PV POWER EVACUATION AND METERING FOR ROOFTOPS

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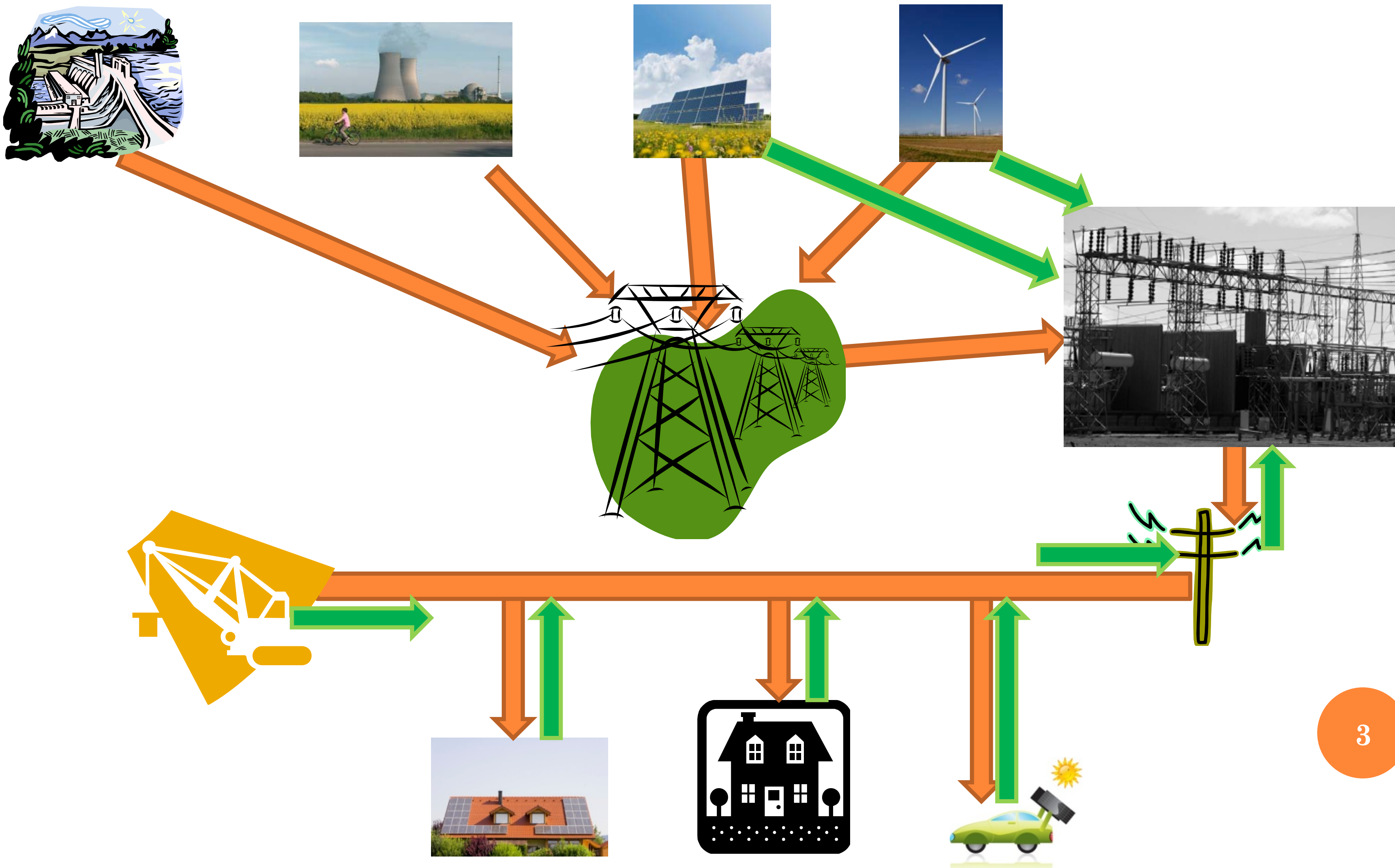
OUTLINE

- PV Power Evacuation
- Issues with Small PV Systems
- Power Management in Multiple Systems
- Net Metering
- Smart Metering

Modern Electricity System



POWER EVACUATION

- Stage wise power evacuation
  - Phase I, Phase II and …….Phase N
- Connecting the power plant to
  - Existing grid substation
  - Nearby substation of another Company/Industry
- Power evacuated under normal conditions
- Power evacuated during Contingency conditions.
- Power plant in the nearby location
- Clear understanding of power system planning in that area/utility
- Plan in sync with utility plans
- Feeder outages

Components of Power Evacuation

- Transformer
- Circuit breaker
- Current Transformer
- Potential Transformer
- Lightning Arrestors
- Cables & Conductors
- Isolator
- Energy Meter

Analysis of Load Flow Results

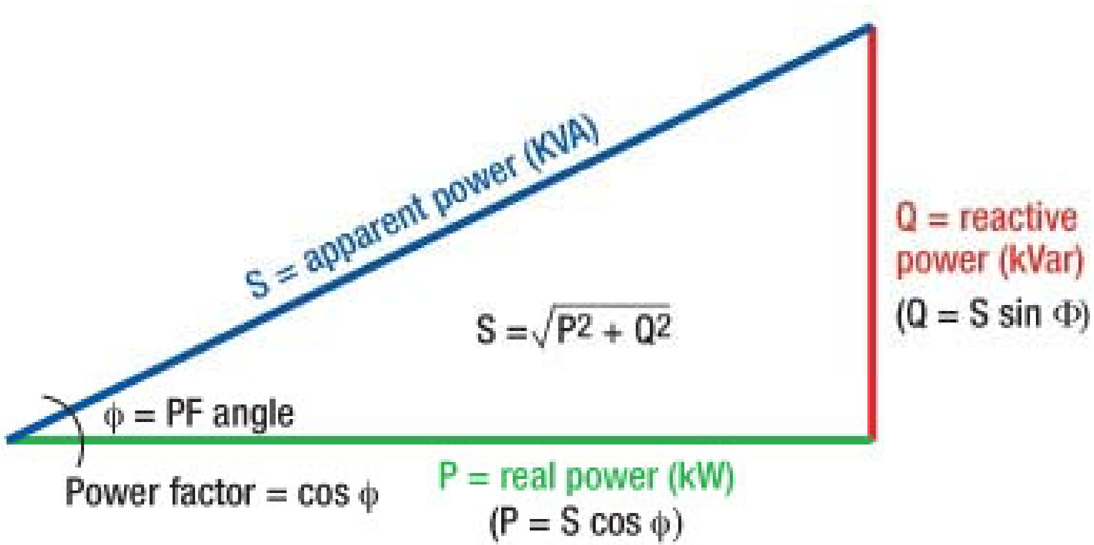
- Options for power evacuation
- Line over loadings because of power evacuation
- Line over loadings during contingency
- Possibility of Microgrids?

Issues with High Penetration of PV

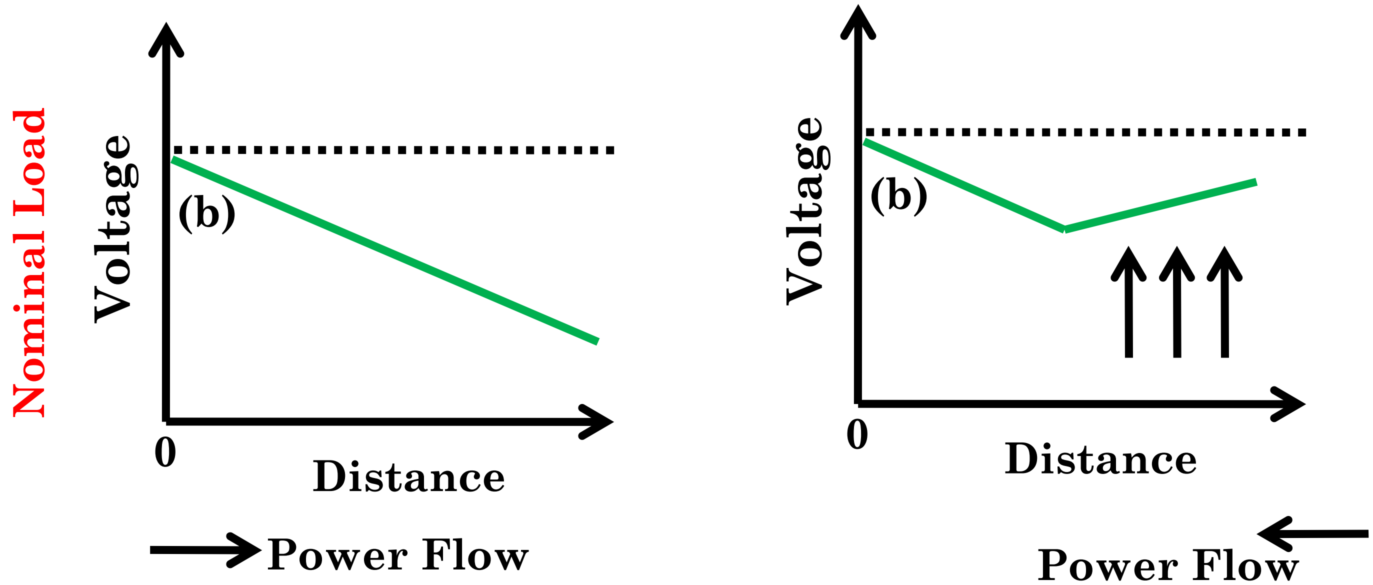
- Stability
- Safety
- Power Factor at Utility
- Local Voltage Rise
- Power Quality

Power Factor at Utility

- Reduction in Active power Supply from Utility
- Reduction in Power factor at Utility Terminal
- Lead to rise in current?

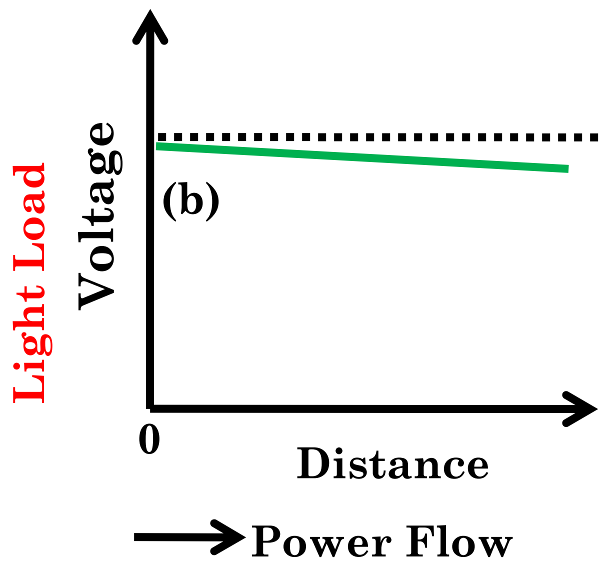


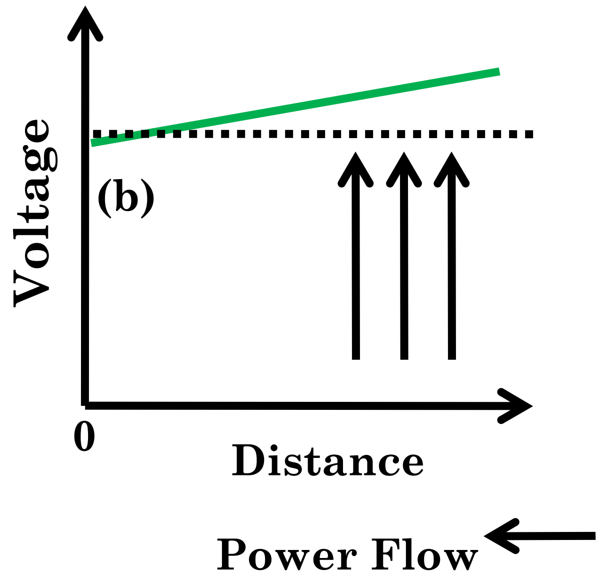
Low Voltage Rise in Distribution Network



- Steady stage voltage rise near inverter terminals
- Inverter continue to export power irrespective of terminal voltage
- Local voltage may exceed voltage level at transformer
  - Tripping of transformer
  - Damage to equipment connected

Low Voltage Rise in Distribution Network





- Degree of voltage rise is linked with impedance of the network
- Weak network (high impedance) → more voltage
  - Inverter may trip
  - Load may trip
  - Worse when system is lightly loaded

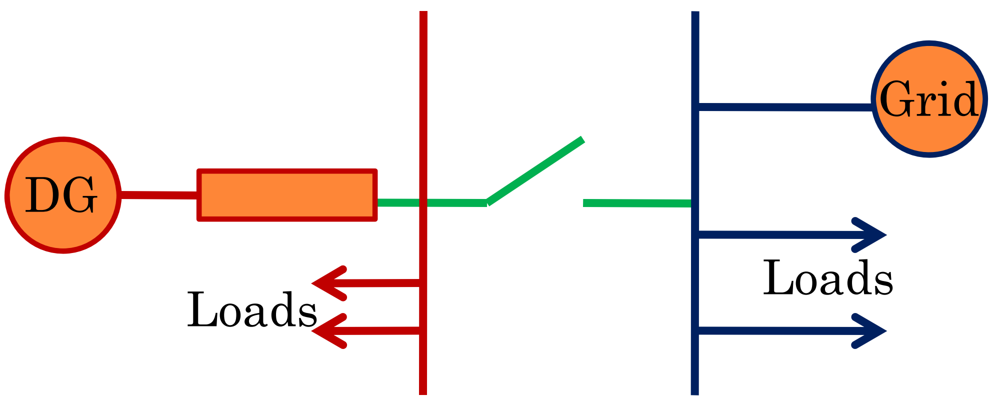
SYNCHRONIZATION

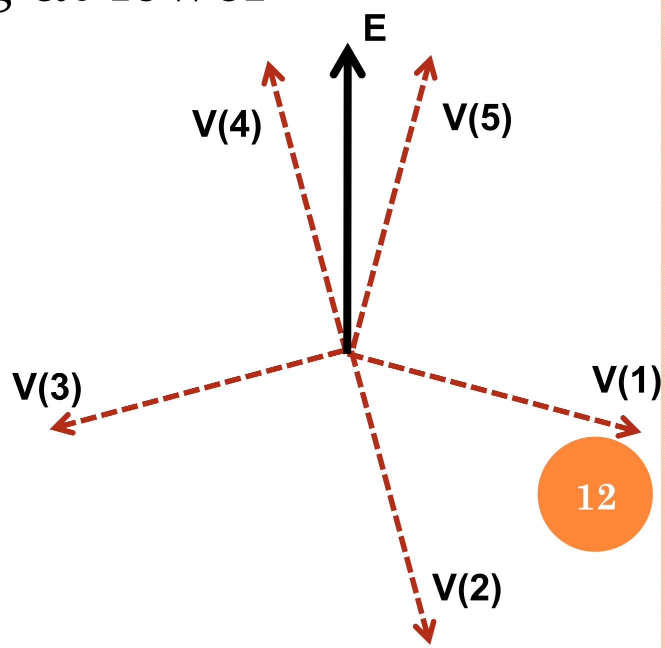
- Re/connection is made when the main grid and MG are synchronized at the PCC in terms of voltage, frequency and phase angle
- Limit values for synchronous interconnection between MG and main grid.

Total DG Rating (kVA)	ΔF (Hz)	(ΔV%)	Δø (^{0})
0-500	0.3	10	20
>500-1500	0.2	5	15
>1500-10,000	0.1	3	10

Synchronization

- Conditions for synchronization
  1. Voltage across the switch/contactor must be small
  2. The voltage with higher frequency shall lead the voltage with lower frequency.
- Power flow is always from unit operating at higher frequency to unit operating at lower frequency





POWER MANAGEMENT

Formation of Microgrids

POWER MANAGEMENT IN MICROGRIDS

- Grid connected systems
  - DG shall maintain a constant power output as the power mismatch are compensated by the main grid.
- Unit output power control
  - DG is constantly controlled to supply power according to the reference
  - Droop control (P-f) is employed
  - When the load increases, DG output power increases and frequency decreases
- Feeder flow control
  - The power in feeder is manipulated according to flow reference - Feeder droop control
  - When load increases during grid connected operation, the DGs increase output to maintain a constant feeder flow
  - Some of the DGs are excessively loaded during transition
- Mixed control
  - Combination of UPC anf FFC

DROOP CONTROL IN MICROGRIDS

- Power transfer between two nodes

$$P = \frac{VE}{X_s} \sin \delta \qquad Q = \frac{E}{X_s}(E - V \cos \delta)$$

- Real Power Vs Frequency droop Control

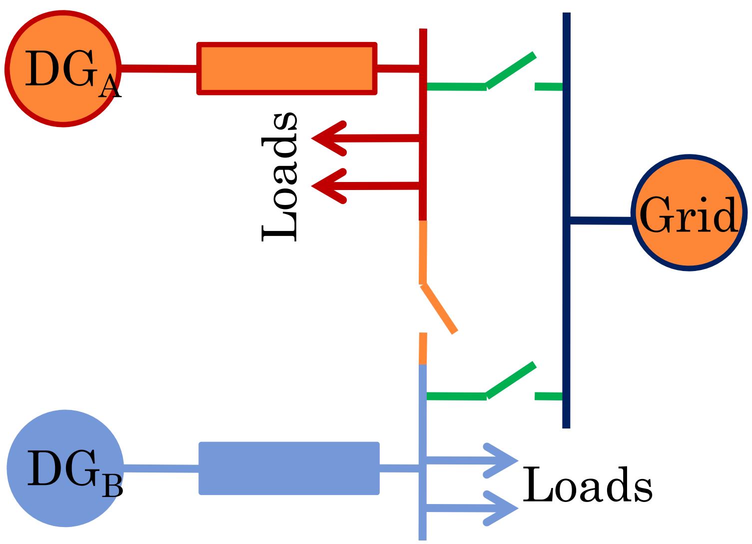
$$f - f_0 = -k_P(P - P_0)$$

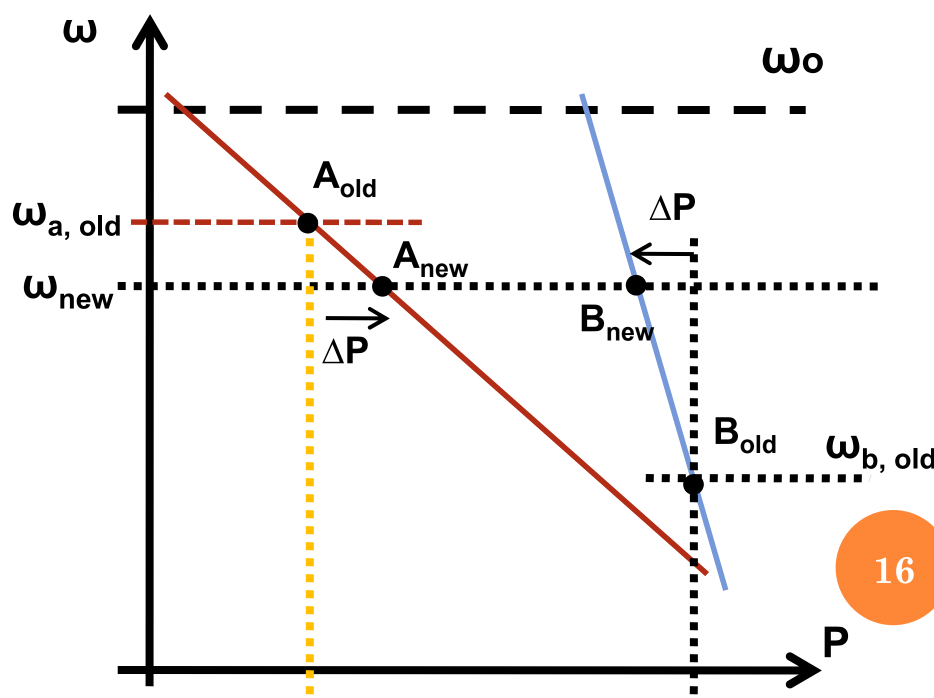
- Reactive Power Vs Voltage droop Control

$$V - V_0 = -k_q(Q - Q_0)$$

POWER SHARING IN DG'S

- At steady state, the active power flow is always from the source with higher frequency to the other with lower frequency, before the connection takes place.

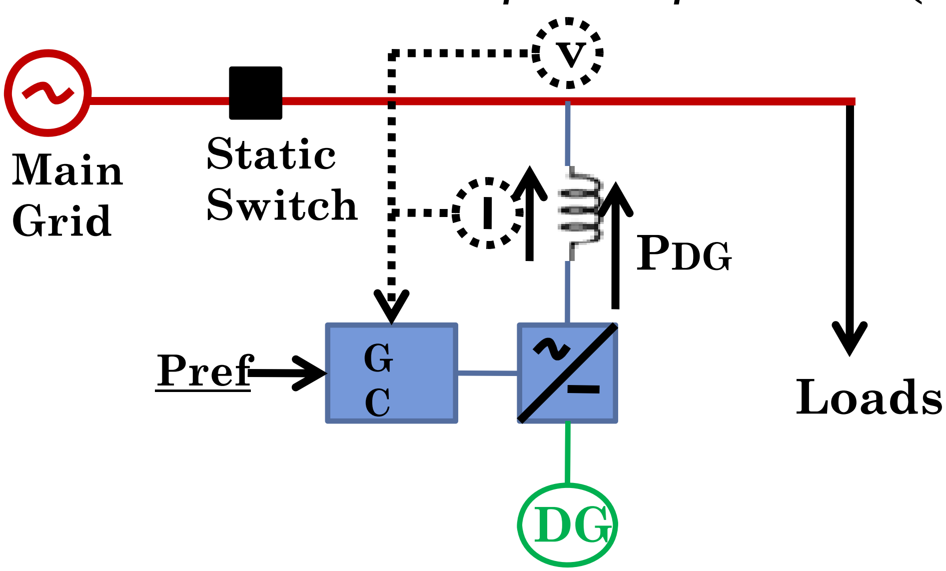


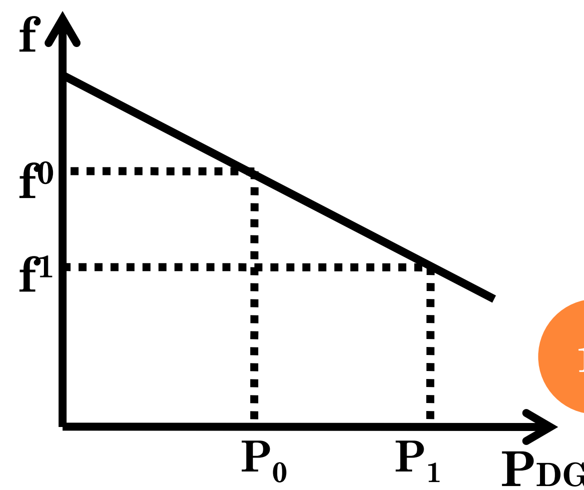


Unit Power output Control (UPC)

- The power injected by the DG is regulated to P_{ref}
- Power injection is calculated from V and I and fed back to the generator controller (GC)
- In autonomous mode, the DG follows (P-f) droop curve to maintain load balance

$$f^{new} = f^{old} - K^{U}(P^{new} - P^{old})$$

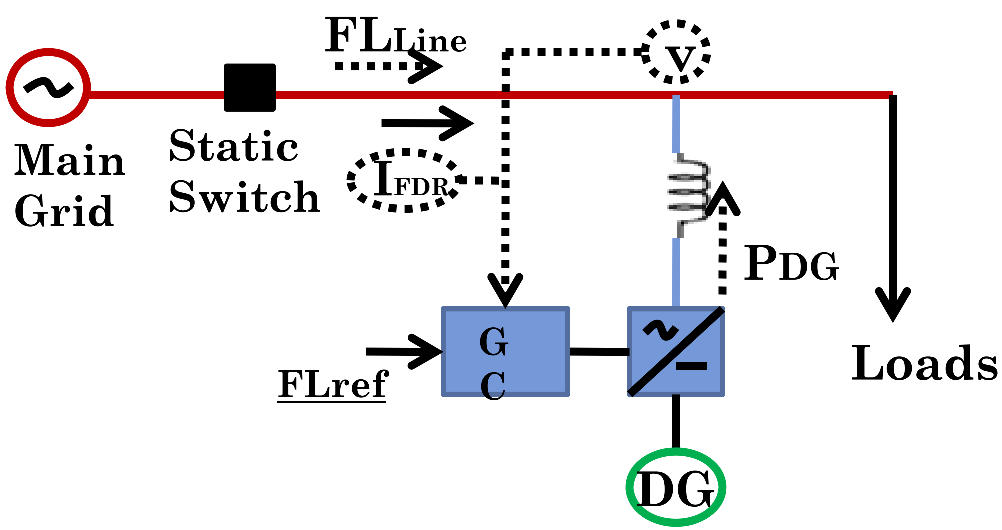


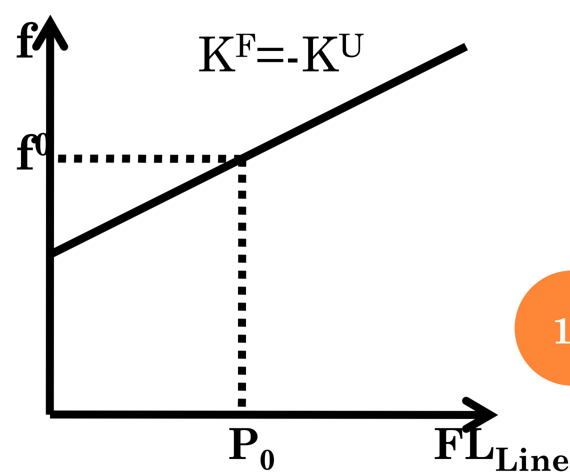


Feeder Flow Control (FFC)

- DG output is controlled to maintain active power flow in the feeder (FL_{line}) constant, irrespective of changes in load
- Microgrid resembles a controllable load from utility point of view.
- In autonomous mode: Flow versus frequency droop characteristic is used:

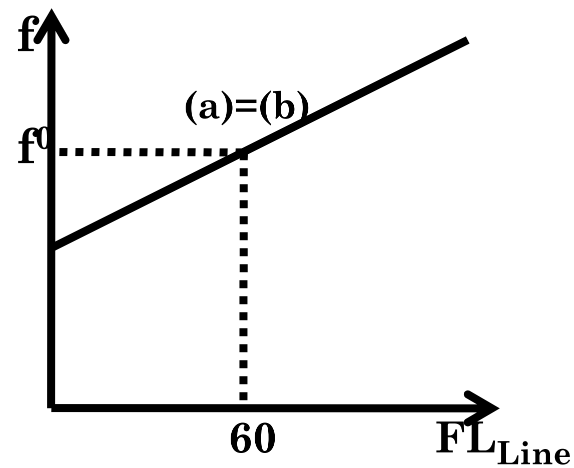
$$f^{new} = f^{old} - K^F (FL^{new} - FL^{old})$$

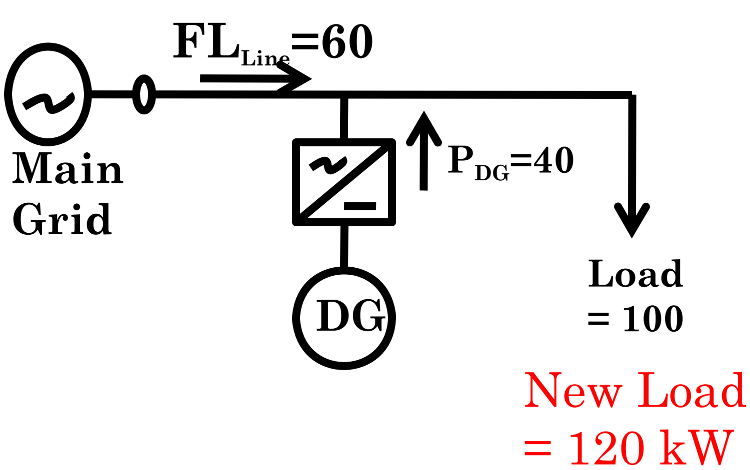


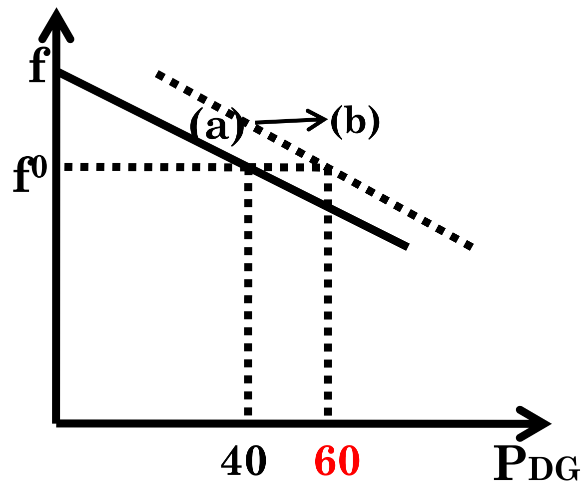


Case A: Load increase - Grid Connected System

- The feeder flow shall remain constant
- The generator (DG) increases its output to cater to the new load requirements

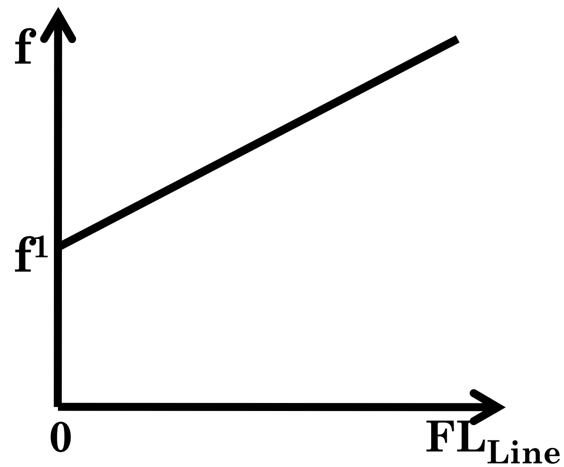


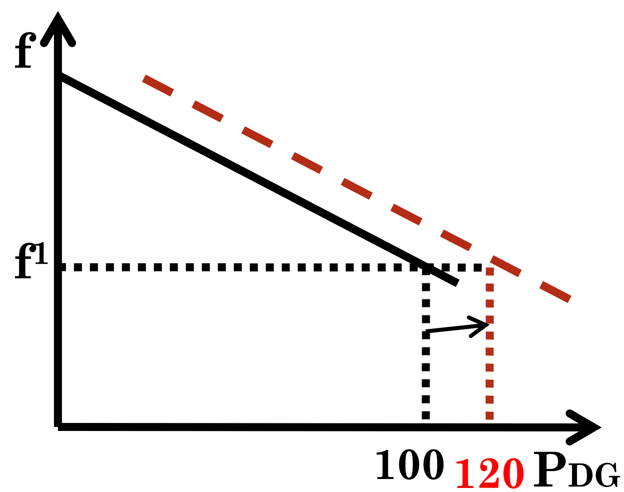


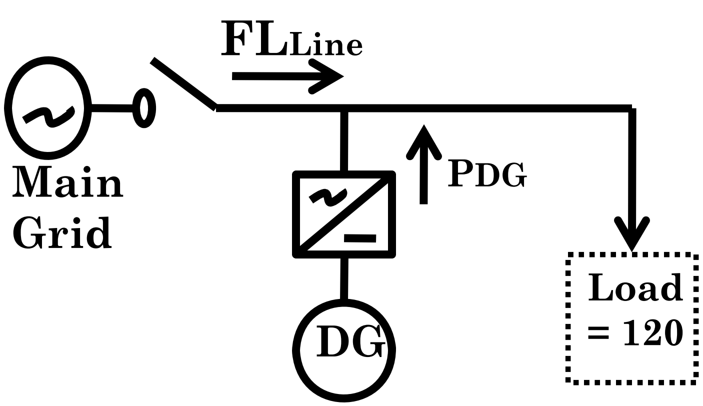


Case B: Isolated System – Load Increases

- During isolated system, frequency changes only if DG cannot maintain feeder flow.
- Feeder flow is Zero, in the case of FFC

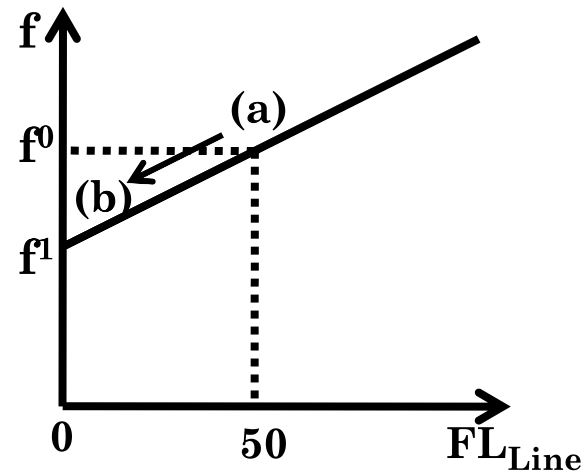


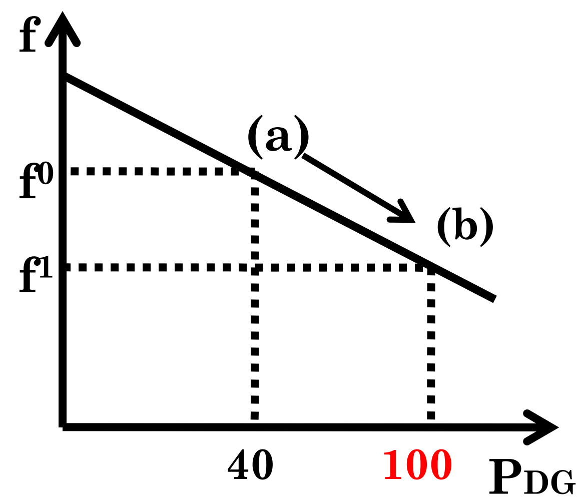


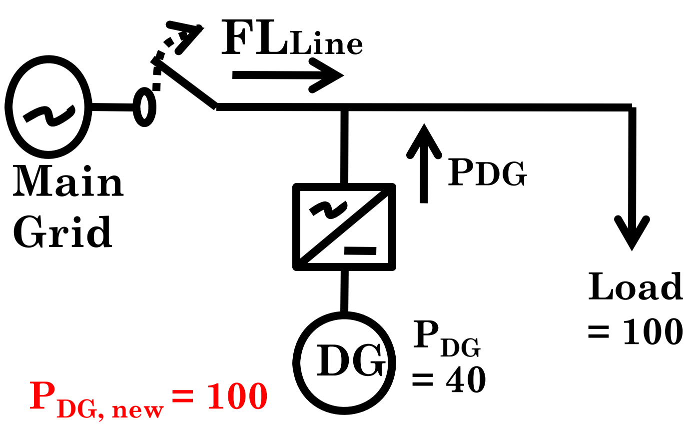


CASE C: LOSS OF MAINS

- The feeder flow is zero at this new condition and hence power flow measured by DG is Zero.
- DG increases its output from 40 kW to 100 kW to compensate the decreased feeder flow







Net Metering

- It is a electricity policy for consumers who own renewable energy facilities or V2G electric vehicles.
- Net = What remains after deductions
- Demand Response
- PV Inverter for reactive power

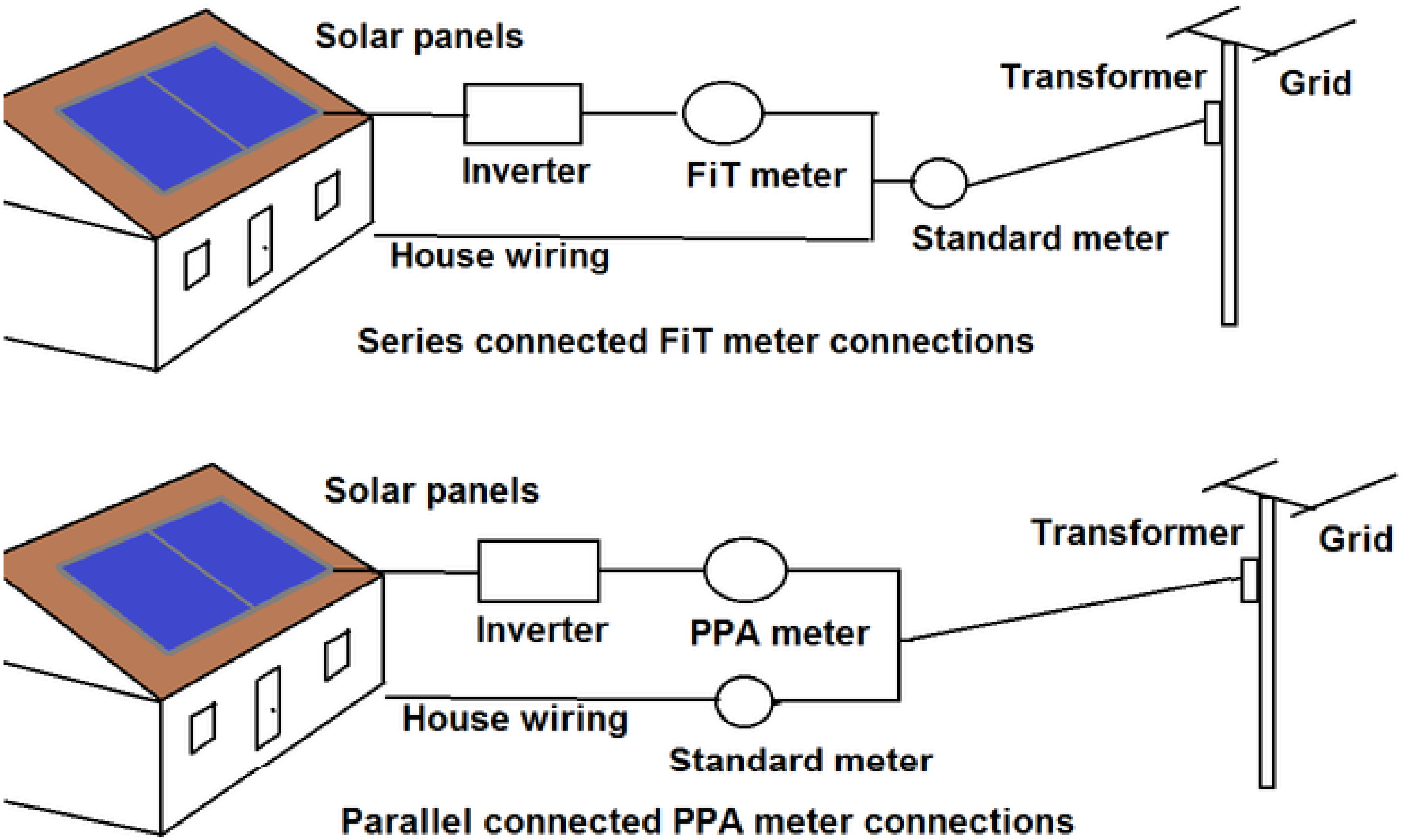
support using smart PV inverters

Source: http://en.wikipedia.org/

Net Metering

- Net metering is an electricity policy for consumers who own small to medium sized renewable energy facilities such as wind, solar power or home fuel cells.
- Metering the net power consumed or supplied a consumer.
- The meters also have ability to record imported or exported power with time stamping to facilitate DISCOMs to calculate monthly electricity bill as per TOU tariff.

Net Metering - Options



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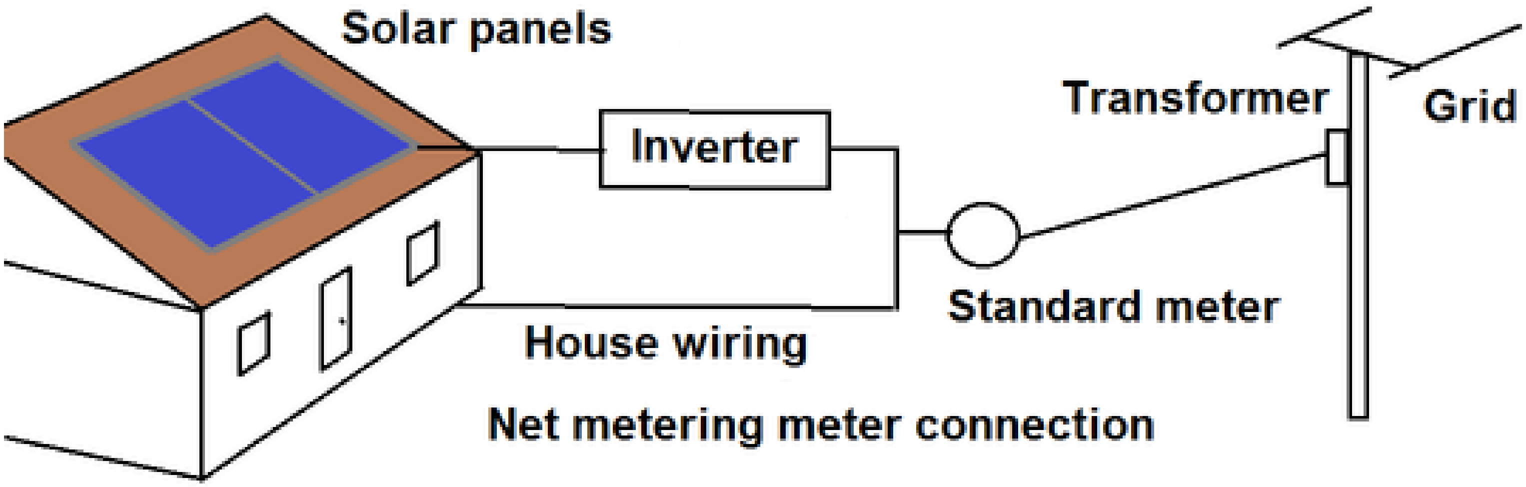
Net Metering - Options



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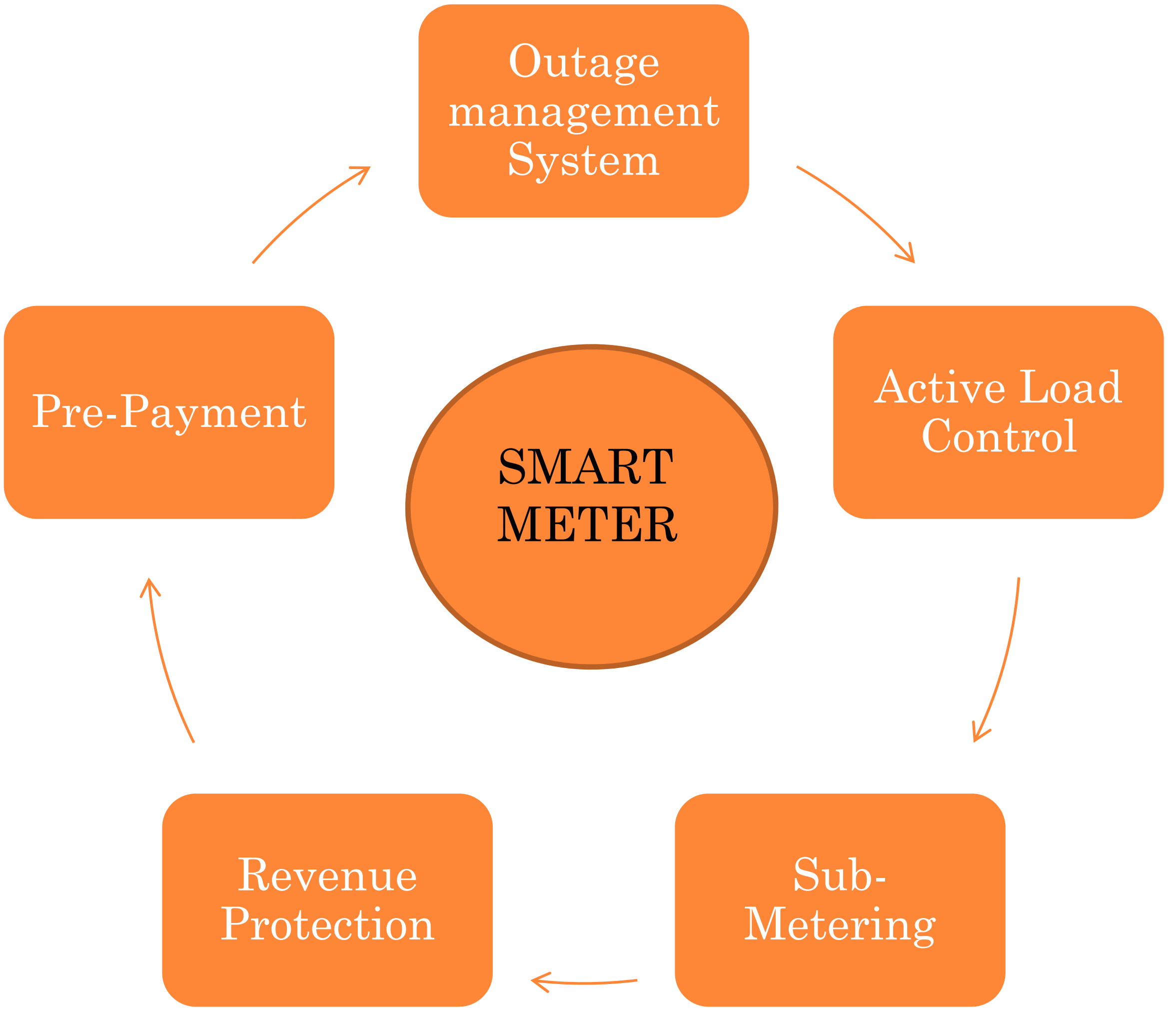
Smart Metering

Advanced Metering Infrastructure

Automated Metering Infrastructure- Smart Meters

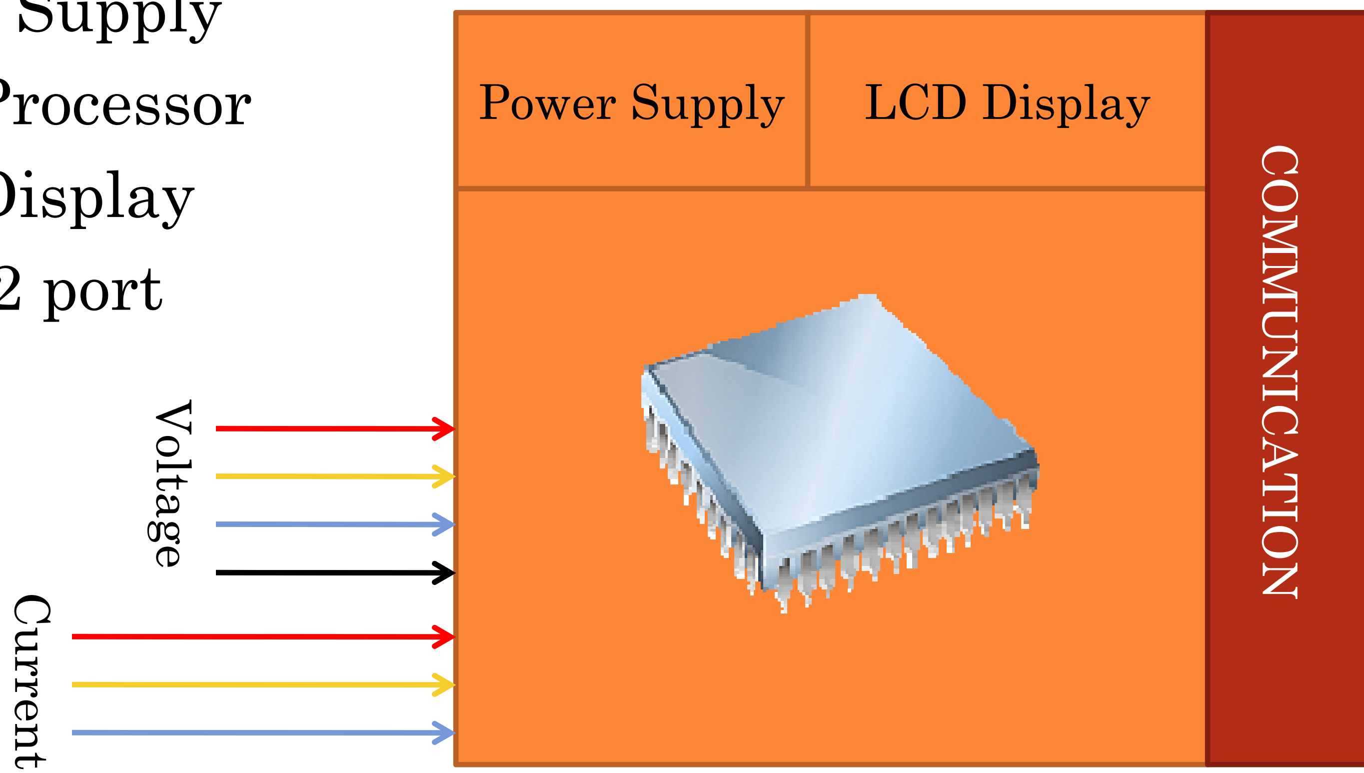


Smart Metering

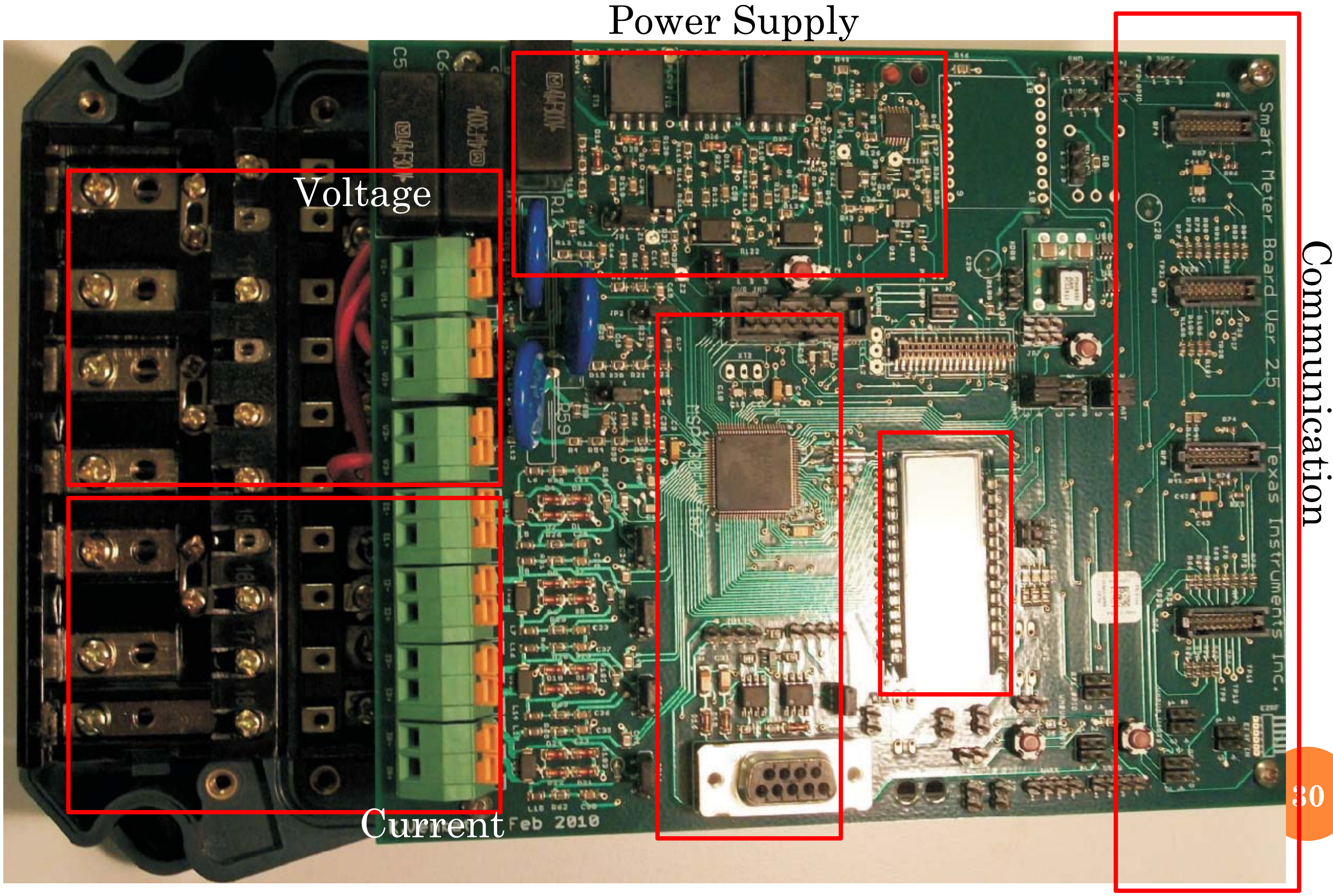
- Digitally capture or record when power is consumed/produced
- Two way communication
  - Transmit the information to a central server
  - Receive commands/information from central server and take appropriate action.
- Control

Functional Components

- Voltage and Current Inputs
- Communication modules
  - Zigbee, RF, PLCC, GSM/GPRS etc.
- Power Supply
- Core Processor
- LCD Display
- RS 232 port

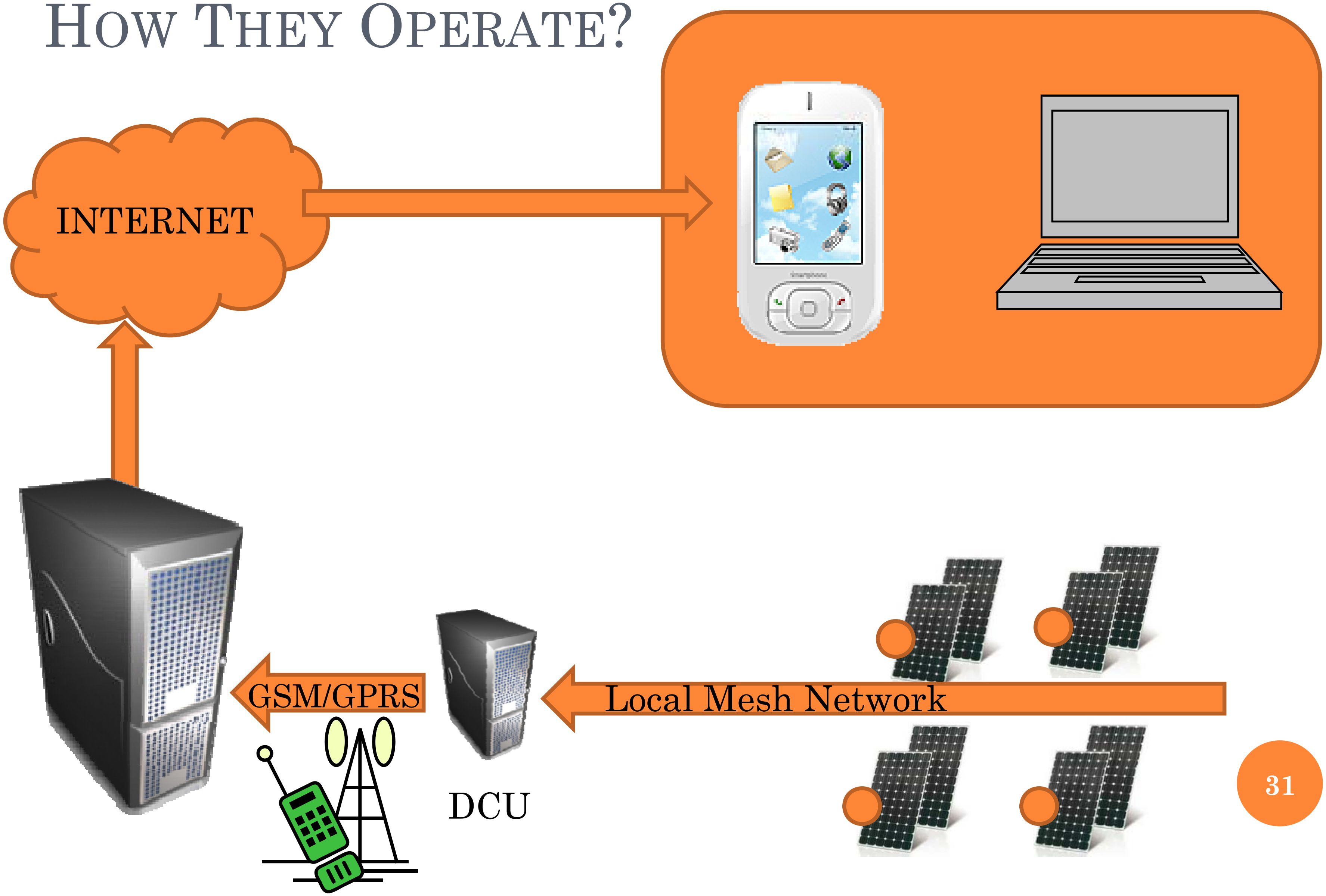


Components

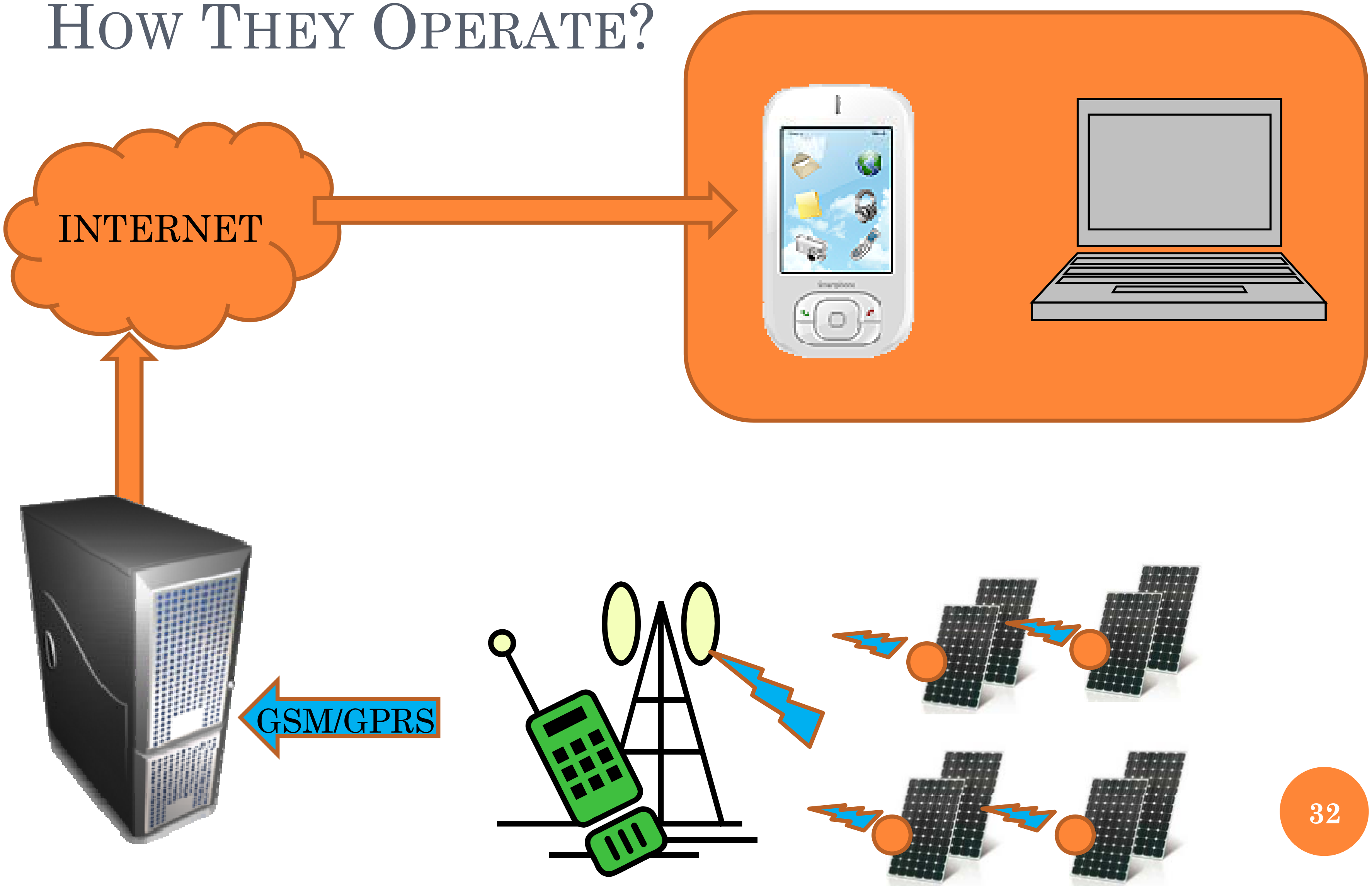


Source: http://www.ti.com/

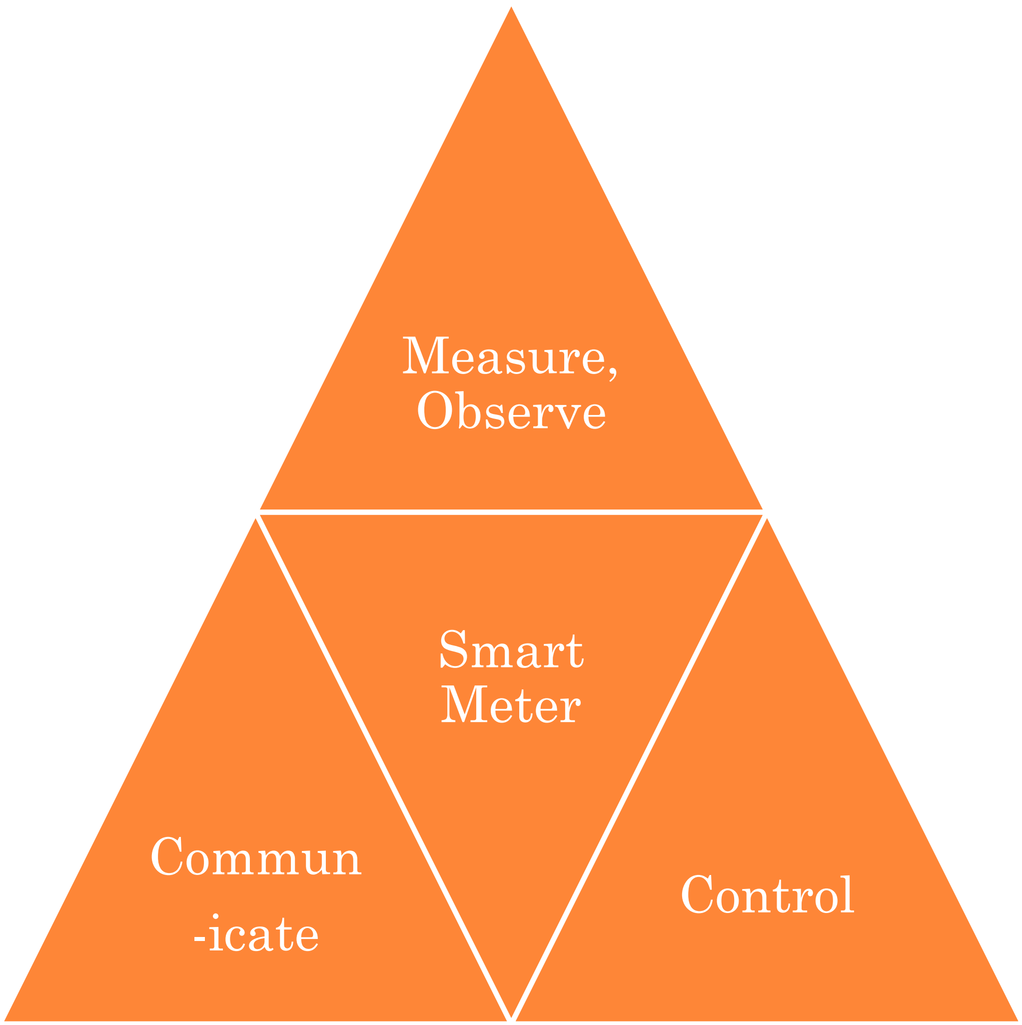
How They Operate?



How They Operate?



TASKS



TASKS

- Measure, Observe & Display
  - Three Phase voltages
  - Three Phase currents
  - Power factor
  - Power flow direction
  - Outages
  - Theft
  - Maximum demand information
  - Tariff rate information
  - Total money/kWh spent/earned
  - Carbon credits
  - Time of use tariff

Communication- Possible Options

- Direct GSM/GPRS
  - Low density Area
- Local mesh (zigbee) and GPRS
  - High density Area
- Local mesh (RF) and GPRS
  - High Density Area
- Local mesh (PLC) and GPRS
  - High Density Area

CONTROL

- Connect/disconnect in case of pre-paid type meters
- Disconnect in case of
  - Power theft
  - Tampering
- Any other control requirement as per utility

What makes it SMART?

Conventional Meter	Smart Meter
Only electricity consumption (kWh)	Voltage, Hourly kWh data, power quality measurements
No communication capability	Integrated two-way communication between the utility and meter
No outage detection	Automated outage detection and notification
No tamper detection	Automated meter tamper alarms
Manual on-site meter reading Manual meter connects and disconnects	Remote meter connect and disconnects Automated and on-demand meter readings
Consumption feedback and cost estimate is done after every month (typical reading time)	Real time feedback provided to customer

THANK YOU

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REFERENCES

- http://www.bchydro.com/energy_in_bc/projects/smart_metering_infrastructure_program/smart_meter_and_grid_technology/smart_meters_smart.html
- http://en.wikipedia.org/
- Report: Cost Effective AMI Framework CEA, India-2011.
- http://www.ti.com/lit/an/slaa467/slaa467.pdf
- S. J. Ahn, J. W. Park, I. Y. Chung, S. I. Moon, S. H. Kang and S. R. Nam, "Power-sharing method of multiple distributed generators considering control modes and configurations of a microgrid", *IEEE Transactions on Power Delivery*, 25(3), July 2010, pp. 2007-2015.
- Kroposki et.al, "Making microgrids work", IEEE Power Magazine, Vol. 6, 2008, pp. 40-53