SMART GRID

MODULE-II

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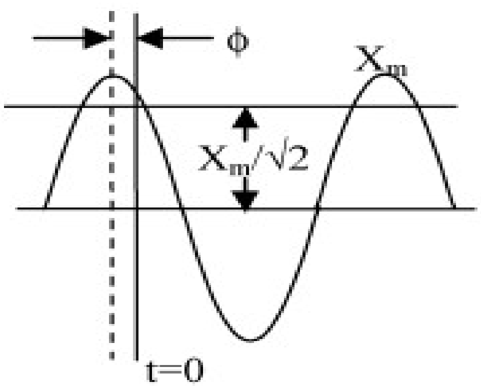
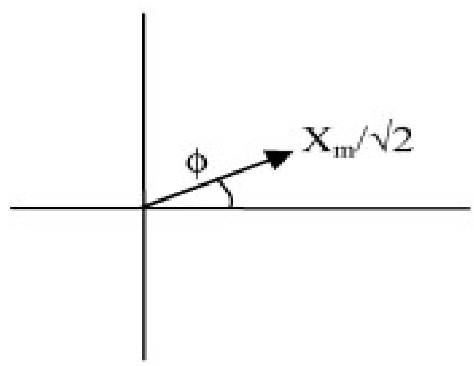
<u>CONTENTS</u>

PHASOR MEASUREMENT UNITS (PMU)

- Classical Definition of a Phasor
  - Phasor is a quantity with magnitude and phase (with respect to a reference) that is used to represent a sinusoidal signal.
  - Here the phase or phase angle is the distance between the signal's sinusoidal peak and a specified reference and is expressed using an angular measure.
  - Here, the reference is a fixed point in time (such as time = 0). The phasor magnitude is related to the amplitude of the sinusoidal signal.



(a) Sinusoidal signal



(b) Phasor representation

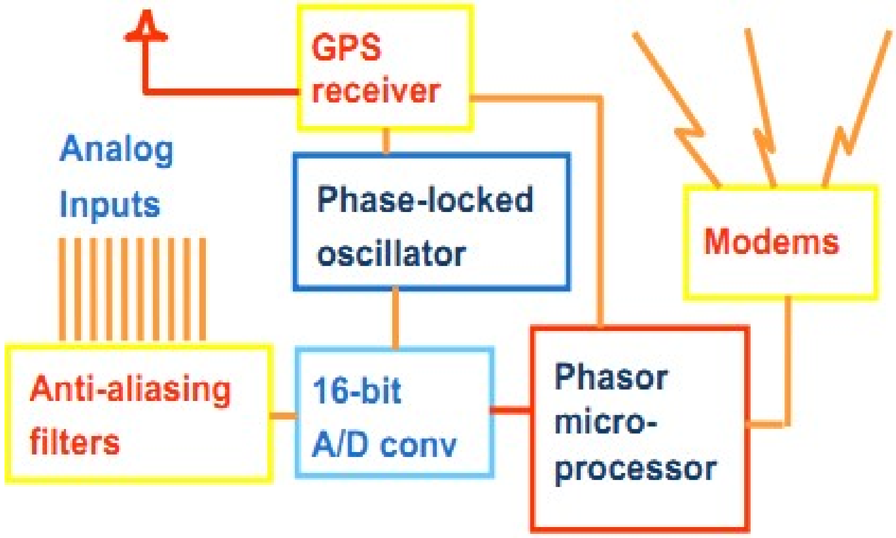
- PMU
  - A phasor measurement unit (PMU) is a device used to estimate the magnitude and phase angle of an electrical phasor quantity (such as voltage or current) in the electric grid using a common time source for synchronization.
  - Time synchronization is usually provided by GPS and allows synchronized real-time measurements of multiple remote points on the grid.

- PMUs are capable of capturing samples from a waveform in quick succession and reconstructing the phasor quantity, made up of an angle. measurement and a magnitude measurement.
- The resulting measurement is known as a synchrophasor. These time synchronized measurements are important because if the grid's supply and demand are not perfectly matched, frequency imbalances can cause stress on the grid, which is a potential cause for power outages.
- PMUS can also be used to measure the frequency in the power grid.
- A typical commercial PMU can report measurements with very high temporal resolution in the order of 30-60 measurements per second. This helps engineers in analyzing dynamic events in the grid. which is not possible with traditional SCADA measurements that generate one measurement every 2 or 4 seconds.
- Therefore, PMUs equip utilities with enhanced monitoring and control capabilities and are considered to be one of the most important measuring devices in the future of power systems.
- A PMU can be a dedicated device, or the PMU function can be incorporated into a protective relay or other device.

- <u>WHY PMU?</u>

- PMU an essential component of Smart Grids.
- It provides Synchrophasor data
- Reports Magnitude, Phase and Frequency of an AC waveform
- Makes the grid observable due to high reporting rates
- Preventive actions can be taken such as black outs

- <u>THE MAIN COMPONENTS OF PMU</u>
- Analog Inputs
- GPS receiver
- Phase locked oscillator
- A/D converter
- Anti-aliasing filters
- Phasor micro-processor
- Modem



– Analog Inputs

- Current and potential transformers are employed at substation for measurement of voltage and current.
- The analog inputs to the PMU are the voltages and from currents obtained the secondary winding of potential and current transformers.

– Anti-aliasing filters

- Anti-aliasing filter is an analog low pass filter which is used to filter out those components from the actual signal whose frequencies are greater than or equal to half of nyquist rate to get the sampled waveform.
- Nyquist rate is equal to twice the highest frequency component of input analog signal.
- If anti aliasing filters are not used, error will be introduced in the estimated phasor

– Phase lock oscillator

- Phase lock oscillator along Global Positioning reference with System source provides the needed high speed sampling. synchronized
- Global Positioning System (GPS) is system a satellite-based providing for position and time.

– A/D converter

- It converts the analog signal to the digital signal.
- Quantization of the input involves in ADC that introduces a small amount of error.
- The output of ADC is a sequence of digital values that convert a continuous time and amplitude analog signal to a discrete time and discrete amplitude signal.
- It is therefore required to define the rate at which new digital values are sampled from the analog signal.
- The rate of new values at which digital values are sampled is called the sampling rate of the converter.

– Global Positioning System

- The synchronized time is given by GPS uses the high accuracy clock from satellite technology.
- Without GPS providing the synchronized time, it is hard to monitor whole grid at the same time.
- The GPS satellites provide a very accurate time synchronization signal, available, via an antenna input, throughout the power system. This means that that voltage and current recordings from different substations can be directly displayed on the same time axis and in the same phasor diagram.

– Processor

- The microprocessor calculates positive- sequence estimates of all the current and voltage signals using the DFT techniques.
- Certain other estimates of interest are frequency and rate of change of frequency measured locally, and these also are included in the output of the PMU.
- The timestamp is created from two of the signals derived from the GPS receiver.
- The time-stamp identifies the identity of the "universal time coordinated (UTC) second and the instant defining the boundary of one of the power frequency periods.

- Modem
  - A device that modulates an analog carrier signal and encodes digital information from the signal and can also demodulate the signal to decode the transmitted information from signal is called modem.
  - The objective of modem is to produce a signal that can be transmitted and decoded to make a replica of the original digital data.
  - Modem can be used with no means of transmitting analog signals

- <u>FEATURES OF A PMU</u>

- PMUS are Measures 50/60 Hz AC waveforms (voltage and current) typically at a rate of 48 samples per cycle.
- PMUS are then computed using DFT-like algorithms, and time stamped with a GPS.
- The resultant time tagged PMUS can be transmitted to a local or remote receiver at rates up to 60 samples per cycle.

- <u>PMU Applications in power system</u>

- SCADA Displays
- State estimation
- Control (WAMS)/SPS
- Measurement based controls for:
- Voltage Stability
- Angle Stability
- Frequency Stability
- Event and system analysis
- Improved operational observability
- Dynamic System Stability Probe & Control
  - Power system damping-PSS
- PMU data trends can detect CB/switch status changes in the network, which will improve the topology estimation

- <u>Applications of PMU in power System</u>

– Adaptive relaying

– Instability prediction

– State estimation

– Improved control

– Fault recording

– Disturbance recording

– Transmission and generation modeling verification

– Wide area Protection

– Fault location

- <u>PMU for Wide Area Monitoring and Control</u>

– Potential PMU Applications

  » Wide-Area Visualization and Monitoring;
  » Angle and Frequency Monitoring;
  » Interarea Oscillation Detection & Analysis;
  » Proximity to Voltage Collapse;
  » State Estimation;
  » Fast Frequency Regulation;
  » Transmission Fault Location Estimation;
  » Dynamic Model Validation.

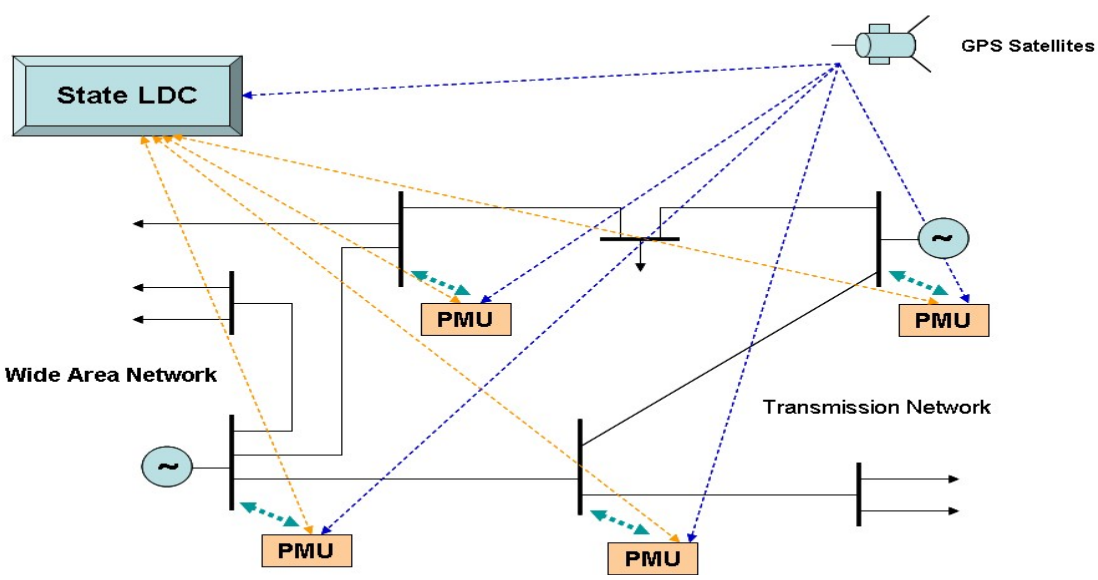
– Though the above applications are from the view of ISO, the PMUs-based applications also benefit generator owners and other market participants.

– PMUs are able to continuously record several different signals which are the requirements of ancillary services like spinning reserve, frequency control and voltage control.

– Once the infrastructure is permanently installed at the power plant, the online tests such as voltage step-change can be easily applied and recorded.

WIDE AREA MEASUREMENT SYSTEM(WAMS)

- Advanced measurement technology to collect information.
- Wide area monitoring systems (WAMS) are essentially based on the new data acquisition technology of phasor measurement and allow monitoring transmission system conditions over large areas in view of detecting and further counteracting grid instabilities.
- The WAMS technologies are comprised of two major functions:
  - Obtaining the data
  - Extracting value from it
- Getting the data is accomplished with a new generation a new generation of data recording hardware that produces high volume recordings.
- Data is extracted and analyzed using several signal analysis tools and algorithms.



- Need of WAMS

- In order to avoid regional blackouts such as those occurred in India and North America and Canada in 2003.
- When constant monitoring applications are available immediate action can be taken if some failures are detected.
- This early warning system contributes to increase system reliability by avoiding the spreading of large area disturbances, and optimizing the use of assets.

- Components of WAMS

- Phasor Measurement Unit(PMU)
    - They are devices which use synchronization signal from the global positioning system (GPS) satellite and provide the phasor voltage and currents measured at a given substation.
    - A phasor is a complex number that represents both magnitude and phase angle of the sine waves found in electricity.
    - PMU can different Date Rate i.e. 60,30,10 frame per second.

- Phasor Data Concentrator(PDC)
    - It is node in a system where phasor data from a number of PMUS or PDCs is correlated and fed out as a single stream to other applications.
    - PDC would performs the Real time monitoring, alarming, event triggering.
    - It perform loacal archiving.
    - It perform various quality checks on the phasor data.

- Basic Idea
    - Current, voltage and frequency measurements are taken by Phasor Measurement Units (PMUS) at selected locations in the power system and stored in a data concentrator every 100 milliseconds. The measured quantities include both magnitudes and phase angles, and are time synchronised via Global Positioning System (GPS) receivers

with an accuracy of one microsecond. The phasors measured at the same instant provide snapshots of the status of the monitored nodes. By comparing the snapshots with each other, not only the steady state, but also the dynamic. state of critical nodes in transmission and sub-transmission networks can be observed. Thereby, a dynamic monitoring of critical nodes in power systems is achieved.

- Opportunities Provided by WAMS

➢ _On-line or real time monitoring and state estimation
  - We can realize 1 state estimator run per cycle
  - provides us an opportunity to peep into electromechanical system dynamics in real time
    - » upgrade from local control to wide area controller e.g., for PSS & damping controllers etc
    - » improve performance of the apparatus protection schemes
    - » improve performance of the system protection schemes

➢ Accurate measurement of transmission system data in real time

- Benefit of Using PMU in WAMS

– Real time monitoring : Improve calculation for real time path flow and optimal dispatch provide actual limits of the system instead of the conservative ones from offline calculations

– Post-disturbance analysis : Easier to understand sequence of events when using synchronized data from PMU

– Adaptive protection : Improved backup protection Adaptive protection setting to avoid cascading outage

– Power system restoration : System operator have more confidence during restoration Reduce chance of recurrence of system outage Reduce time needed for a system restoration

- WAM applications

– Protection
    - » Power Swing blocking
    - » Improved back up protection
    - » Current Differential protection

– Continuous Closed Loop Control
  e.g., PSS using global signals
  Unfortunately: Require to accurately determine the communication latencies for continuous control
  Emergency Control (System Protection Schemes)

– Controlled System Separation

– Triggering of load shedding based on NON-LOCAL signals. Better df/dt relaying.

– Triggering other schemes (generator shedding, dynamic brake, governor) etc.
  Some may require accurate loss of synchronism *prediction*

– Islanding Detection

– Loss of Synchronism detection

– Average line temperature can be estimated from true line impedance: picture of thermal overloading if it exists

– Power System Restoration
    - ▪ Better picture – better confidence level – better decisions.
    - ▪ More remote actions

WIDE-AREA BASED PROTECTION AND CONTROL

– Wide area based protection and control (WAPC) is a key aspect of smart grid technology that helps to improve the reliability, efficiency, and safety of power systems. WAPC uses advanced communication and control technologies to enable real-time monitoring and control of power systems over a wide geographic area, typically spanning multiple substations and transmission lines.

– The main purpose of WAPC is to detect and respond to system disturbances or faults quickly and accurately, to prevent or mitigate potential power outages or blackouts. By using advanced monitoring, communication, and control technologies, WAPC allows power system operators to detect and diagnose problems more quickly, and to take appropriate actions to isolate and correct the problem before it can spread and cause widespread outages.

- WAPC relies on a range of advanced technologies, including synchrophasor measurement systems, which provide highly accurate and synchronized voltage and current measurements across the power system. These measurements are then transmitted to a central control center, where they can be analyzed and used to detect and diagnose system disturbances or faults.
- WAPC can also incorporate advanced analytics and machine learning algorithms to help predict and prevent potential system failures before they occur. By analyzing historical data and real-time system data, these algorithms can identify potential risks and anomalies and alert system operators to take action to prevent or mitigate potential outages.
- Overall, WAPC is a key technology for improving the reliability and efficiency of smart grids, and it is expected to play an increasingly important role in the future of power systems as more renewable energy sources are integrated into the grid and the demand for electricity continues to grow.

MICRO-GRID CONCEPTS

- A micro-grid is a small-scale power grid that can operate independently or collaboratively with other small power grids. The practice of using micro-grids is known as distributed, dispersed, decentralized, discrete or embedded energy production.
- Any small-scale, localized power station that has its own generation and storage resources and definable boundaries can be considered a micro-grid. If the micro-grid can be integrated with the area's main power grid, it is often referred to as a hybrid micro-grid.
- Micro-grids are typically supported by generators or renewable wind and solar energy resources and are often used to provide backup power or supplement the main power grid during periods of heavy demand.
- A micro-grid strategy that integrates local wind or solar resources can provide redundancy for essential services and make the main grid less susceptible to localized disaster.

- A micro-grid is a local energy grid with control capability, which means it can disconnect from the traditional grid and operate autonomously.
- Micro-grid is an integration platform for supply-side (micro- generation), storage units and demand resources (controllable loads) located in a local distribution grid.
- A micro-grid should be capable of handling both normal state (grid-connected) and emergency state (islanded operation)
- The difference between a micro-grid and a passive grid penetrated by the micro-sources lies mainly in terms of management and coordination of available resources

- <u>How does a micro-grid works?</u>

In order to work, micro-grids must include three essential components:

- Locally produced energy to ensure they can operate independently in the event they are disconnected (photovoltaic panels, wind turbines, cogeneration, heat pumps, biomass plants, hydroelectric turbines, etc.) and an additional back-up supply of energy (power generators). In theory indeed, micro-grids can go completely off the grid, but so far this rarely occurs in practice;
- A storage system: batteries, a supply of water for pumped-storage hydroelectricity and, in the future, super-capacitors and a chemical- based latent-heat storage system;
- A smart management system to ensure the continuous balance between electricity generation and demand.

- <u>How does a micro-grid connect to the grid?</u>
  - A micro-grid connects to the grid at a point of common coupling that maintains voltage at the same level as the main grid unless there is some sort of problem on the grid or other reason to disconnect. A switch can separate the micro-grid from the main grid automatically or manually, and it then functions as an island.

- Micro-grid benefits

– Provides power quality, reliability, and security for end users and operators of the grid
– Enhances the integration of distributed and renewable energy sources
– Cost competitive and efficient
– Enables smart grid technology integration
– Locally controlled power quality
– Minimize carbon footprint and green house gas emissions by maximizing clean local energy generation
– Increased customer (end-use) participation

- Composition of micro-grid
  – DG: It can be various types of new energy such as PV, Energy storage (ES), Wind, Fuel cell; or combined heat and power (CHP), combined cooling, heat and power (CCHP).
  – Loads: It includes common load and critical loads.
  – ES: It includes physical, chemical, and electromagnetic forms, for storage of renewable energy, load shifting, and black-start of micro-grid
  – Control Devices: They constitute the control systems for DGs, ESS, and transfer between grid connected mode and islanded mode, facilitating real time monitoring and energy management

- Classification

– Classification: Type-1 AC micro-grid
➢ An AC micro-grid connects distribution via an AC bus to the network
➢ ES and DG are connected to the AC bus via inverter
➢ No inverter is required for power supply to AC loads

- Control and operation are difficult

– Classification: Type-2 DC micro-grid

- In a DC micro-grid, DG, ES, and DC load are connected to the DC bus via a converter and the DC bus is connected to AC loads via an inverter to power both DC and AC loads
- As DG control solely depends on DC voltage, it is easier to realize coordinated operation of the DGs
- DG and load fluctuations are compensated by ES on the DC side
- Compared with an AC micro-grid, a DC micro-grid is easier to control, does not involve synchronisation among DGs, and thus it is easier to suppress circulating current
- Inverters are required for power supply to AC loads

– Classification: Type-3 AC-DC micro-grid

- An AC/DC hybrid micro-grid is a micro-grid consisting of an AC bus and a DC bus
- AC bus and DC bus allow for direct supply to AC loads and DC loads

- <u>Classification of micro-grid by capacity</u>
  - Simple micro-grid: <2 MW
  - Corporate micro-grid: 2-5 MW
  - Feeder area micro-grid: 5-20 MW
  - Sub-station area micro-grid: >20 MW
  - Independent micro-grid: Depending on the loads on an island, a mountainous area or a village

- <u>Classification of micro-grid by function demand</u>
  - Simple micro-grid: A simple micro-grid contains only one type of DG, has simple functions and design, and is intended for use of CCHP or continuous supply of continuous loads
  - Multi-DG micro-grid: A multi-DG micro-grid is composed of multiple simple micro-grids or multiple type of complementary, coordinated DGs. Compared with a simple micro-grid, the design and operation of such a grid are much more complicated. Some loads need

to be identified as sheddable loads in case of emergency to maintain power balance in an emergency.

- Utility micro-grid: All DGs and micro-grids that meet specific technical conditions can be integrated into a utility micro-grid. In such a micro-grid, loads are prioritized based on users requirements on reliability, and high priority loads will be powered preferentially in an emergency.

- <u>Micro-grid operating modes</u>
  - Micro-grid may operate either in grid connected or in islanded mode
  - Grid connected mode of operation is further divided into power matched operation and power mismatched operation according to power exchange.
  - The micro-grid is connected to the distribution network via a PCC
- <u>Grid connected operation</u>
  - In grid connected mode, the micro-grid is connected to and exchanges power with the distribution system of the utility grid via PCC
  - Utility grid is active
  - Static switch is closed
  - All the feeders are supplied by the grid
  - Adopt P-Q control
- <u>Islanded operation</u>
  - Islanded operation means that the micro-grid is disconnected from the distribution system of the main grid at the PCC following a grid failure or as scheduled, and that the DGs, Ess, and loads within the micro-grid operate independently.
  - Static switch is open
  - Feeder A,B,C are supplied by micro-sources
  - Feeder D is dead.
  - Adopts V-f control mode

- <u>Conventional grid vs micro-grids</u>

- Efficiency of conventional grid is low compared to micro-grid.
- Large amount of energy in the form of heat is wasted in conventional grid.

– Power sources in the micro-grid are small and located close to the load.

- Advantages of micro-grid

– Micro-grid generation resources can include fuel cells, wind, solar, or other sustainable energy sources.
– Multiple dispersed generation sources and ability to isolate the micro-grid from a larger network provides highly reliable electric power.
– By product heat from generation sources such as micro turbines could be used for local process heating or space heating, allowing flexible trade off between the needs for heat and electric power.
– Generate power locally to reduce dependence on long distance transmission lines and cut transmission losses.

- Disadvantages of micro-grids
    – Voltage, frequency and power quality are the three main parameters that must be considered and controlled to acceptable standards whilst the power and energy balance is maintained.
    – Electrical energy needs to be stored in battery banks or as mechanical energy in flywheels thus requiring more space and maintenance.
    – Resynchronisation with the utility grid needs to be made carefully.
    – Micro-grid protection is one of the most important challenges facing the implementation of micro-grids

Need and Application Of Micro-grid

- Need

– Micro-grid could be the answer to our energy crisis.
– Transmission losses gets highly reduced.
– Micro-grid results in substantial savings and cuts emissions without major changes to lifestyles.
– Provide high quality and reliable energy supply to critical loads

- Application

– Small remote community
– University / Institution campus

- Hospital
- Commercial area
- Industrial cite
- Military Base
- Data center

ISSUES OF INTERCONNECTION

- Electricity grids must have standard conditions of supply to ensure that end-use equipment and infrastructure can operate safely and effectively. These conditions are commonly referred to as power quality requirements and are defined in standards or by supply authorities.
- They most commonly relate to voltage and frequency regulation, power factor correction and harmonics.
- In all distribution networks, challenges to maintaining these power quality requirements arise from the technical characteristics and end-user operation of electrical loads, and the network equipment and lines.
- Some loads have significant power demands that increase network current flows pulling down line voltage (such as electric hot water heaters and large air- conditioners).
- Some have very short-lived but major power draws on start-up (such as standard induction motors) driving voltage fluctuations.
- Some have significant reactive power needs (again including motors) or create significant harmonics (such as computer power supplies and fluorescent lighting).
- Power quality at different points of the distribution network at any time is impacted by the aggregate impacts of loads and network equipment in highly complex ways.

(a) Voltage fluctuation and regulation: Voltage fluctuation is a change or swing in voltage, and can be problematic if it moves outside specified values.

(b) Power factor correction: Poor power factor on the grid increases line losses and makes voltage regulation more difficult.

(c) Frequency variation and regulation: Frequency is one of the more important factors in power quality. The frequency is controlled by maintaining a balance between the connected loads and generation.

- Disruptions in the balance between supply and demand lead to frequency fluctuation, it falls when demand exceeds supply and rises when supply exceeds demand.

(d) Harmonics: Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency.

- The standard frequency's 50 or 60 Hz depending on the country, and so harmonic in a 50 Hz country could be 100, 150, 200Hz, etc.
- Harmonics can also be eliminated using passive and active filters, which are generally cheaper than inverters.
- Passive filters are composed of passive elements such as capacitors or reactor s, and absorb harmonic current by providing a low- impedance shunt for specific frequency domains

(e) Unintentional islanding: Unintentional islanding occurs when distributed generation delivers power to the network even after circuit breakers have disconnected that part of the network from the main grid and associated generators

PROTECTION AND CONTROL SYSTEMS FOR MICRO-GRID

- BASICS
  - Energy management in micro-grids is usually a three-level hierarchical control system
  - The first level of control often called as a primary or autonomous control,
  - consists of a number of local, autonomous controllers.

- Each controller is governed by a power electronics converter and it is responsible to interface generators, storage devices and loads with the micro-grid.
- A secondary level of control employs a low bandwidth communication to fix the frequency and amplitude of the micro-grids units, restoring their nominal values.
- Finally, the tertiary level of control is related to the control of active power flow and reactive power flow.
- This level of control is related to energy management system and also for the optimization of the micro-grid resources

- Protection issues of micro-grid

  When it is grid connected mode and islanded mode of operation are as follows:

  A. Events or Faults During Grid Connected Mode:

– For a fault within micro-grid, the response of line or feeder protection must be to disconnect the faulty portion from the rest of the system as quick as possible and how it is done depends on the features and complexity of micro-grid and protection strategy is used.

– There may be some non fault cases which are resulting in low voltages at PCC like voltage unbalance and non fault open phases which are difficult to be detected and it may create hazards for sensitive loads, micro sources etc.

– Therefore, some protection mechanisms must be developed to avoid such situations

  B. Events or Faults During Islanded Mode:

– The nature of problems are different in islanded mode than grid connected mode.

– In grid connected mode, the fault currents of higher magnitude (10- 50 times the full load current) which are available from the utility grid for activate conventional OC protection devices.

– For islanded mode of micro-grid, fault current is five times the full load current.

- When a large number of converter based DERS are connected in micro-grid, the fault currents are 2-3 times the full load current or even less depending on the control method of converter.
- The conventional OC protection devices are usually set at 2-10 times the full load current.
- Hence, due to this drastic reduction in fault level, the time current coordination of OC protective devices is disturbed, the high set instantaneous OC devices and extremely inverse characteristics OC devices like fuses are most likely to be affected

- The other major issues in micro-grid protection and control include
- Bidirectional power flows:
- ➢ The power flow in a conventional distribution system is unidirectional, i.e. from the substation to the loads.
- ➢ Reverse power flows when integration of DGS on the distribution side of the grid. As a result, the conventional protection coordination schemes are no longer valid;
- Stability issues:
- ➢ As a result of the interaction of the control system of micro generators local oscillations may arise. Hence, small signal stability analysis and transient stability analysis are required to ensure proper operation in a micro-grid;
- ➢ For maintaining power quality, active and reactive power balance must be maintained within the Micro-grid on a short-term basis;
- Intermittent Output: Renewable energy resources (photovoltaic or wind) in micro-grid as distributed generation are intermittent in their power output because of the availability of sources.
- Hence, coordination between DGs and storage devices is essential

- CONTROL
    - The micro-grid control center (MGCC) is the core of the micro-grid control system. It centrally manages DGS, ESS and loads and monitors and controls the entire micro-grid.
    - In grid connected operation, the layer regulates the micro-grid for best operational performance;

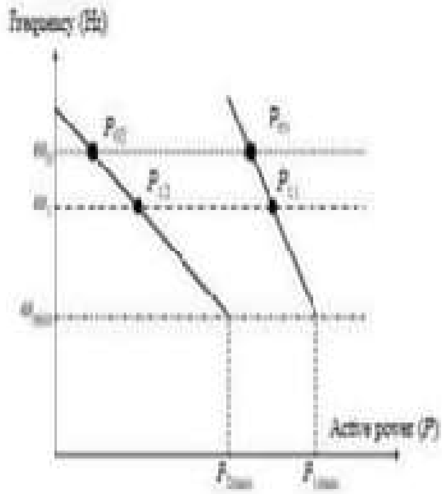
- In islanded operation, the layer adjusts the DG output and load consumption to ensure stable and safe operation of the micro-grid.
- The Control Centre (CC) also performs protection co-ordination.
- CC performs the overall control, operation, protection of Micro-grid.
- Also it maintains the specified voltage and frequency at the load end through power-frequency (P-f) and voltage control.
- The Control Centre (CC) also performs protection co-ordination and provides the power dispatch and voltage set points.
- When necessary the CC is designed to operate in automatic mode with provision for manual intervention.
- In centralized monitoring system, the central monitoring unit communicates with various switches, gives orders and also sets the switch action range.

A. Voltage control

- Active and reactive power control, voltage control at the Micro-grid bus are needed for overall stability and reliability of Micro-grids.
- Micro-grids may suffer from reactive power oscillations without proper voltage control with a large number of micro source

B. Load sharing through P-f control

- Micro-grid controllers have smooth and automatic change over from grid-connected mode to stand-alone mode and vice-versa.
- This is similar to the operation of uninterrupted power supply (UPS) systems.
- During transition to standalone mode, the MC of each micro source exerts local P-f control to change the operating point so as to achieve local power balance at the new loading.
- The controller does this autonomously after proper load tracking without Active power versus frequency droop characteristics. waiting for any command from the CC or neighboring MCs.
- Fig. shows the drooping P-f characteristic used by the MCs for P-f control



Active power versus frequency droop characteristics.

- <u>The Protection Schemes For micro-grid</u>

– There are three main categories in protection schemes which are as follows:

➢ The schemes for only grid connected mode
➢ The schemes for islanded mode
➢ The schemes for both grid connected and islanded mode

A. The schemes for only grid connected mode

– Protection scheme based on over current principle and time dependent characteristics of current to prevent high fault clearing time and maximizing the DG connection to the distribution network strategy provides extra benefit of running extensive radial networks with directly coupled DGS (D-DGs) or closed loop networks with converter based DGS (C-DGs). However, this scheme is more effective when number of relays are increased.

– Overcurrent pickup strategy for MV feeder with CDGs updates the OC relay minimum pickup current on the basis of the fault analysis of the system.

– However, when some of DGs are disconnected, then this scheme is more effective.

– A protection strategy using conventional OC relays with definite time grading for LV micro-grid with both C-DGS and D-DGs scheme is economical because, this scheme does not use any communication link and can be applied without any modification of existing protection scheme.

- Based on intelligent protection scheme for radial OHL distribution system without DG and for closed loop system with DG scheme, as compared to conventional protection provides higher speed of back up protection, autonomous system monitoring and adjustment of parameters, but needs a high speed communication.
- It has been used to fault current limier(FCL) in series with DG unit to limit the fault current during fault and thus return the system to it "so original state as if no DG was connected.
- In this way, without disconnection of DG, the original directional OC relay settings can be used. The use of TCSC (thyristor controlled series capacitor) as an FCL offers many advantages like no DG disconnection, use of original relay settings, for handling large currents avoids upgrading of equipment.
- But, its cost increases due to impedance of FCL increases with increase in individual DG capacity

B. The Protection Schemes For Only Islanded Mode:

- A protection scheme based on monitoring harmonic content of C-DGs in an islanded mode, which includes the total harmonic distortion (THD) of the voltage at the converter terminal..
- The protection relay monitors DG continuously and when THD exceeds a threshold value during a fault, the converter gets shut down by relay.
- For detecting the fault type, the variation of the amplitude of fundamental frequency of faulted the phase is used, it means that the frequency of faulted phase is dropped as compared to sound phase and also comparison of THD of voltage between sound and faulted phase is used for fault location i.e., faulted phase has greater THD than sound phase.
- The relay with more THD is considered to be in fault zone and it has to be trip for clear the fault. However, for correct relay to trip, communication links are provided for synchronization of relays.
- A protection scheme based on the principle of symmetrical components and residual current measurement also used.
- The differential current measurement is also applied. The scheme uses residual current devices as primary protection of LG faults for the zones of

upstream faults and the zero sequence currents for primary protection of LG faults for the zones of downstream the faults.

- The negative sequence current is used for primary protection of LL faults. I^2T protection is used for primary backup protection for both LG and LL events.
- Protection scheme based on telecommunication and modern protection relays or IEDS for micro-grid with C-DGs has been applied to MV feeder divided into four protection zones and between each zone a circuit breaker is installed which is controlled by IED.
- The IEDs are provided with voltage and current measurement, directional OC protection and these are connected with each other through high speed communication links.
- This method uses the voltage measurement for fault detection and current direction for fault location.
- The complete system selectivity and speed is obtained through transfer of fault direction and interlocking information between IEDs.

C. The Protection Schemes For Both Grid Connected and Islanded Mode

1) Differential Protection Scheme:

- Differential protection scheme using digital relays working on the principle of synchronized Phasor measurement for MV micro-grid including C-DGs and D-DGS.
- Instantaneous differential protection is used for primary protection and for backup protection adjacent relays are used in case of breaker failure.
- In case of relay failure, voltage protection is used as a tertiary protection. However, the proposed scheme is un economical to implement and assumes advanced technical features such as high performance relays and breakers, high sensitive current transformers, which are still not present.
- A protection scheme based on the principle of differential current and utilizing the traditional OC relay and communication link for micro-grid including C-DGs and D-DGs.

- This protection offers economical implementation, but not effective during unbalanced load.
- A differential protection scheme used for primary protection for MV micro-grid with C-DGs for grid connected and islanded mode of operation uses OC and under voltage based protection for backup protection in case of breaker failure.
- Current differential relays used for feeder and bus protection, while DGs are protected using under voltage, reverse power flow, over voltage.
- This scheme may suffer due to switching transients and unbalanced loads

2) Adaptive Protection Schemes:

- Adaptive protection scheme is based on the principle of network zoning which includes zoning of the feeders in such a way that each zone has appropriate balance of DG and load with DG capacity slightly larger than load.
- Each zone, at least largest DG is equipped with load frequency control capability. After zoning, fast operating switches are equipped with synchronization check relays and having capability to receive remote signals from substation breaker which are placed between each of two zones.
- A computer based relays are used, which having high processing power, large storage capacity, capability to communicate with zone breakers and DG relays which are installed at sub transmission substation.
- A computer based relays performs the online fault detection and isolate the faulty zone by tripping of appropriate zone breaker and DG connected to that zone

STORAGE

- Role of storage in smart grid
- When the sun is shining, solar cells produce a large amount of electricity that is then fed into the grid, where it needs to find consumers. However, if clouds appear, power output will drop suddenly.
- In general, the more fluctuating energy sources, such as sun and wind power, are connected to the grid, the more difficult it is to ensure grid stability.

Supply and demand have to be balanced at all times. If they are not, the resulting fluctuations in voltage and frequency can disrupt or even destroy electronic equipment.

- In view of this, it is clear that energy storage systems will become increasingly important in the future. Storage units take in surplus electricity that is not needed at a given time and then feed it back into the grid when demand rises.
- For decades now, efficient pumped-storage electrical power stations have been used for long-term storage needs.

- Different types of storage technologies
- BATTERIES
- SMES (SUPERCONDUCTING MAGNETIC ENERGY STORAGE)
- PUMPED HYDRO
- COMPRESSED AIR ENERGY STORAGE

BATTERIES

- "Battery systems connected to large solid-state converters have been used to stabilize power distribution networks".
- For example, in Rico a system with a capacity of 20 megawatts for 15 minutes (5 megawatt hour) is used to stabilize the frequency of electric power produced on the island.
- A 27 megawatt 15-minute (6.75 megawatt hour) nickel-cadmium battery bank was installed at Fairbanks Alaska in 2003 to stabilize voltage at the end of a long transmission line.
- Another possible technology for large-scale storage is the use of specialist large-scale batteries such as flow and liquid metal and Sodium-lon. Sodium-sulfur batteries could also be inexpensive to implement on a large scale and have been used for grid storage in Japan and in the United States.

- Battery storage power station
- A battery storage power plant is a form of storage power plant, which uses batteries on an electrochemical basis for energy storage.

– STORAGE CAPACITY- Unlike common storage power plants, such as the pumped storage power plants with capacities up to 1000 MW, the benefits of battery storage power plants move in the range of a few kW up to the low MW range.

- TYPES OF BATTERIES

– FLOW BATTERIES
– LIQUID METAL
– SODIUM ION
– LEAD ACID
– SODIUM-SULFUR
– Ni-Cd
– Al-ion
– Li-lon

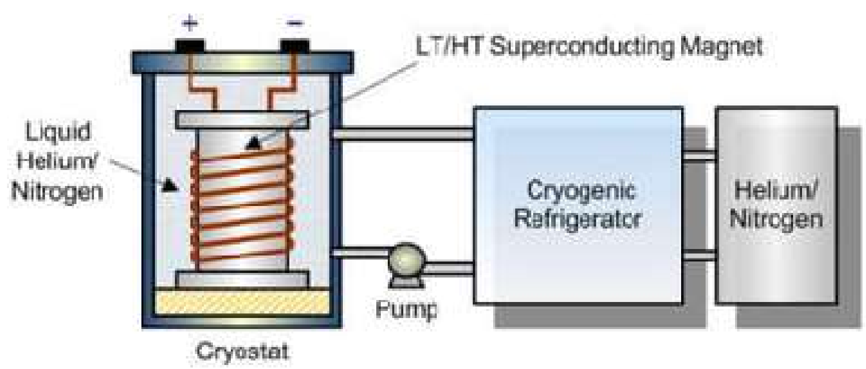
- Technology comparison for Grid-Level applications

Technology	Moving Parts	Operation at Room Temp	Flammable	Toxic Materials	In production	Rare metals
flow	Yes	Yes	No	Yes	No	No
liquid metal	No	No	Yes	No	No	No
Sodium-Ion	No	No	Yes	No	No	No
Lead-Acid	No	Yes	No	Yes	Yes	No
Sodium-sulfur batteries	No	No	No	Yes	Yes	No
Ni-Cd	No	Yes	No	Yes	Yes	Yes
Al-ion	No	Yes	No	No	No	No
Li-ion	No	Yes	Yes	No	Yes	No

SMES (SUPERCONDUCTING MAGNETIC ENERGY STORAGE)

– Superconducting Magnetic Energy Storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature.

- A typical SMES system includes three parts:
  - Superconducting coil,
  - Power conditioning system and
  - Cryogenically cooled refrigerator.
- Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. The stored energy can be released back to the network by discharging the coil.
- It store electrical energy in the magnetic field generated by Direct current flowing through a coiled wire.
- A SMES can recharge within minutes and can repeat the charge/discharge sequence thousands of times without any degradation of magnets.

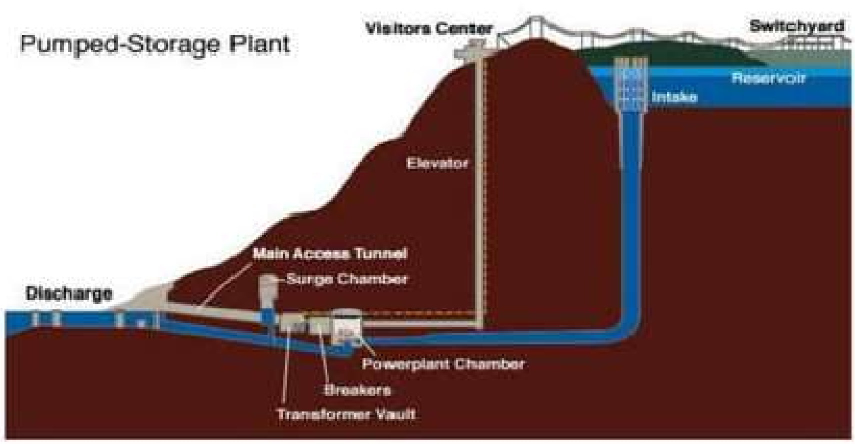


- **HOW IT WORKS?**
  - Store electric energy in magnetic field.
  - Superconductors have zero resistance to DC at low temperature.
  - Very low ohmic heat dissipation.
  - Energy stored is given by:

$$E = \frac{1}{2}LI^2$$

PUMPED HYDRO

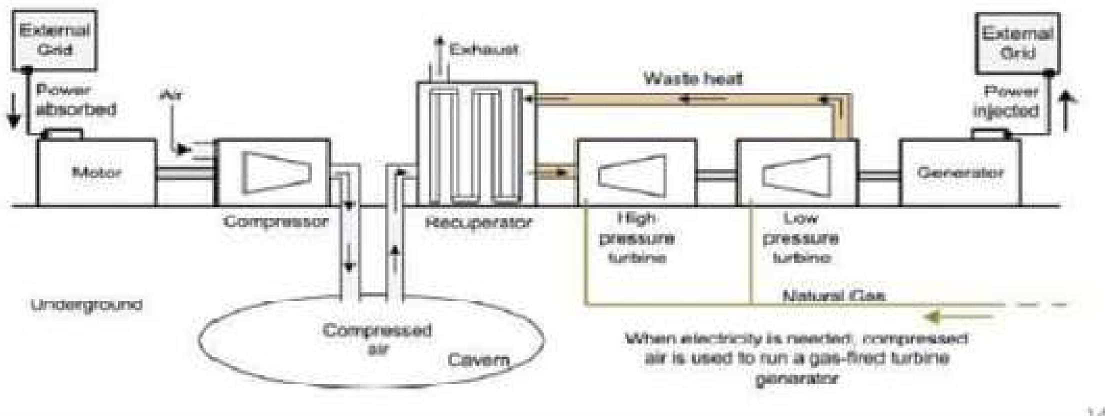
- Pumped-storage hydroelectricity (PSH), or Pumped Hydroelectric Energy Storage (PHES), is a type of hydroelectric energy storage used by electric power systems for load balancing. The method stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation.
- Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines to produce electric power. Although the losses of the pumping process makes the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest.
- Pumped storage is the largest-capacity form of grid energy storage available. At times of low electrical demand, excess generation capacity is used to pump water into the higher reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine, generating electricity. Reversible turbine/generator assemblies act as pump and turbine (usually a Francis turbine design)



COMPRESSED AIR ENERGY STORAGE

- Compressed air energy storage (CAES) is a way to store energy generated at one time for use at another time using compressed air.

- ➢ At utility scale, energy generated during periods of low energy demand (off-peak) can be released to meet higher demand (peak load) periods.
- ➢ Large scale applications must conserve the heat energy associated with compressing air; dissipating heat lowers the energy efficiency of the storage system.



- <u>WORKING</u>

– Compression of air creates heat; the air is warmer after compression. Expansion requires heat. If no extra heat is added, the air will be much colder after expansion. If the heat generated during compression can be stored and used during expansion, the efficiency of the storage improves considerably