capture
  - » Transient events
  - » Power quality
    - – Locate origin of problem/event
- Compare measurements at different locations:
  - » On a distribution system
  - » Or a transmission system
- Waveform measurement unit
  - » Data concentrators

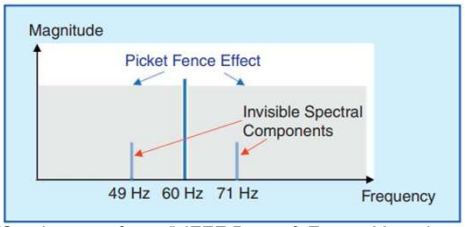
Separate transient current from the 60 Hz



From: H. Mohsenian-Rad and W. Xu, "Synchro-waveforms," *IEEE Power & Energy Magazine.* Sept/Oct 2023

Synchro-waveforms: Possible Applications

- Analyze response of IBRs
  - » Fault response
  - » Disturbance response
- System response characterization
- Low frequency oscillations
- Oscillation source
- Protection
- Control



From: H. Mohsenian-Rad and W. Xu, "Synchro-waveforms," *IEEE Power & Energy Magazine*. Sept/Oct 2023

Growing Interoperability Needs Beyond the Substation

- Transmission control devices, energy storage, HVDC, etc.
- Technology interoperability needs
  - » Harmonized plug and play solutions
  - » Compliance of same or different technologies
    - – AC and DC systems
    - – Testing
    - – Modeling for planning/operations studies
- Vendor interoperability
  - » Operation compatibility of same technologies from different vendors
  - » Compatibility of different technologies from different vendors
- Testing→ who and where

Distribution Systems

- Large amount of equipment and circuits
- Communication and automation can have local impact
- Often less visibility on distribution system prior to last 10-15 years
  - » Cost versus benefit

Distribution Applications: Some History

- Initially little communication within distribution system
- Some utilities looked at demand side management
  - » 1980's
  - » Power line carrier, some radio
  - » Control water heaters or air conditioners to reduce load peaks
- Digital metering
  - » Drive by versus communication network
- Voltage control
  - » Conservation voltage reduction (old name)
    - – Integrated Volt Var Control
  - » Coordinate capacitor banks/voltage regulators
  - » Starting to add inverters

Many More Distribution Applications

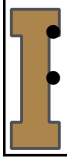
- Fault location, identification and system reconfiguration (FLISR)
- Outage management systems (OMS)
- Distribution management systems (DMS)
- Smart meters—how get data to OMS and DMS?
- And so on….
- Coordination of these tools
  - » Many have their own communication and databases
  - » **Advanced distribution management systems (ADMS)**

Distributed Energy Resources

- Integration and Coordination of distributed energy resources (DER)
- Distributed generation
- Energy storage
- Demand response
- Could be a bunch of stand-alone devices
- Could coordinate…
  - » DERMS
  - » Microgrids

Microgrids

- Growth of non-utility owned generation with move toward re-regulation of utility industry
- Public Utility Regulatory Policies Act of 1978 initial step
  - » Encouraged industry facilities to install generation and sell to grid
- 1990's significant increase in interest in distributed generation
  - » Starting to see increase in renewable, but mostly rotating machine
  - » Big concern at the time was unintentional islanding—detection and isolation
- IEEE Standard 1547 development
- IEEE 2030 → communications, including security



Initial Concepts

- DOE working groups and IEEE groups started looking at creation of intentional islands
  - » Sufficient location generation to support loads
  - » Much of initial discussion looked at distribution systems
- Coining of the term Microgrid

DOE Definition of a Microgrid

- "A group of interconnected loads and distributed energy resources within a clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid connected and island mode"

Early Applications

- Quickly became a very active area for research/papers
- Early field installations largely niche cases that already had significant distributed generation
  - » Isolated loads
  - » Industrial facilities
  - » Military bases
  - » University campuses
  - » Supporting high value loads—super UPS

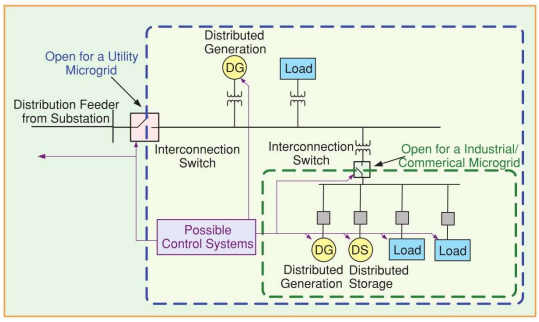
Other early examples

- Early applications: uninterruptible power supplies
- Isolated distribution systems fed by inverters/batteries
- Microgrids dominated by inverters
- VSC HVDC to:
  - » islands, off-shore oil platforms, or other wind platforms
  - » Black start

Present Status

- Microgrids are moving from niche applications to utilities systems
- Improved power system resilience—from end user perspective
- Support increased renewable generation penetration
- Enable new business models

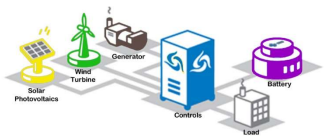
Generic Microgrid



Source : Making Microgrids work , IEEE Power and Energy Magazine, 2008

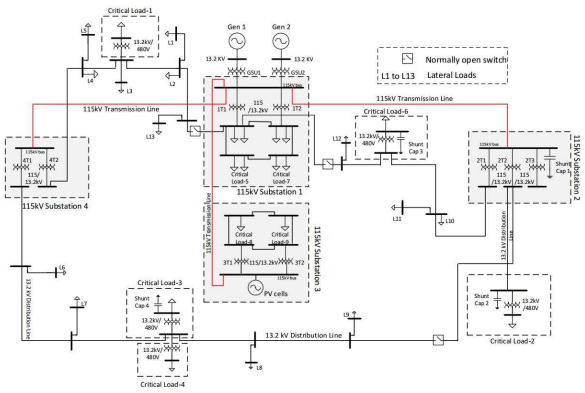
Components

- Power generation resources (variety, includes renewables)
- Electrical loads (controls)
- Energy storage system (optional)
- ***Microgrid controller***
- ***Communications***
  - » Communication standards
  - » Interoperability



Possible Classifications of Microgrids (1)

- Several different views:
  - » 50/60 Hz AC distribution systems
  - » 50/60 Hz AC transmission and distribution
  - » DC
  - » High or low frequency AC



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Possible Classifications of Microgrids (2)

- Single owner
  - » University campus, industrial facility, base, etc.
    - – Coordinated control is easier
    - – Appear as a single entity to utility already
- Geographically tied group
  - » Agree to work together
    - – Financial (pricing)
    - – Coordinated control
    - – Act as a single controlled entity
  - » Increased challenges for communication

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Communication Requirements

- Measurements with controller
- Controller to actuators
  - » Generators
  - » Loads
    - – Responsive loads—Demand Response
    - – Load shedding…
  - » Storage
  - » Protection and control
- With larger grid
  - » Grid connected versus isolated mode

Power Sources

- Rotating machines
  - » Diesel
  - » Gas
  - » Some utilize steam from other processes
  - » Small to medium sized hydro
- Power electronic controlled or interfaced (mostly voltage sourced converters)
  - » Photovoltaic (1 or 3 phase)
  - » Wind
  - » Energy storage

Some other terms

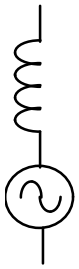
- Isochonous operation: frequency (and voltage) is independently held constant, zero generator droop
- Droop Control: applied to generators for frequency control (sometimes voltage) allowing parallel generator operation

Grid Following Inverter

- Fast current control— current source
  - » Current references from outer control
  - » Often related to P and Q related controls
- Synchronization to the power system
  - » Fast tracking of changes in angle or frequency
  - » Maintain current setpoint – fault current limiting
  - » Looks like nearly zero inertia

Grid Forming Inverter

- Inverter controlled to maintain:
  - » Voltage magnitude
  - » Frequency
  - » Angle reference
  - » Back to early VSC control concepts
- Effectively a voltage behind a reactance
  - » Needs current limiting control
  - » Faults or other disturbances



Grid-Forming with Multiple Sources

- One generator is designated to run in isochronous mode
  - » Larger and higher inertia prime movers normally reference
  - » Problem with one machine/inverter as absolute reference
- All others follow in droop mode
- PV inverters may operate in a droop mode
  - » Volt/Var
  - » Volt/Watt an others