Smart Grid Technologies and Applications

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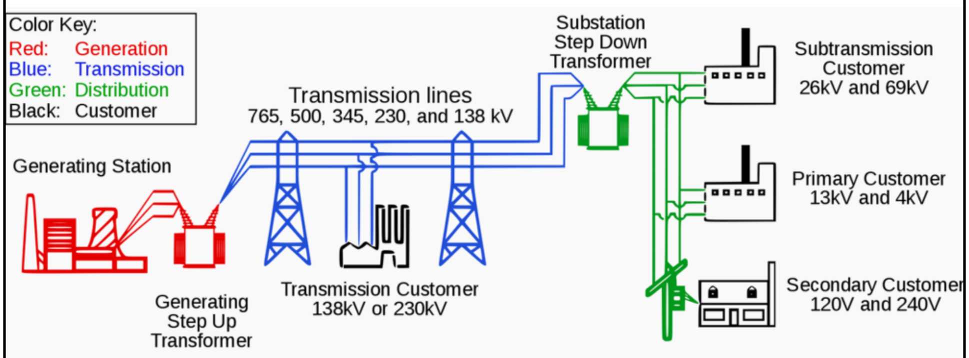
Outline

- Electric Power System
- Electric Power Grid: past, present, future
- What is a Smartgrid?, Why?
- Traditional Grid vs Smart Grid
- Rationale for the smartgrid
- What is a Microgrid?
- Microgrid Architecture
- Component of Microgrid
- Application of Microgrid
- Classification of Microgrid
- Microgrid Operating Modes
- Requirement for ESSs in Microgrids
- Advantages & Disadvantages of Microgrid
- Future Directions on Microgrid Research
- Sample Microgrid Configuration: Case Study

Here is the outline of my presentation.

Electric Power System



From a general perspective, an electric power system is usually understood as a very large network that links power plants (large or small) to loads, by means of an electric grid that may span a whole continent, such as Europe or North America. A power system thus typically extends from a power plant right up to the sockets inside customers' premises. These are sometimes referred to as full power systems as they are autonomous.

Smaller power systems could be made of part or sections of a larger, full system.

Electric Power System
Central Generation

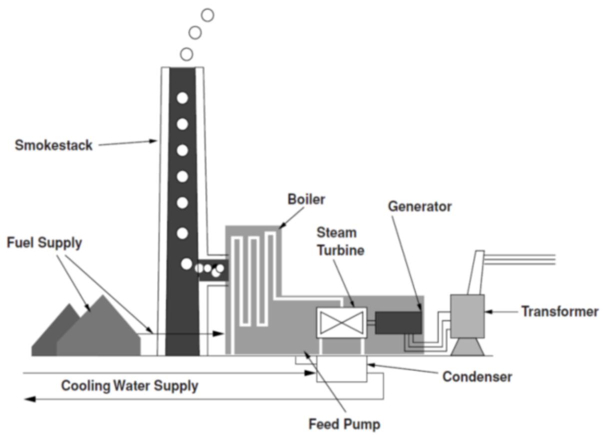


Figure 1.4 Cartoon of a fossil fired power plant

Power plants convert the energy stored in the fuel (mainly coal, oil, natural gas, enriched uranium) or renewable energies (water, wind, solar) into electric energy. Conventional modern generators produce electricity at a frequency that is a multiple of the rotation speed of the machine. **Voltage is usually no more than 6 to 40 kV.** The power output is determined by the amount of steam driving the turbine, which depends mainly on the boiler. The voltage of that power is determined by the current in the rotating winding (i.e., the rotor) of the synchronous generator.
The output is taken from the fixed winding (i.e., the stator). The voltage is stepped up by a transformer, normally to a much higher voltage. At that high voltage, the generator connects to the grid in a substation.

Electric Power System
Central Generation

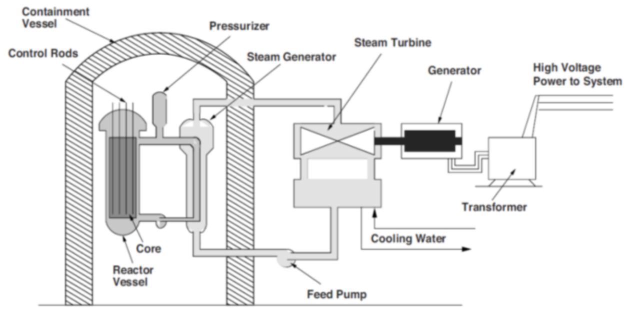


Figure 1.5 Cartoon of a nuclear power plant

Central Generation or CG is the electric power production by central station power plants that provide bulk power. Most of them use large fossil-fired gas or coal boilers, or nuclear boilers to produce steam that drives turbine generators. In some cases, large hydro is also used. These enormous plants require costly management of large infrastructures. CG plants are susceptible to unreliability and instability under unforeseeable events, and are often vulnerable to attacks. Their limitations, in terms of efficiency and environmental impact as well as stability to sustain them, have given rise to renewable energy resource options for researchers and policy-makers.

Electric Power System
Central Generation

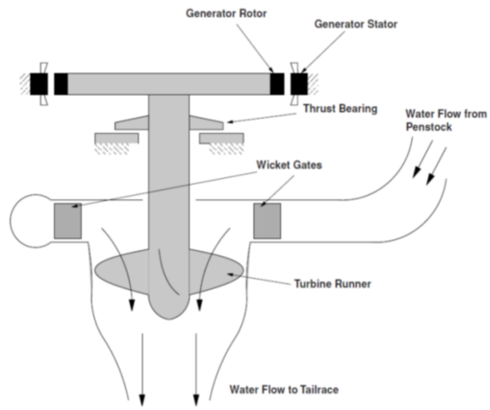
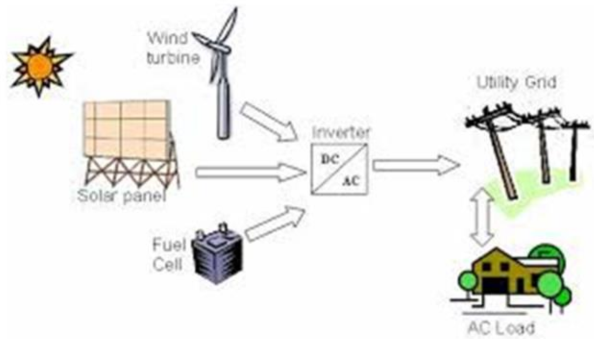


Figure 1.6 Cartoon of a hydroelectric generating unit

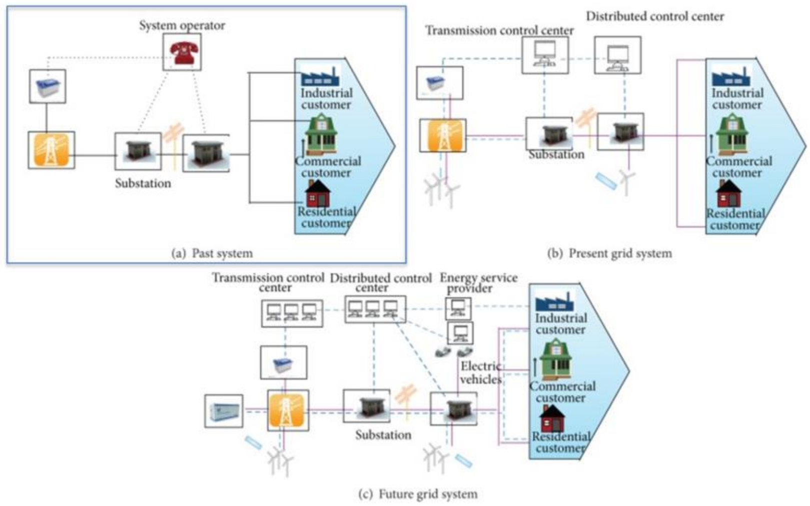
Central Generation or CG is the electric power production by central station power plants that provide bulk power. Most of them use large fossil-fired gas or coal boilers, or nuclear boilers to produce steam that drives turbine generators. In some cases, large hydro is also used. These enormous plants require costly management of large infrastructures. CG plants are susceptible to unreliability and instability under unforeseeable events, and are often vulnerable to attacks. Their limitations, in terms of efficiency and environmental impact as well as stability to sustain them, have given rise to renewable energy resource options for researchers and policy-makers.

Electric Power System Distributed Generation



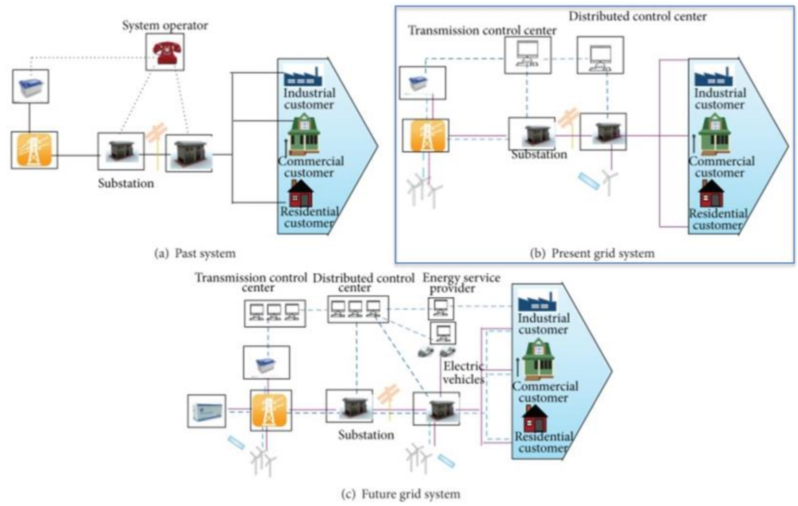
DG is not a new concept. A number of utility consumers have been using DG for decades. Over the last 10 years, the DG market has been somewhat turbulent. In the late 1990s, new regulations/subsidies, such as net metering and renewable portfolio requirements, and the development of new DG technologies, have sparked broader interests in distributed generation. DG is power generation built near consumers. DG sources include small-scale, environmentally-friendly technologies (e.g., photovoltaic and wind) installed on and designed primarily to serve a single end user's site. But when reliability and power quality issues are critical, DG most often includes more traditional fossil fuel fired reciprocating engines or gas turbines.

Electric Power Grid: past, present, future



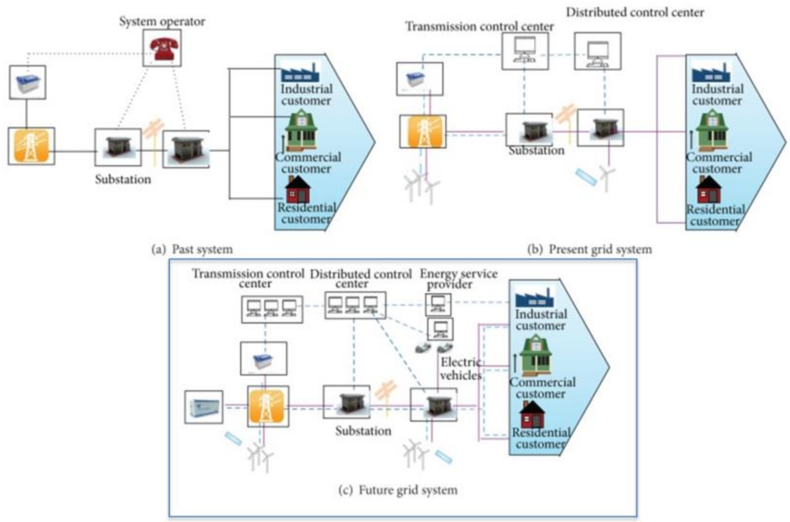
The limited generation in the power sector has continually been exacerbated by load growth, power demand, limitations in the ability to site new transmission lines, limitations in the ability to construct large scale generation due to increased environmental regulation, and lack of technology development to meet the new requirements. Manpower is required to achieve the development of a sustainable, secured, and economically-viable society and infrastructure. The growth in developed and developing countries has created an energy divide in terms of wealth. The major disparities of energy consumption per capita are reflected in developing countries. The universal electrification challenge to meet the world's population growth in order to attain its current per capita electricity consumption will require massive increases in electricity generation capacities.

Electric Power Grid: past, present, future



In some cases, properly planned and operated DG can provide consumers, as well as society, with a wide variety of benefits. These include economic savings because of government subsidies and improved environmental performance. Many utilities have installed DG on their systems and support federal funding of research to develop new technologies. The interconnection of DG with the electric grid continues to pose genuine safety and reliability risks for the utility. DG could reduce the demand for traditional utility services. DG also poses an economic risk to incumbent utilities and their consumers unless appropriate rate structures or cost recovery mechanisms are put into place.

Electric Power Grid: past, present, future



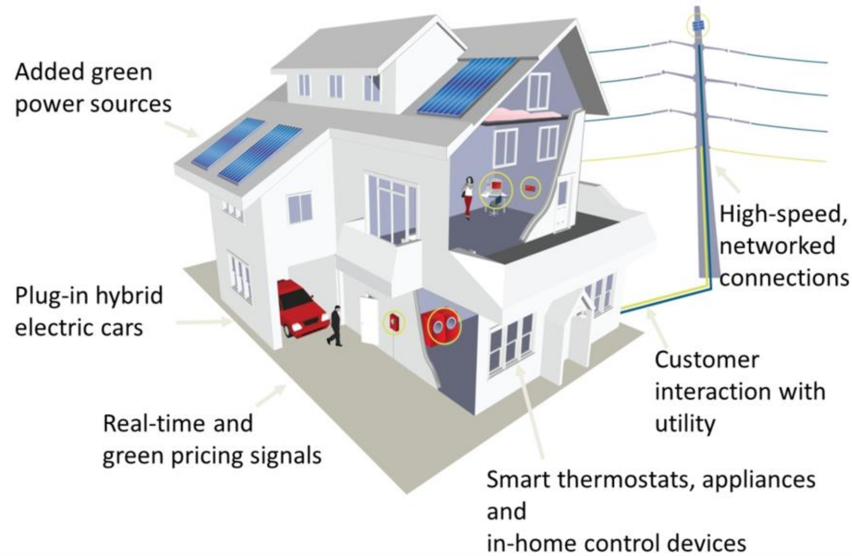
Though a small scale power plant, DG is environmentally friendly due to its "friendly" technologies. These "friendly" technologies include: photovoltaic's (PV), fuel cells, small wind turbines, or more conventional technologies such as: micro turbines and reciprocating engines that are fueled by renewable fuels, for instance, landfill gas. DG encompasses generation built near to a consumer's load despite size or energy source. The latter definition could include diesel-fired generators with significant emissions.

What is the Smart Grid?

An application of digital information technology to optimize electrical power generation, delivery and use

- Optimize power delivery and generation
- Self-healing
- Consumer participation
- Resist attack
- High quality power
- Accommodate generation options

What is Smart Grid?



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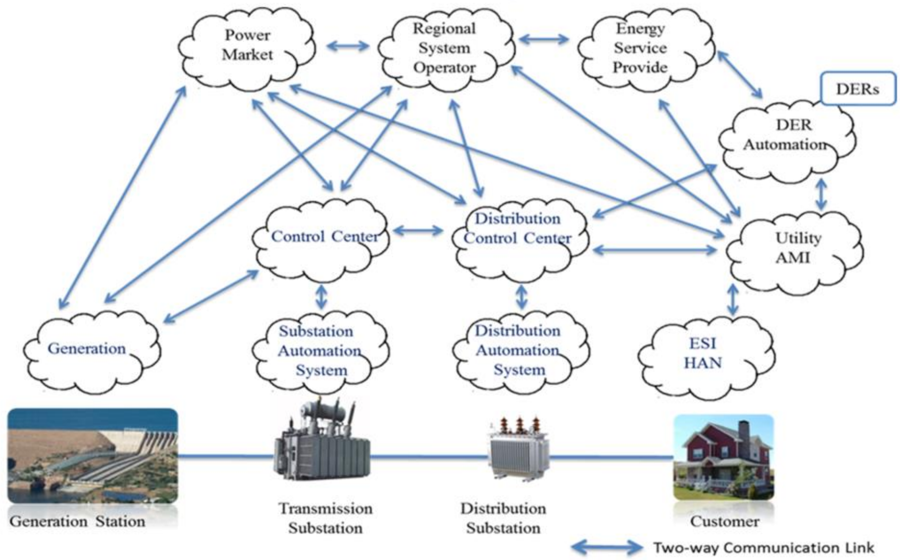
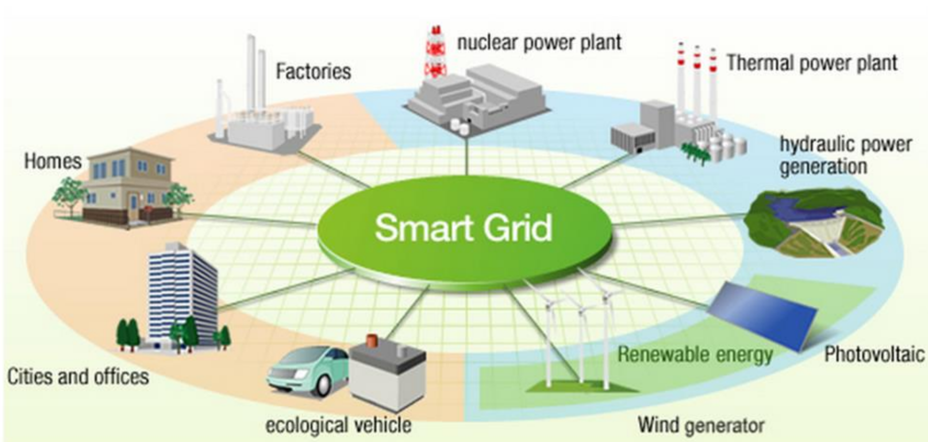


What is the Smart Grid?



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Why Smart Grid ?

- Better situational awareness and operator assistance
- Autonomous control actions
- Efficiency enhancement
- Integration of renewable sources
- Improved market efficiency through innovative solutions for product types
- Higher quality of service

Current Grid vs Smart Grid

Characteristics	Traditional Power grid	Smart Grid
Distribution	**One-Way Distribution:** Power can only be distributed from the main plant using traditional energy infrastructure.	**Two-Way Distribution:** While power is still distributed from the primary power plant, in a smart grid system, power can also go back up the lines to the main plant from a secondary provider. An individual with access to alternative energy sources, such as solar panels, can actually put energy back on to the grid.

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Current Grid vs Smart Grid

Characteristics	Traditional Power grid	Smart Grid
Technology	**Electromechanical:** Traditional energy infrastructure is electromechanical. This means that it is of, relating to, or denoting a mechanical device that is electrically operated. The technology of this manner is typically considered to be "dumb" as it has no means of communication between devices and little internal regulation.	**Digital:** The smart grid employs digital technology allowing for increased communication between devices and facilitating remote control and self-regulation.

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Current Grid vs Smart Grid

Characteristics	Traditional Power grid	Smart Grid
Generation	**Centralized:** With traditional energy infrastructure, all power must be generated from a central location. This eliminates the possibility of easily incorporating alternative energy sources into the grid.	**Distributed:** Using smart grid infrastructure, power can be distributed from multiple plants and substations to aid in balancing the load, decrease peak time strains, and limit the number of power outages.

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Current Grid vs Smart Grid

Characteristics	Traditional Power grid	Smart Grid
Sensors	**Few Sensors:** The infrastructure is not equipped to handle many sensors on the lines. This makes it difficult to pinpoint the location of a problem and can result in longer downtimes.	**Sensors Throughout:** In a smart grid infrastructure system, there are multiple sensors placed on the lines. This helps to pinpoint the location of a problem and can help reroute power to where it is needed while limiting the areas affected by the downtime.

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Current Grid vs Smart Grid

Characteristics	Traditional Power grid	Smart Grid
Monitoring	**Manual:** Due to limitations in traditional infrastructure, energy distribution must be monitored manually.	**Self:** The smart grid can monitor itself using digital technology. This allows it to balance power loads, troubleshoot outages, and manage distribution without the need for direct intervention from a technician.

Current Grid vs Smart Grid

Characteristics	Traditional Power grid	Smart Grid
Restoration	**Manual:** In order to make repairs on traditional energy infrastructure, technicians have to physically go to the location of the failure to make repairs. The need for this can extend the amount of time that outages occur.	**Self-Healing:** Sensors can detect problems on the line and work to do simple troubleshooting and repairs without intervention. For problems related to infrastructure damage, the smart grid can immediately report to technicians at the monitoring center to begin the necessary repairs.

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Current Grid vs Smart Grid

Characteristics	Traditional Power grid	Smart Grid
Equipment	**Failure & Blackout:** As a result of aging and limitations, traditional energy infrastructure is prone to failures. Failure of infrastructure can lead to blackouts, a condition where the end customer is receiving no power to their unit causing downtime.	**Adaptive & Islanding:** Using a smart grid system, power can be rerouted to go around any problem areas. This limits the area impacted by power outages and can do it on a per residence level.

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Current Grid vs Smart Grid

Characteristics	Traditional Power grid	Smart Grid
Control	**Limited:** Using traditional power infrastructure, energy is very difficult to control. After leaving the power plant or substation, companies have no control over the energy distribution.	**Pervasive:** With the increased amount of sensors and other smart infrastructure, energy companies have more control than ever over power distribution. Energy and energy consumption can be monitored all the way down the line; from the moment it leaves the power plant, all the way to the consumer.

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Current Grid vs Smart Grid

Characteristics	Traditional Power grid	Smart Grid
Customer Choices	**Fewer:** The traditional power grid system infrastructure is not properly equipped to give customers a choice in the way they receive their electricity. Alternative energy sources, for example, have to be separated from power plants and traditional grid infrastructure. This is also part of the reasoning behind the establishment of electric companies as a public utility.	**Many:** Using smart technologies, infrastructure can be shared. This allows more companies and forms of alternative energy to come on to the grid allowing consumers to have more choice in how they receive energy.

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Preferred Characteristics	Today's Grid	Smart Grid
Active Consumer Participation	Consumers are uninformed and do not participate	Informed, involved consumers—demand response and distributed energy resources
Accommodation of all generation and storage options	Dominated by central generation—many obstacles exist for distributed energy resources interconnection	Many distributed energy resources with plug-and-play convenience focus on renewables
New products, services, and markets	Limited, poorly integrated wholesale markets; limited opportunities for consumers	Mature, well-integrated wholesale markets; growth of new electricity markets for consumers
Provision of power quality for the digital economy	Focus on outages—slow response to power quality issues	Power quality a priority with a variety of quality/price options—rapid resolution of issues
Optimization of assets and operates efficiently	Little integration of operational data with asset management—business process silos	Greatly expanded data acquisition of grid parameters; focus on prevention, minimizing impact to consumers
Anticipating responses to system disturbances (self-healing)	Responds to prevent further damage; focus on protecting assets following a fault	Automatically detects and responds to problems; focus on prevention, minimizing impact to consumers
Resiliency against cyber attack and natural disasters	Vulnerable to malicious acts of terror and natural disasters; slow response	Resilient to cyber attack and natural disasters; rapid restoration capabilities

Rationale for the Smart Grid

- Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services options.
- Provision to consumers of timely information and control options.
- Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.
- Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.
- Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric vehicles, and thermal-storage air conditioning.

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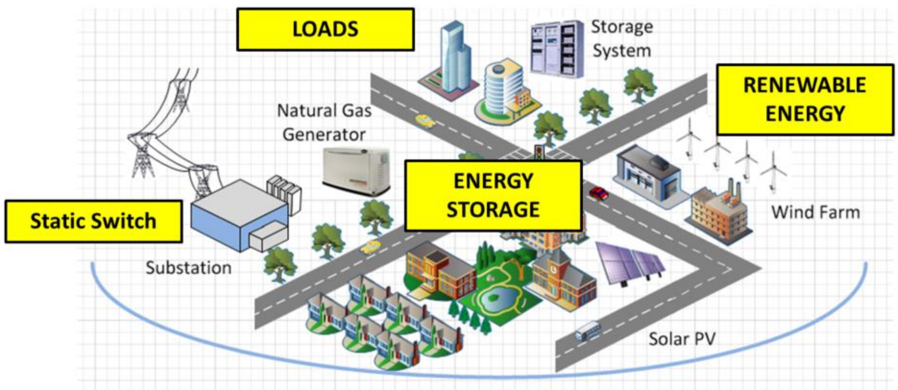
Rationale for the Smart Grid

- Dynamic optimization of grid operations and resources, with full cyber-security.
- Deployment and integration of distributed resources and generation, including renewable resources.
- Integration of ''smart'' appliances and consumer devices.
- Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid options.
- Deployment of ''smart'' technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.

What is a Microgrid?



- A group of interconnected loads and distributed energy resources within 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 or island mode.

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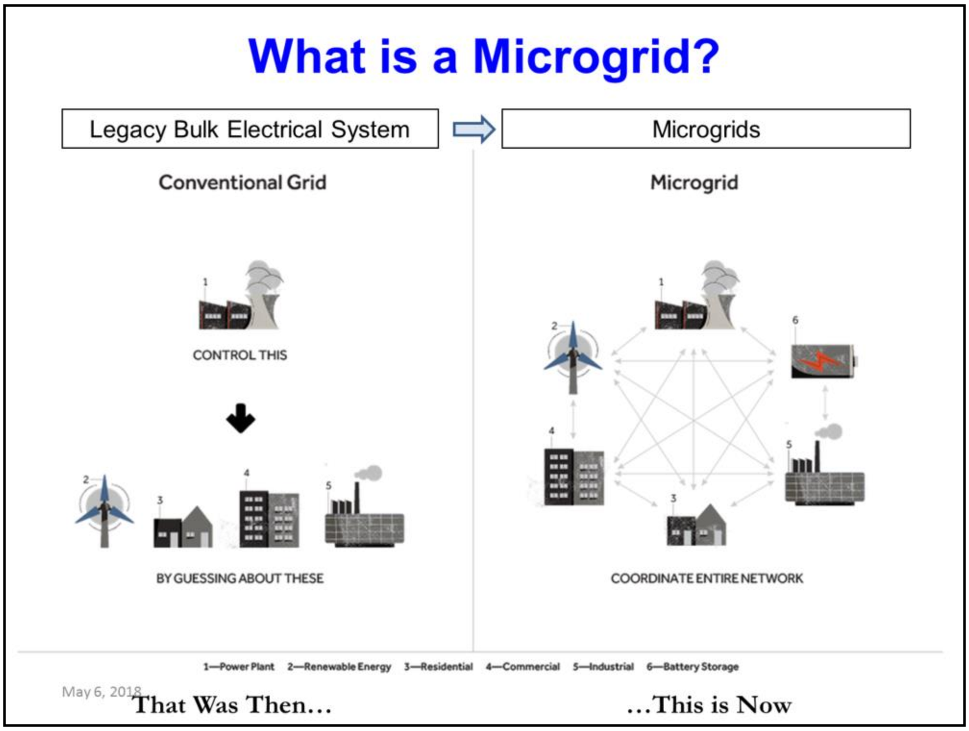
The most compelling feature of a microgrid is the ability to separate and isolate itself from the utility's distribution system unintentionally during events (i.e., faults, voltage collapses, black-outs).It may also intentionally disconnect during grid maintenance and also when the quality of power from the grid falls below certain standards. Microgrids can be reconnected to the utility grid without any interruption to critical load once the utility is recovered.

What is a Microgrid?

- It is a small-scale power supply network that is designed to provide power for a small community.
- It enables local power generation for local loads.
- It contains of various small power generating sources that makes it highly flexible and efficient.
- It is connected to both the local generating units and the utility grid thus preventing power outages.
- Excess power can be sold to the utility grid or can store in storage system.
- Size of the microgrid may range from housing estate(few kW) to municipal regions(few MW).



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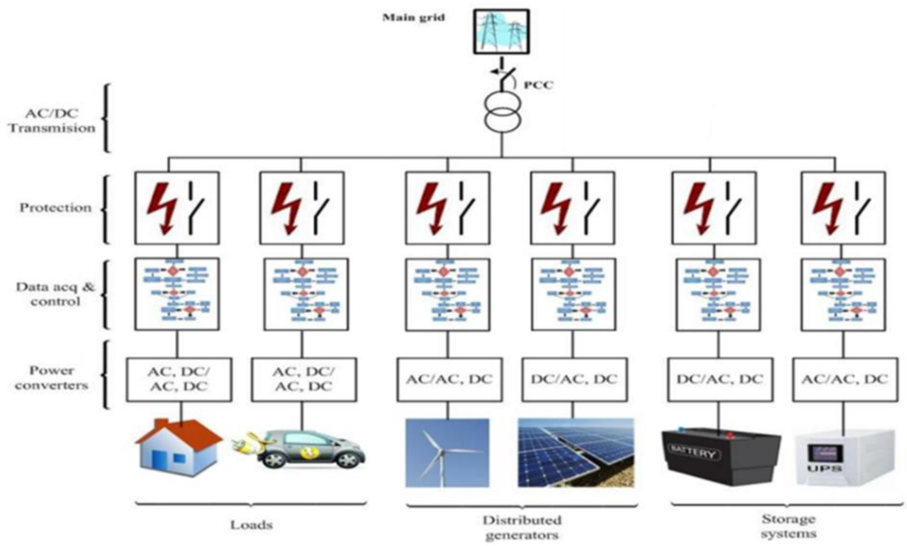
Microgrid Architecture



Component of Microgrid

1.Distributed Generations:

The classification of microgrid generation technologies has given below

- Renewable/Inverter based distribution generations (solar thermal, photovoltaic PV, wind, fuel cell, CHP, hydro, biomass, biogas etc.)

- Non-renewable/Inertia based distribution generations (diesel engine, steam turbine, natural gas generator, induction and synchronous generators etc).

Component of Microgrid

2. Energy Storage Device :

The classification of microgrid storage technologies has given below

- Electrochemical systems (Embracing batteries and flow cells such as Li-ion, Zn-bromide)
- Kinetic energy storage systems (Flywheel energy storage)
- Potential energy storage (Pumped hydro or compressed air storage)

Component of Microgrid

3. Load:

- Resistive load such as household load
- Inductive load for instance Industrial Load
- Sensitive or critical load such as data center, electronic load
- And demand high-level reliability Load for example Hospital
- Sheddable & Unsheddable Load

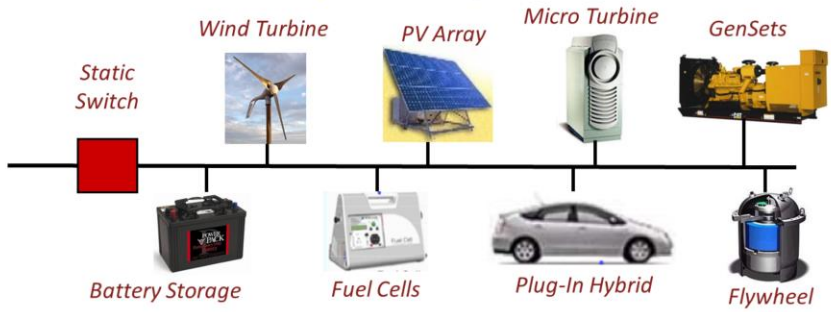
Application of Microgrid

Couple of special application of microgrid, in the regions of underdeveloped transmission infrastructure, for example

- Remote villages
- Islands

Microgrid helps to reduce transmission losses significantly.

Microgrid Importance



- Microgrids provide the most promising means of integrating large amounts of distributed sources into the power grid
- Particularly important for renewable energy sources
- Microgrids can provide higher reliability, energy security and surety, and open the door to significant system efficiency improvements using Combined Heating & Power (CHP)

The control operation of microgrid is required

- To add or subtract new micro-sources without any modification of present component in the system
- For selecting or optimising operation point of microgrid autonomously as well as manually
- To connect or to isolate microgrid from the grid immediately and smoothly when demanded
- For controlling active and reactive power independently.
- For the correction of voltage sag and system imbalances.
- To meet the load dynamics involvement of grid

Features required to achieve flexibility of microgrid

- The microgrid should capable to follow voltage ride-through standard of that particular area.
- It is very important to have black-start quality if system needs to restart for natural disaster or maintenance purpose.
- Microgrid needs to estimate grid impedance prior to connected or disconnect with it.
- The most important feature gives microgrid better control is a storage energy management and a comprehensive control system.

Requirement for ESSs in Microgrids

- Microgrids range in generating capacity from kW's to MW's and provide power to a variety of users ranging from small cell phone towers to large commercial, industrial and military customers.

- Energy storage is used to enhance the stability and efficiency of microgrids by decoupling the generation source from the load.

Requirement for ESSs in Microgrids

- This is particularly useful for systems with diesel generation or intermittent renewables as the means of electricity production.

- Each microgrid is a unique response to a customer need. Whether energy storage is incorporated in a system is a strong function of the microgrid systems integrator, the customers' technological sophistication, and budget.

Requirement for ESSs in Microgrids

- Sizing of a suitable battery bank in terms of power and energy help in shaving the peak demand.

- The ESS stores excess renewable energy and supply load when renewable energy is low.

- When ESS discharges its energy to power grid its generating positive real power.

Classification of Microgrid

Based on microgrid application, we can classified microgrid into

Classification of Microgrid								
Classification	Integrated Level	Utilities' Impact	Responsibility	Application Area	Operational Mode	Geographically Span	Power Quality	Remarks
Facility Microgrid	Middle level	Little impact on utilities	For complement mostly for vital systems	Mainly found in North America specially for Industry/Institution application where technology is matured	intentional or unintentional island Mode	2 miles	High	Making great use of renewable energy, increasing energy efficiency, reducing pollution, greenhouse gas emissions & high power quality reliability for sensitive loads as well to single business-entity
Remote Microgrid	Low level	No impact on utilities	Independent system for isolated electrification	Mainly found in distant areas, Islands, developing countries etc	Islanded Mode only	30 miles	Relaxed	Mostly decentralized control & maximum power use is limited for the customers
Utility Microgrid	High level	Massive impact on utilities	For support of power systems	Mainly found in Japan, Europe, China where renewable energy is rapidly developing	Grid tie Mode	15 miles	Medium	Providing high power quality & reliability to sensitive local loads, contributing to utility stability & robustness as well

Advantages of Microgrid

- The foremost benefit of microgrid is its ability to operate in islanded mode when there is any disturbance in utility grid or for economy purpose. Hence, it increases the overall system reliability.
- During peak load time, microgrid helps utility grid to function properly by share its loads, hence failure of utility grid can be prevented. We can save Billion dollars if we can manage few hundred summer pick hours by shifting or eliminating loads.
- Microgrid utilities local green energy to feed local demand instead of using fossil fuel. Hence, lowering carbon foot print.
- Opportunity for big customer/company to improve power quality, and power stability. Besides, optimizing cost to take back of your energy control.
- If every user (building/company/hospital/market) thinks about reliable power and keep own generation/battery/diesel engine as a backup. That is most expense power system. In Microgrid system we can get rid of those backup because user doesn't have to think feeding load during critical time.

Advantages of Microgrid

- Combined heat and power (CHP) with non-renewable generator helps to improve overall efficiency.
- In microgrid system, user can produce his demand energy which mitigates the electricity costs.
- Microgrid can remove stress from macrogrid.
- Generation and demand are happened in distribution level without transmission.
- Hence, reduce the network and transmission losses and provide local voltage support as well.
- Microgrid could be the answer to our energy crisis. It is the "energy security" to the power industry.

Disadvantages of Microgrid

- It is hard to maintain standard level of voltage, frequency and power quality while keep continues fighting to maintain balanced with intermittent supply and variable demand.
- For reliability purpose storage device is required which occupied more space and maintenance.
- It is difficult to achieve synchronization with utility grid.
- Distributed system could create stress for macrogrid when it operates as a load.
- Sophisticated protection system is the challenge for implementing microgrid.
- Microgrid has critical issues for example standby charges and net metering which needs to be addressed.
- A better interconnect standard is needed to develop for keeping consistency with IEEE P1547.
- Adding more uncertainty sources (like wind, solar), it is much more difficult to control centrally (Eastern/Western grid) but it is easy to control locally by knowing the behavior of the load.
- Utility produce more fossil power after monitoring more solar/wind power is connected to the system because of its intermittent nature.
- Huge harmonics effects from inrush current of transformers or Induction machine.
- Three phase unbalance could be occurred from single phase loads of single phase generators such as photovoltaic

Power Quality Issue

Power Quality Issues related to DG systems				
Power Quality Issues	Wind Energy	Solar Energy	Micro-hydro turbine	Diesel
Voltage sag/swell	"		"	"
Under/Over Voltage	"			"
Unblanced Voltage		"		
Voltage Transient	"			
Voltage Harmonics	"	"	"	
Flicker	"	"		"
Current Harmonics	"	"	"	
Interruption	"	"		

Future Directions on Microgrid Research

- To investigate full-scale development, field demonstration, experimental performance evaluation of frequency and voltage control methods under various operation modes.

- Transition between grid connected and islanded modes on interaction phenomena between distribution generation and high penetration of distributed generation.

Future Directions on Microgrid Research

- Transformation of Microgrid system today into the intelligent, robust energy delivery system in the future by providing significant reliability and security benefits.

- In the near future when cost of Microgrid system will be affordable then Microgrids will become more popular and conventional grid will be replaced by Microgrid.

- Research are going such as to increase stability and reliability of the Microgrid for effective working.

Sample Microgrid Configuration

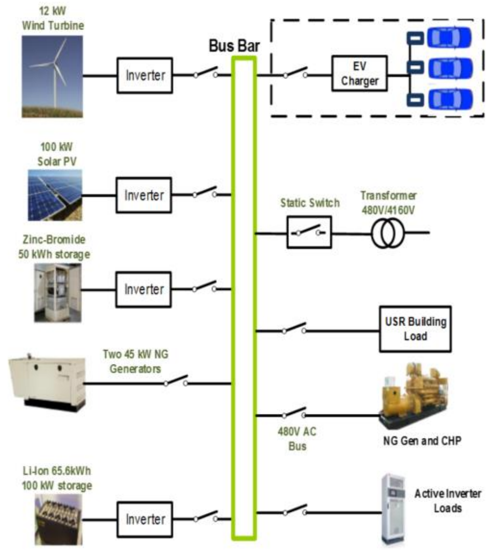
- It is rated at 0.480 kV,60 Hz and 250 kW.
- It is connected to the utility grid through a 0.48kV/13.2 kV transformer and a static switch
- The generation in microgrid includes:

  (1) Two Natural gas generators each rated at 45 kW,

  (2) 100 kW Solar PV system

  (3) 12 kW wind turbine

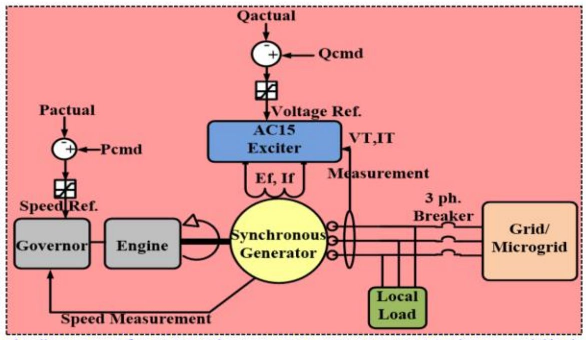
  (4) 114 kW @ 28.8 kWh Li-Ion, 15 kW @ 25 kWh ZBB energy storage system
- The system includes various loads, CHP, EV Charger, etc.



Sample microgrid configuration

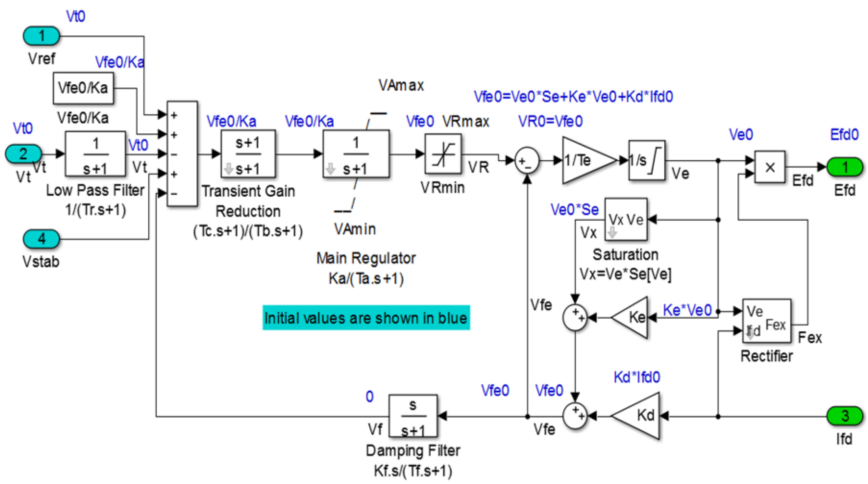
Natural Gas Generator

- Following figure shows the basic block diagram of a natural generator connected to a grid or a microgrid.
- The exciter is in charge of reactive power and governor adjusts the active power.
- In order to accurately study the behavior of the synchronous machine for the power system stability studies, exciter AC1A has been modeled according to IEEE 421.5 standard and gas turbine is modeled with sufficient details.



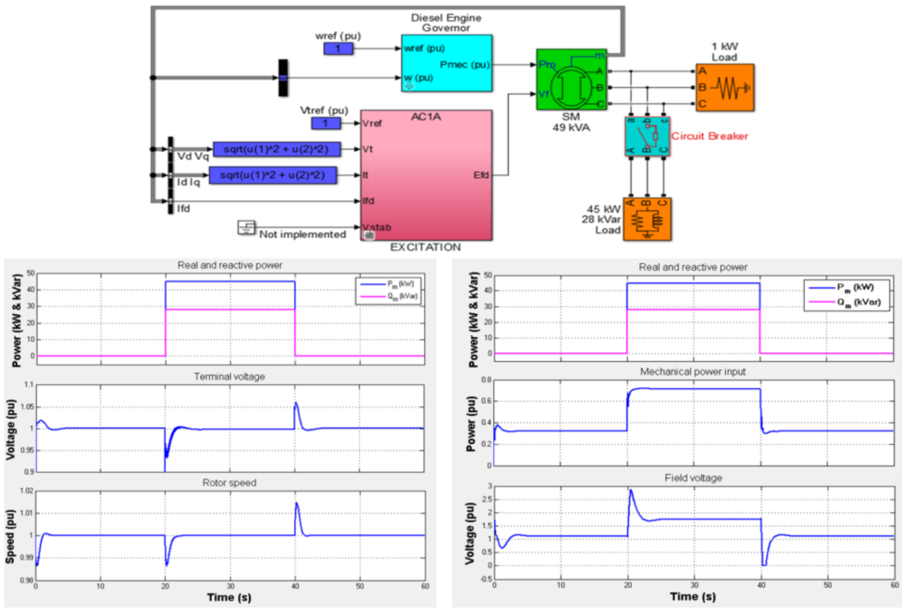
Basic block diagram of a natural gas generator connected to a grid/microgrid.

Exciter AC15 diagram

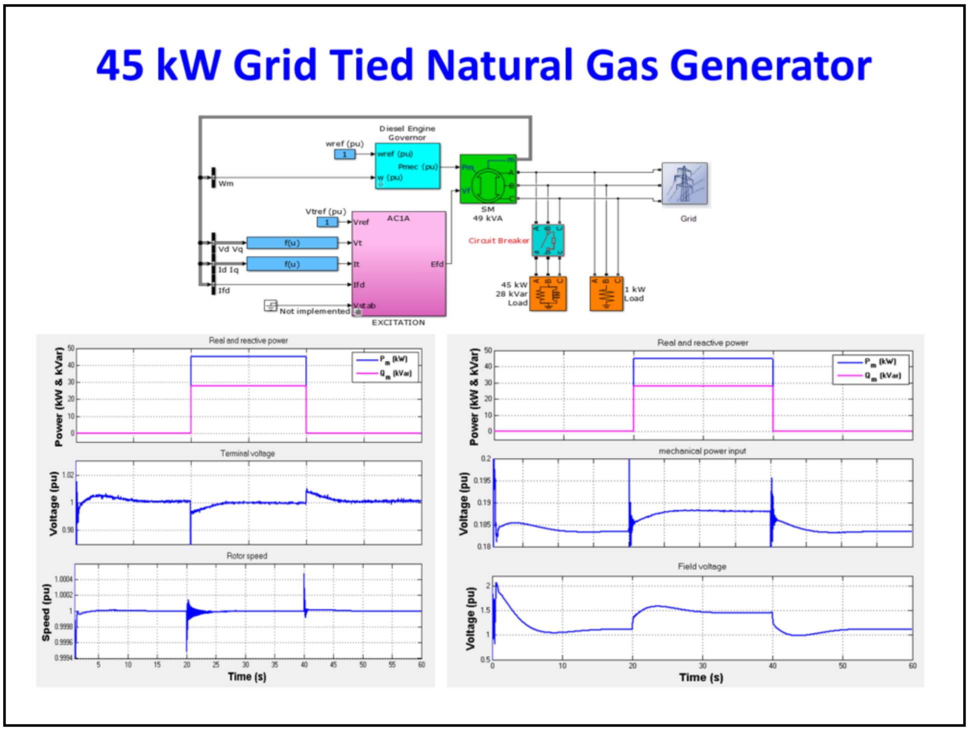


AC15 excitation system

45 kW off grid Natural Gas Generator

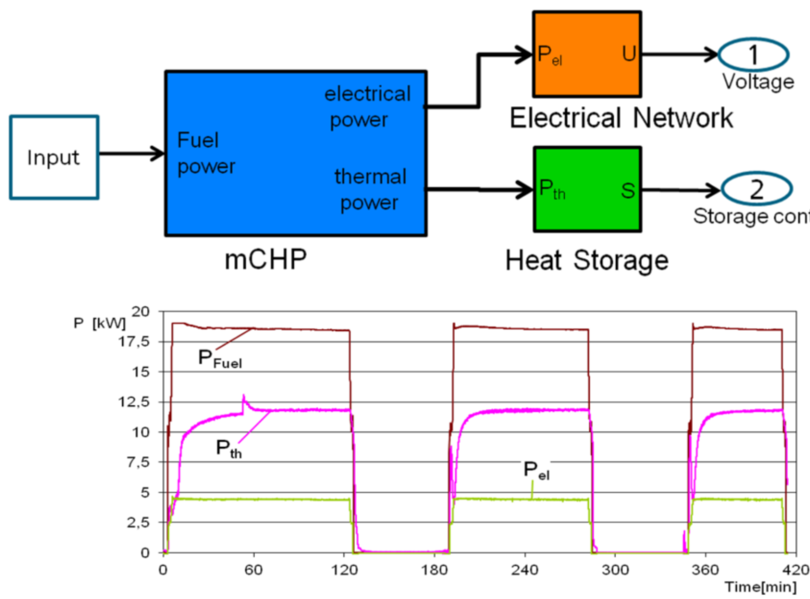


49 kVA Islanded natural gas generator in Matlab
Power, Terminal Voltage, Rotor speed wrt time
Power Electrical ([Real, Reactive], Mechanical), Field voltage



45 kW Grid connected natural gas generator in Matlab
Power, Terminal Voltage, Rotor speed wrt time
Power Electrical ([Real, Reactive], Mechanical), Field voltage

CHP Design



Based on Utility data

Wind Turbine Generator

- The converter is operated in current mode and is configured to provide flexible active and reactive power.
- Power extracted by the blade is given by

$$P_b = \frac{1}{2}\rho A v^3 . C_P$$

Where,

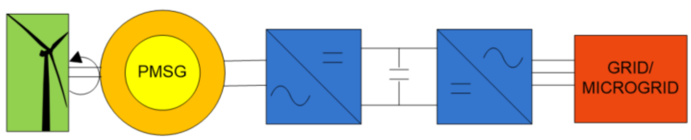
ρ (kg/m3): Air density (1.225kg/m3 at 15°C and 1 atm.)

A (m2): The swept area of the turbine blades

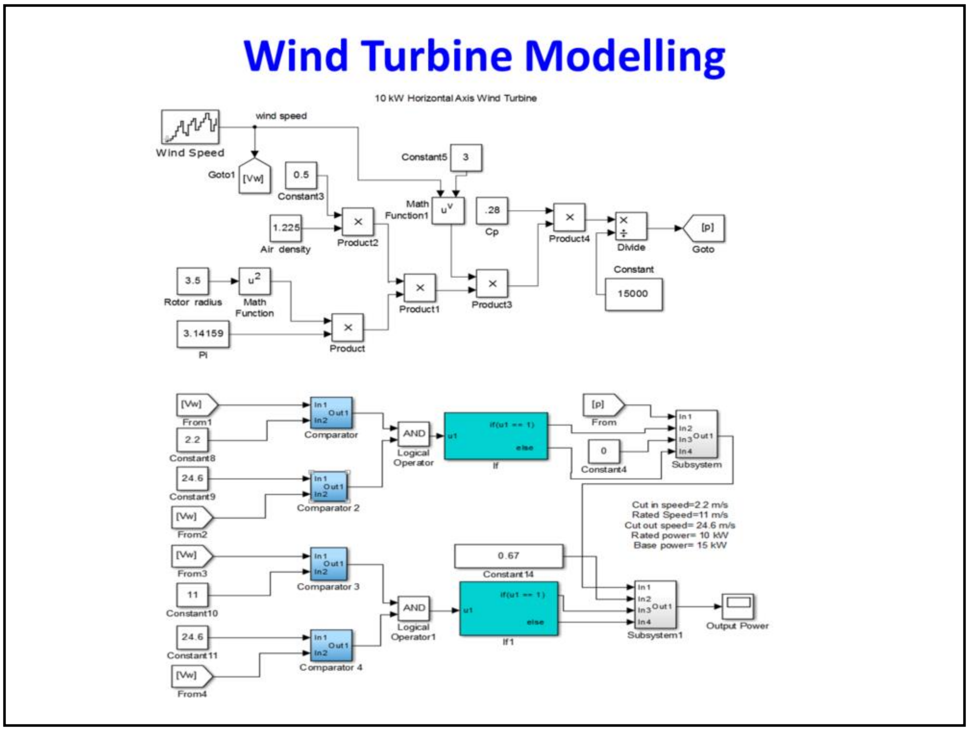
V (m/s): Wind speed

Cp: Power Coefficient

- Above equation is implemented in MATLAB Simulink to get the active power reference to the Inverter



Wind turbine with Full scale converter connected to the grid/microgrid.



Where:
I_{ph} is the solar-induced current:
$I_{ph}=I_{ph0}*I_r/I_{r0}$
Where:

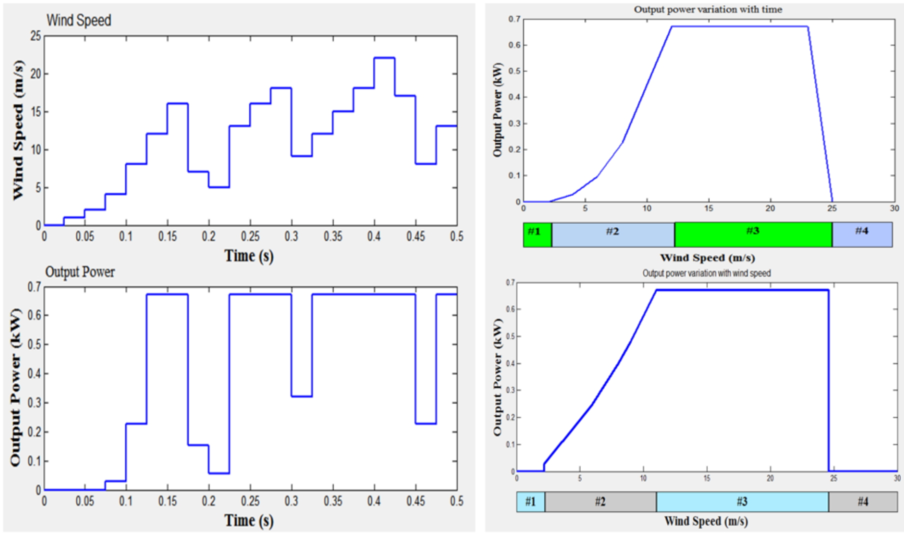
I_r is the irradiance (light intensity) in W/m^2 falling on the cell.
I_{ph0} is the measured solar-generated current for the irradiance I_{r0}.

I_s is the saturation current of the first diode.
I_{s2} is the saturation current of the second diode.
V_t is the thermal voltage, kT/q ,
Where:

k is the Boltzmann constant.
T is the Device simulation temperature parameter value.
q is the elementary charge on an electron.

N is the quality factor (diode emission coefficient) of the first diode.
N_2 is the quality factor (diode emission coefficient) of the second diode.
V is the voltage across the solar cell electrical ports.

Wind Speed and Power Profile



Sample wind speed and wind power profile

Change figures

Power Coefficient & Radius of WT

- An efficiency factor Cp is defined as:

$$C_p = \frac{Power\ output\ by\ wind\ turbine}{Power\ in\ the\ wind}$$

- This can be roughly estimated:

  $C_p = \eta_{rotor} \times \eta_{mechanical} \times \eta_{electrical}$ =40% × 80% × 90% =28.8%

- Finally, the electrical power equation for A HAWT is obtained

$$P_{out} = \frac{1}{2}\rho\pi r^2 v^3 C_p$$

- The radius is derived to be

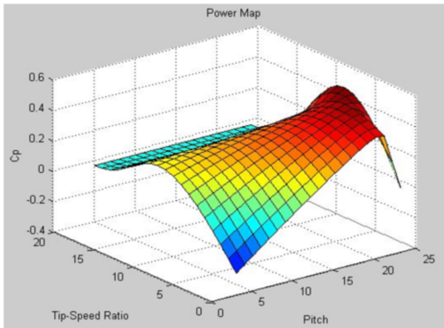
$$r = \sqrt{\frac{2P_{out}}{\rho\pi v^3 C_p}}$$

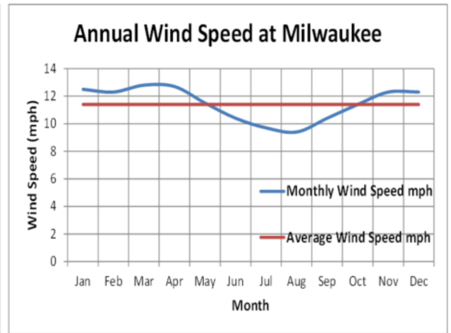
- Considering 11 m/s as the rated speed, a 10 kW wind turbine has a blade radius of

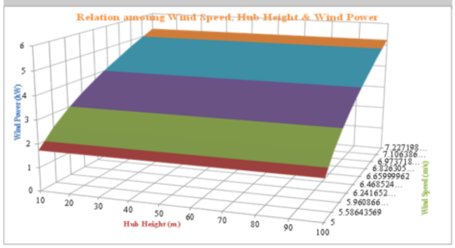
$$= \sqrt{2x10000 \ldots} \approx 3.5m$$

Change figures

Wind Speed and Power Profile

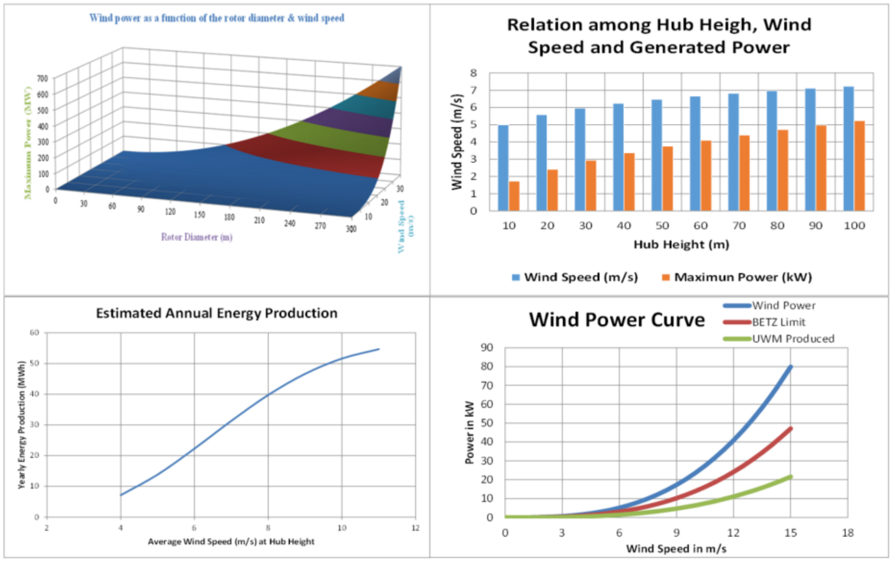






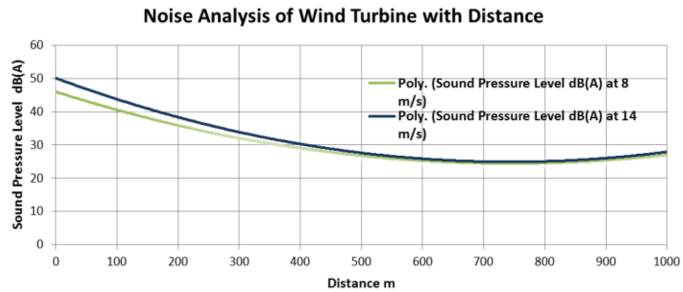
Wind speed does fluctuate a lot with the gradient of temperature. So, during Morning and Late afternoon wind speed change dramatically but during night and winter, we usually get smooth wind speed.

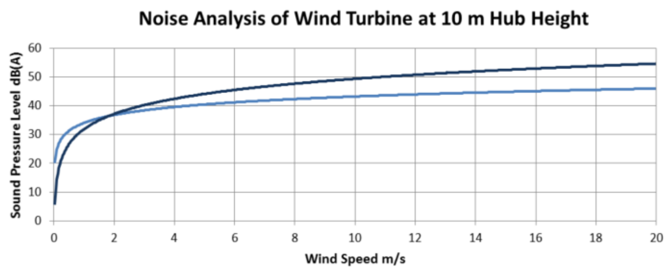
Sample Wind Graphs



Relation among rotor diameter; wind speed and generated power, Relation among hub height, wind speed and generated power; Estimated annual wind energy and Wind power curves at University of Wisconsin Milwaukee(UWM) have shown.

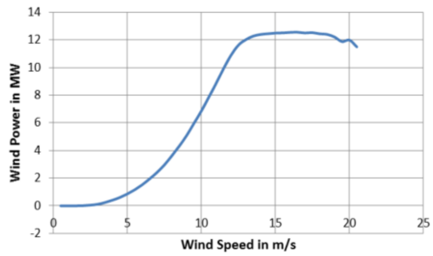
Wind Speed and Power Profile



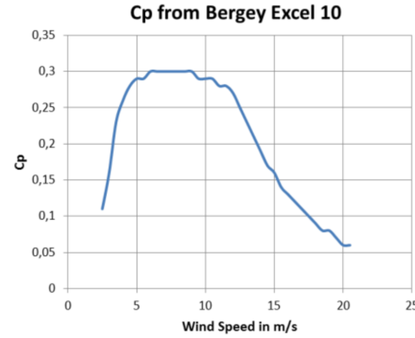


Wind Speed and Power Profile

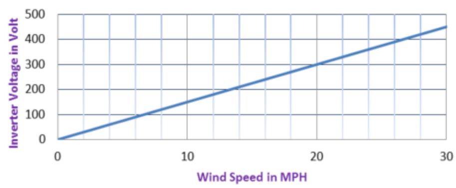
Wind Power Output Curve from Bergey Excel 10



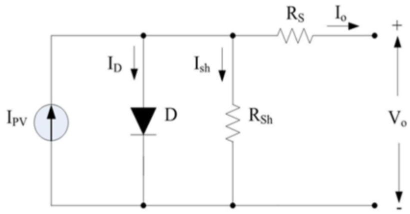
Estimated Coefficient of Performance Cp from Bergey Excel 10



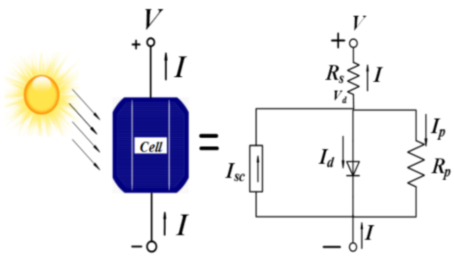
Inverter Terminal Voltage with Wind Speed



Solar Cell Equivalent Circuit



$$I = I_{ph} - I_s * \left(e^{\frac{V+I*Rs}{N*V_t}} - 1\right) - I_{s2} * \left(e^{\frac{V+I*Rs}{N_2*V_t}} - 1\right) - \frac{V + I * R_s}{R_p}$$



Photovoltaic Module SANYO Electric Co., Ltd	
1000 w/m² Irradiance, 25 °C Cell Temperature	
Parameter	Nominal Values
Maximum Power P_{max}	210 W
Short Circuit Current I_{SC}	5.57 A
Open Circuit Voltage V_{OC}	50.9 V
Maximum Power Current I_{pmax}	5.09 A
Maximum Power Voltage V_{pmax}	41.3 V
Maximum System Voltage	600 V
Temperature Coefficient (Pmax)	0.336%/ °C
Temperature Coefficient (Voc)	0.142 V/ °C
Temperature Coefficient (Isc)	1.95 mA/ °C
Cell Efficiency	18.9%
Module Efficiency	16.7%

Where:
I_{ph} is the solar-induced current:
$I_{ph}=I_{ph0}*I_r/I_{r0}$
$Where$:

I_r is the irradiance (light intensity) in W/m^2 falling on the cell.
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I_s is the saturation current of the first diode.
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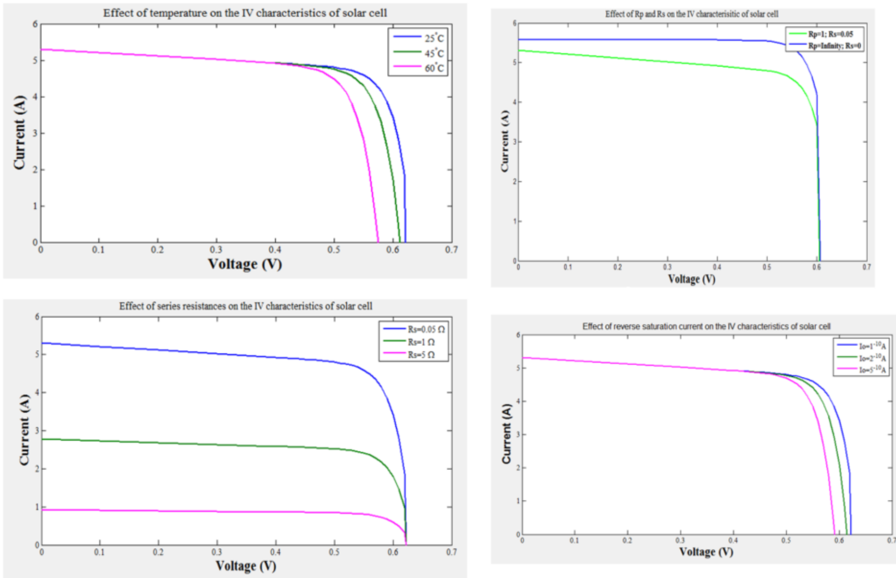
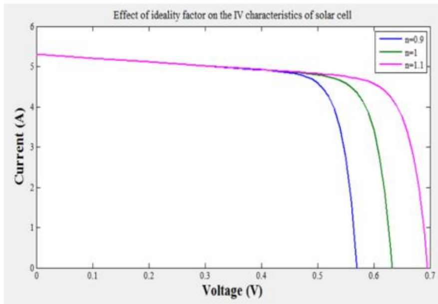
V is the voltage across the solar cell electrical ports.

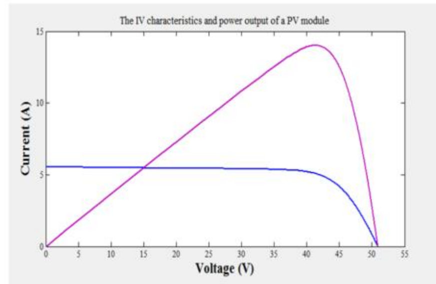
Solar PV Characterisitic

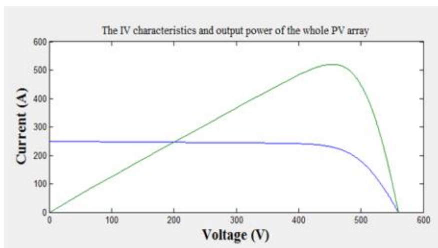


Change figures

Solar PV Characterisitcs







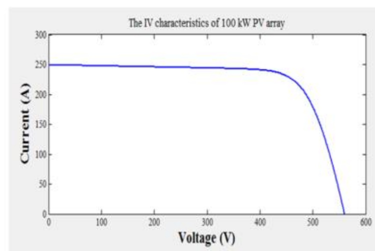


Fig2:Output power is scaled down to 1/15 th times of its original value
Fig3:Output power is scaled down to 1/200 th times of its original value

Solar Profile for a Perfect Day

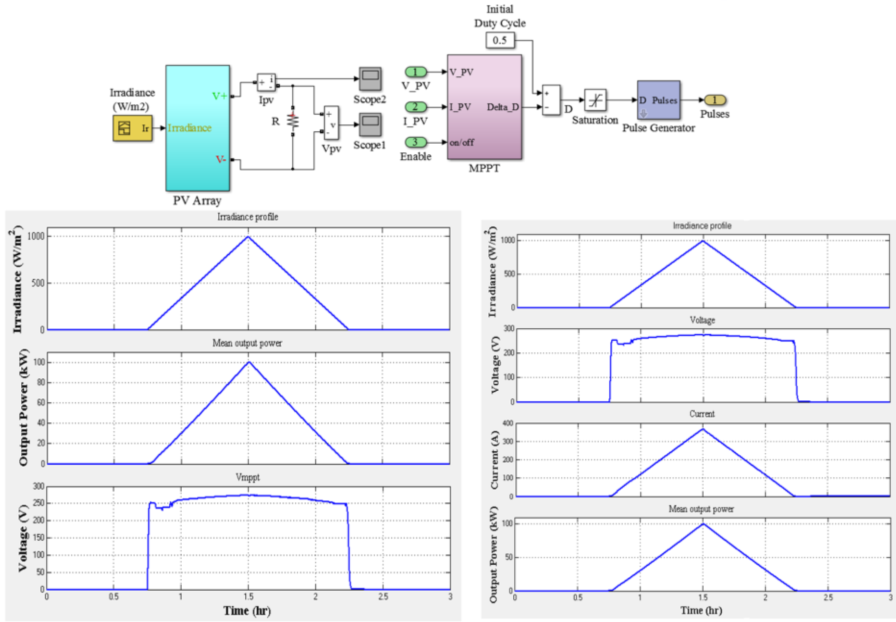
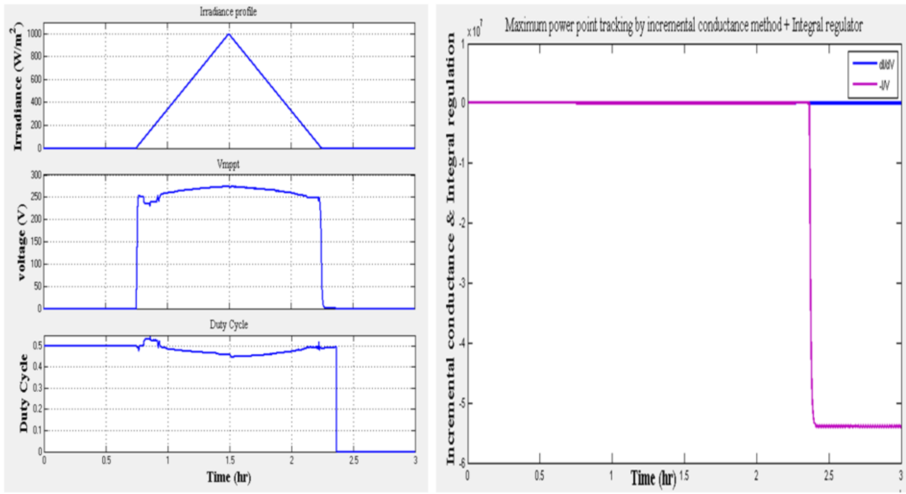


Figure: The PV array and MPPT function.

<u>Solar irradiation profile and output power (For perfect day)</u>*[Time is scaled down to 1/8 th times of its original value]* The solar irradiation profile and output power of the PV array.

Voltage, current and output power variation with irradiation

Solar Profile for a Perfect Day



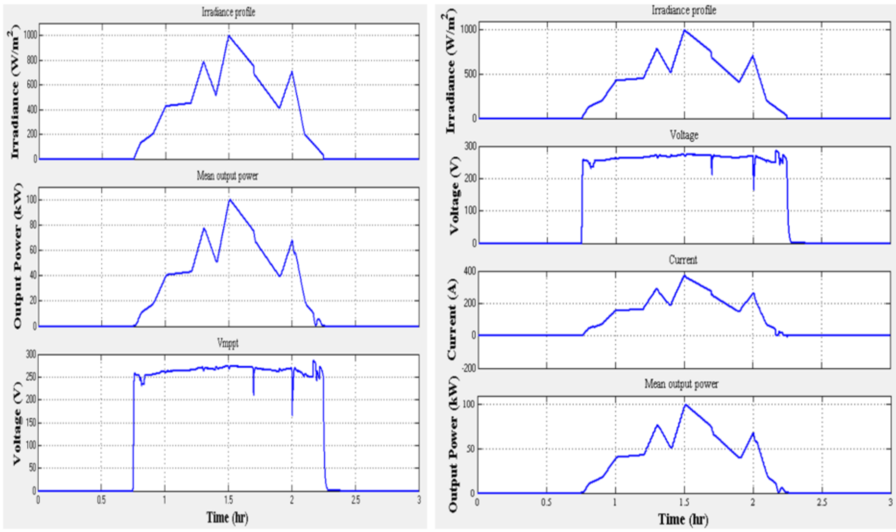
Duty cycle generation using MPPT (For perfect day):

Implementation of MPPT (For perfect day):[Incremental conductance & Integral regulator**

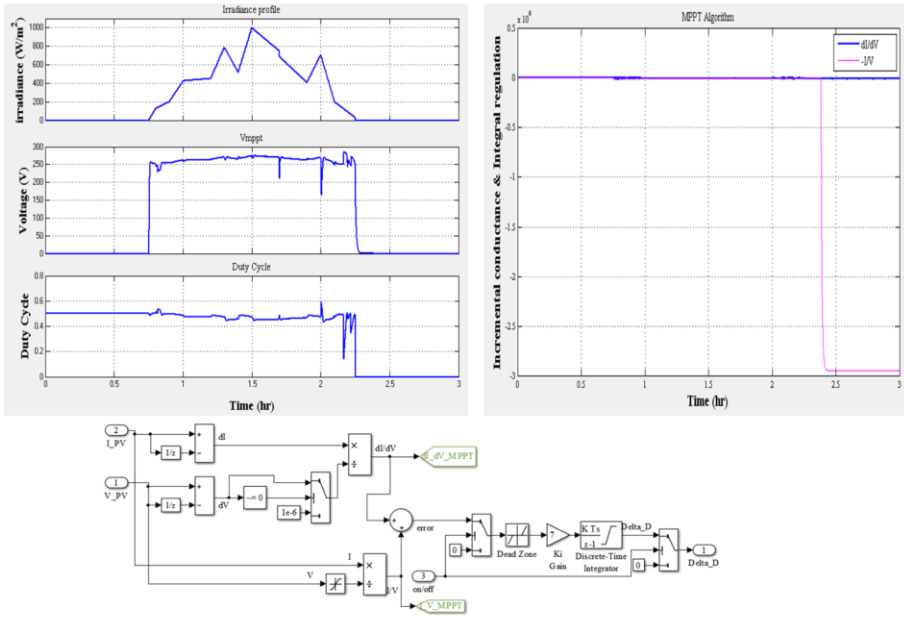
***Time is scaled down to 1/8 th times of its original value*

]

Solar Profile for a cloudy day



Solar Profile for a cloudy day



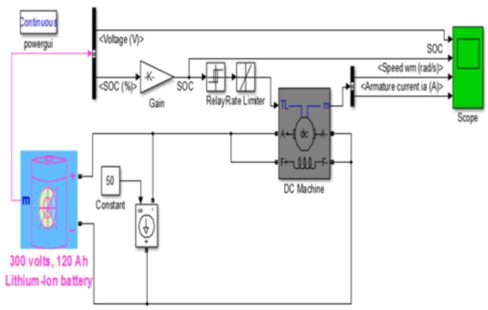
Duty cycle generation using MPPT

Implementation of MPPT (For cloudy day):Incremental conductance & Integral regulator

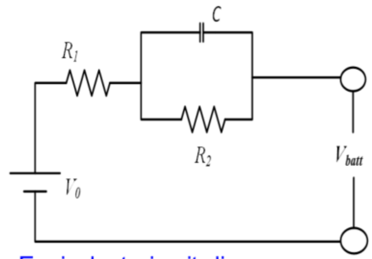
MPPT Controller

Li-Ion Energy Storage System

- A 114kW, 28.8kWh Li-ion battery storage



Simulation Model Li-Ion Battery



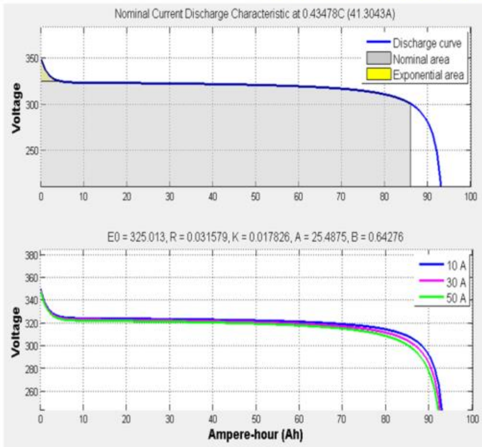
Equivalent circuit diagram

$$V_{batt} = \left(\frac{Q}{C} + I_c \times R_2\right) \times \exp\left(-\frac{t_c}{R_2 \times C_1}\right) + V_0 - \left(I_c \times (R_1 + R_2)\right)$$

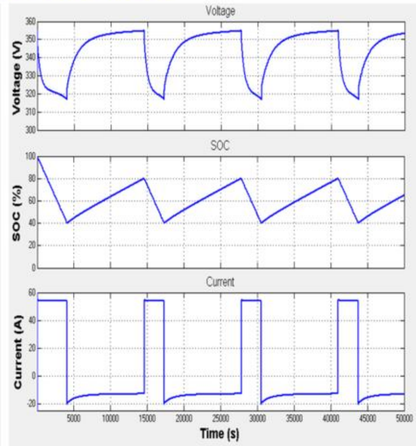
Time dependent cell voltage at constant current

The parameters R_1 , R_2 , C and V_o can be represented in terms of polynomial equation to represent the nonlinear phenomenon in the battery

Li-Ion Characterisitics

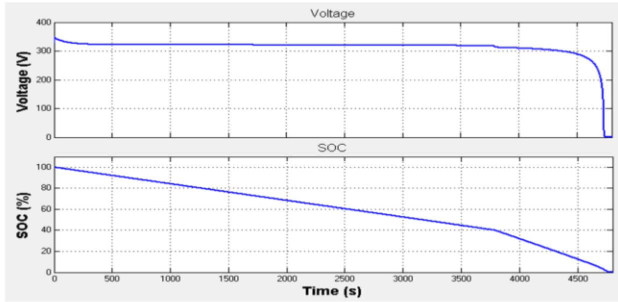


Discharging characteristics of Li-Ion

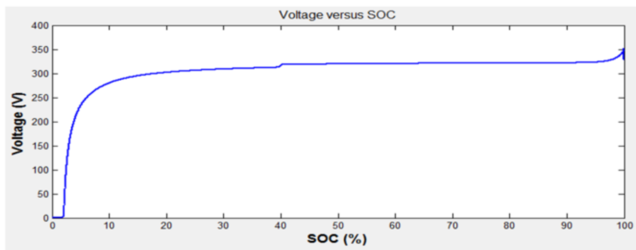


The SOC(%) variation with charging and discharging of Lithium-Ion battery

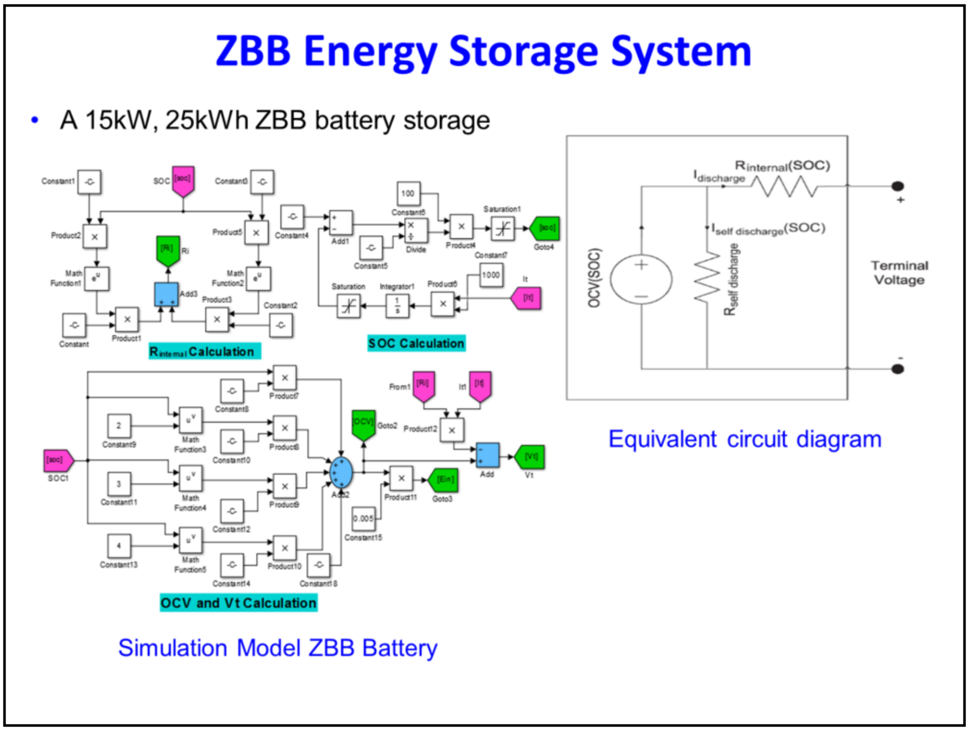
Li-Ion Characteristics



Voltage VS SOC while discharging of Li-Ion battery

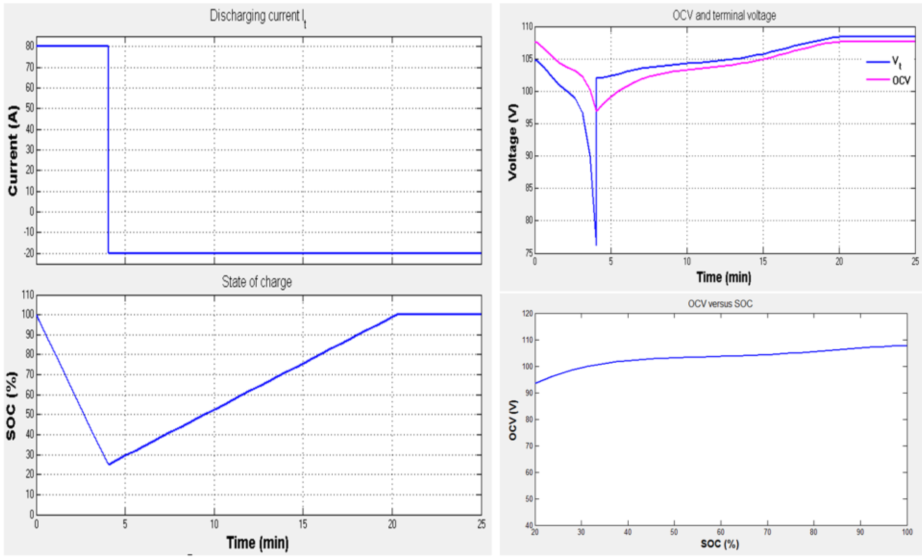


Voltage VS SOC while charging of Li-Ion battery

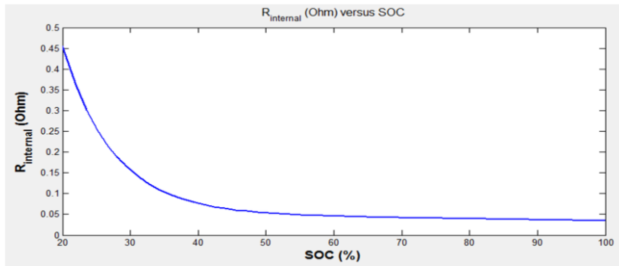


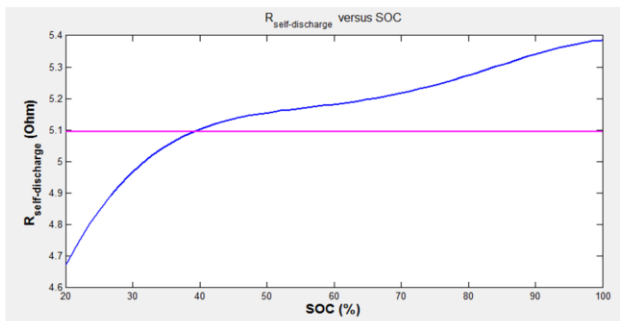
The parameters R_1 , R_2 , C and V_o can be represented in terms of polynomial equation to represent the nonlinear phenomenon in the battery

ZBB Energy Storage System

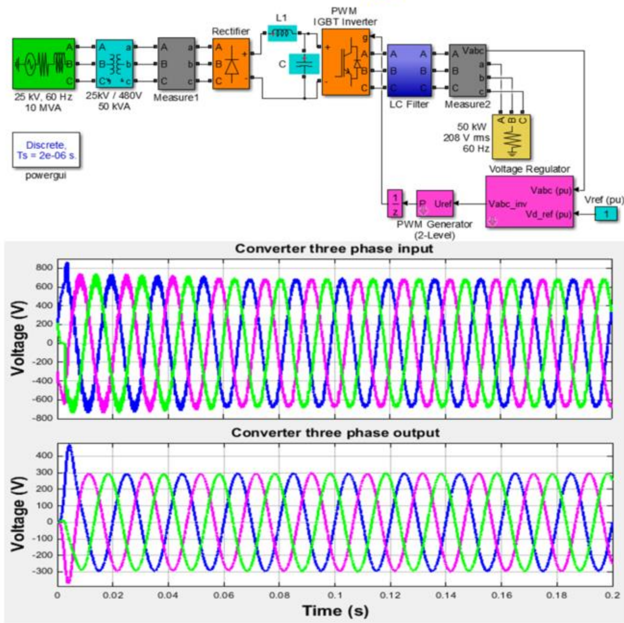


ZBB Energy Storage System

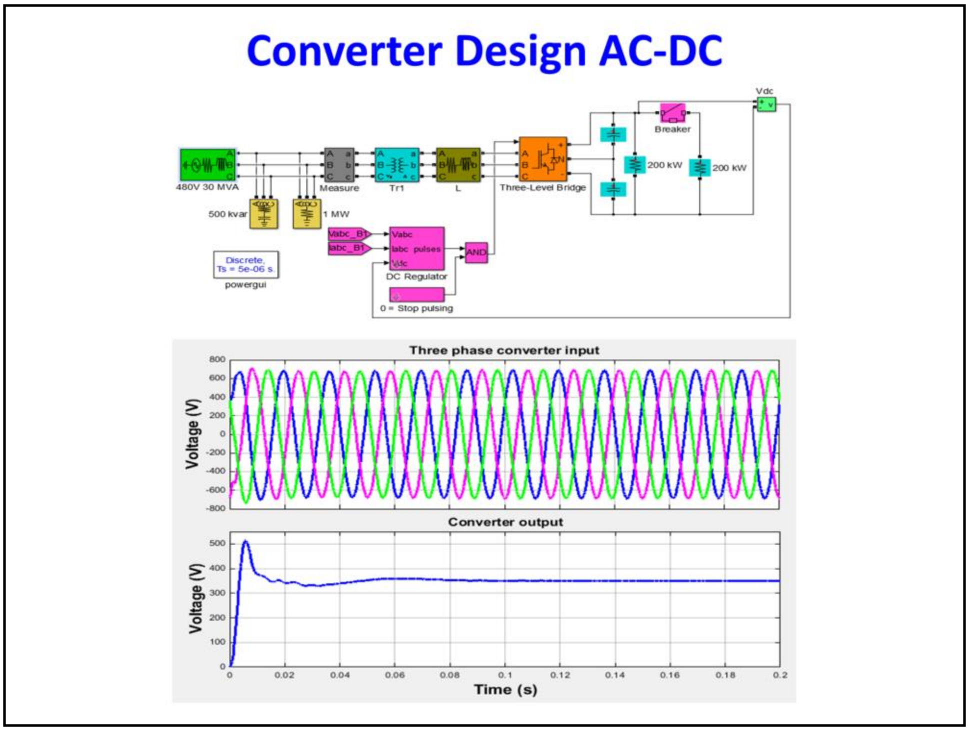




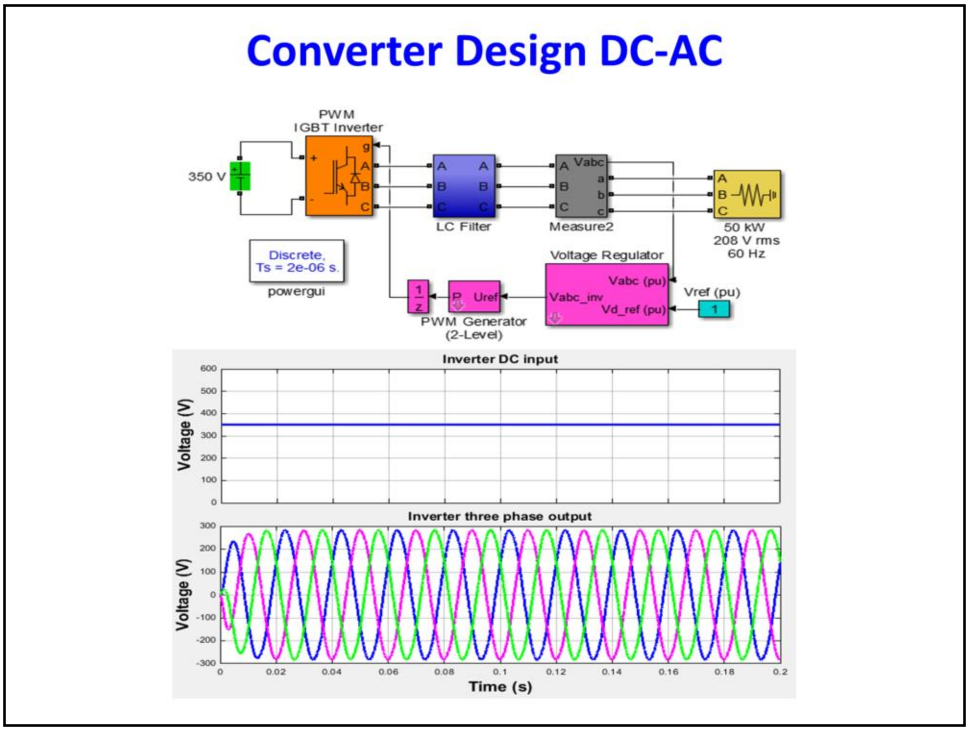
Converter Design AC-AC



AC-AC Converter (480 V AC-208 V AC):

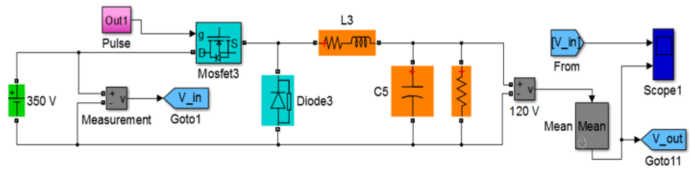


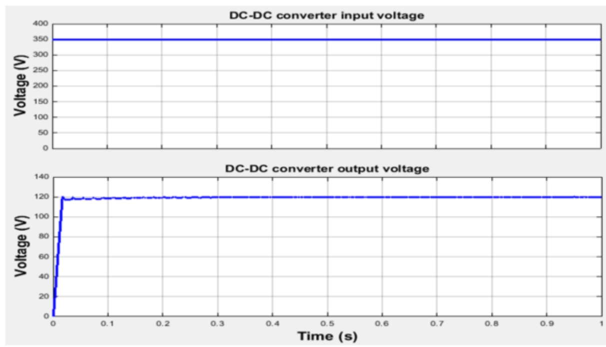
AC-DC Converter (480 V AC-350 V DC):



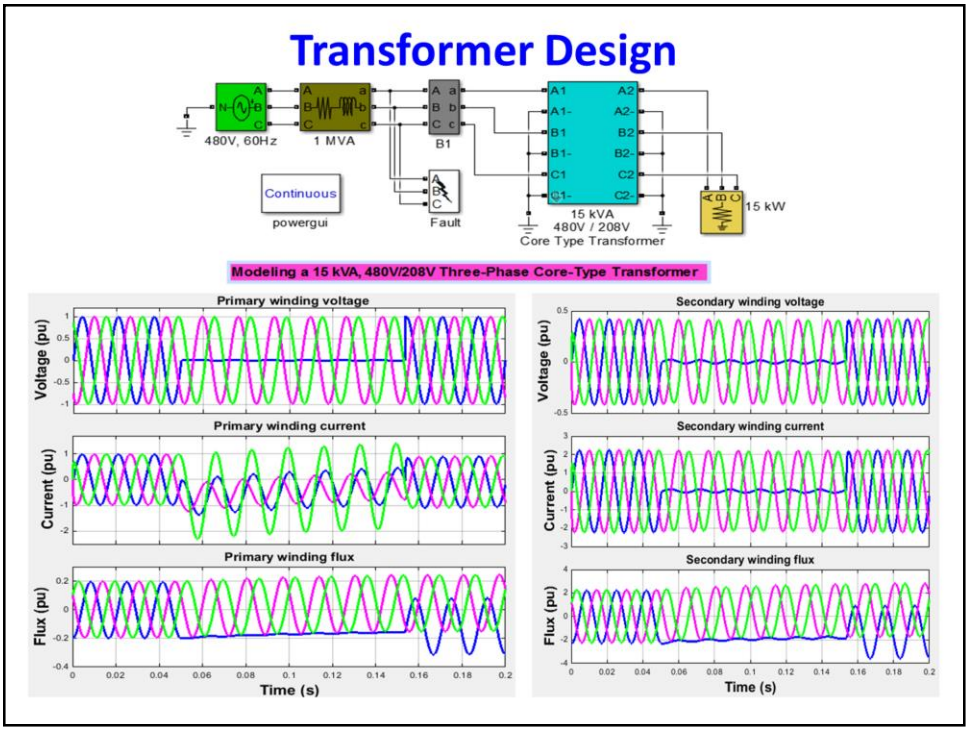
DC-AC Converter (350 V DC-208 V AC):

Converter Design DC-DC



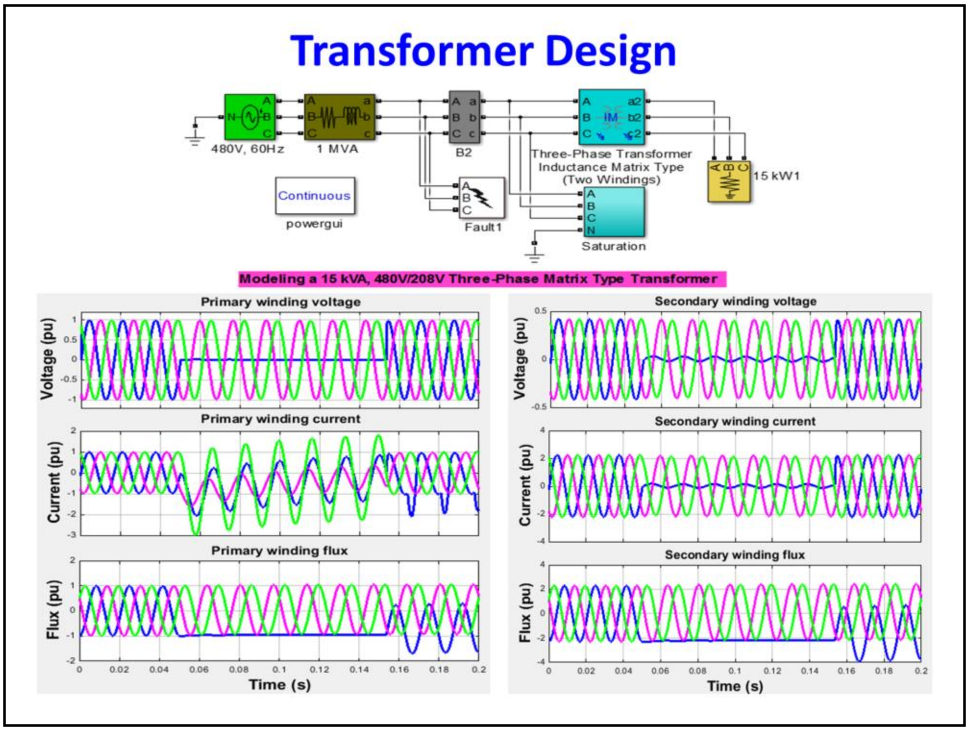


DC-DC Converter (350 V DC-120 V DC):



Circuit 1: Transformer model using core geometry and BH curve:

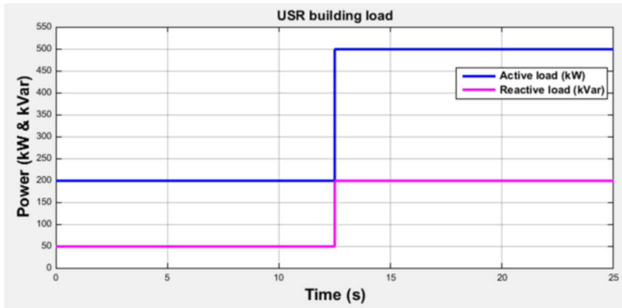
****fault occurs at phase A.*



Circuit 2: using Inductance Matrix Type Transformer model

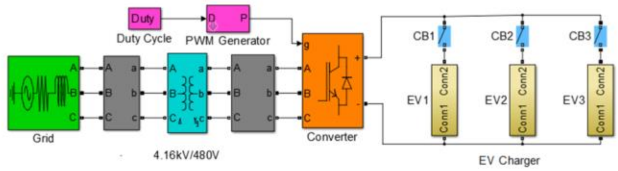
****fault occurs at phase A.*

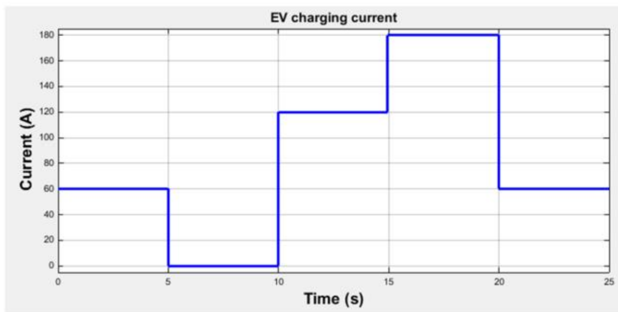
USR Building Load



Based on Utility data

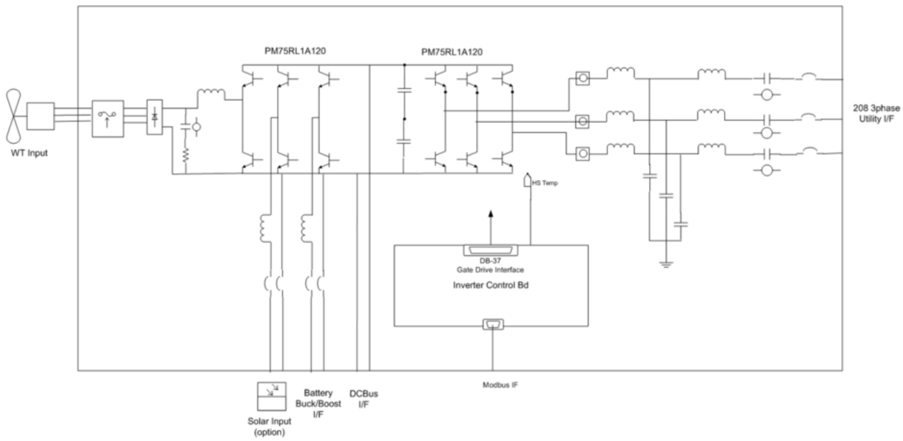
EV Charger





Based on Utility data

ADP-10K Pseudo Schematic

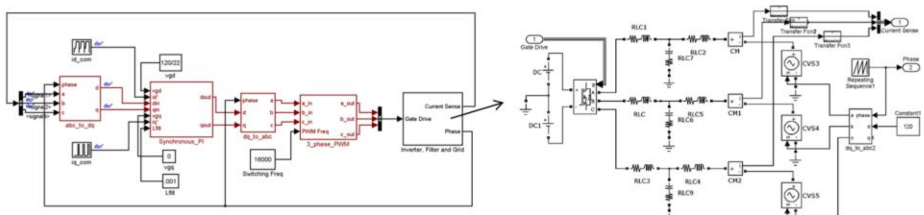


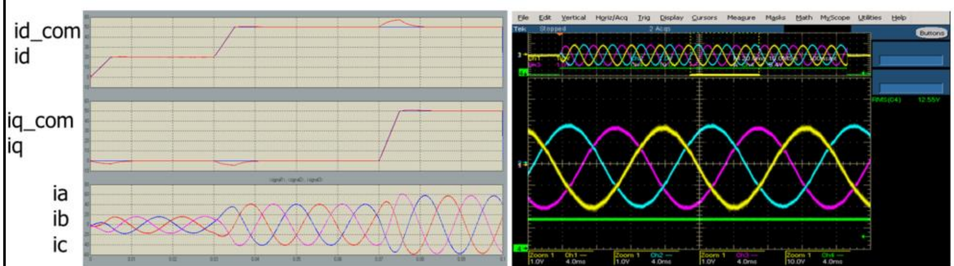
Based on Intelligent Power Module: PM75RL1A120

84

3-Phase Current Control

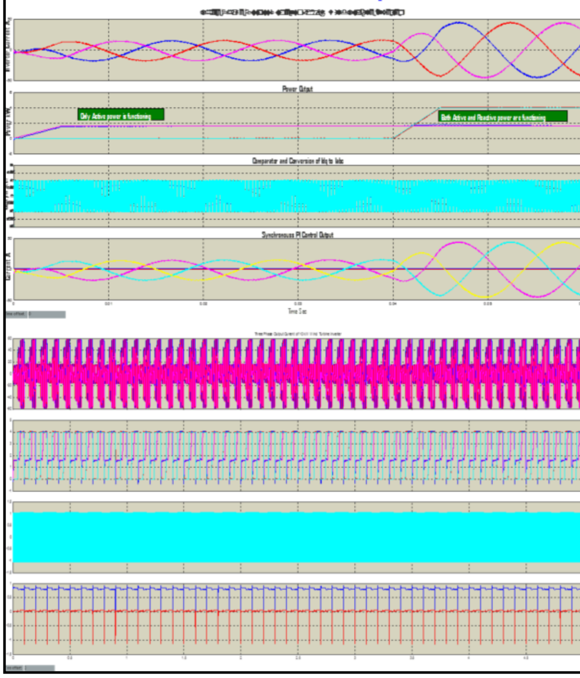
- response to real and reactive current command

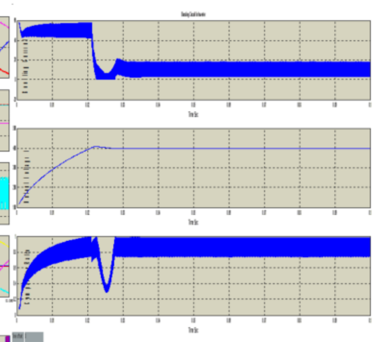




Altera Advanced DSP Builder:
Auto-coded VHDL with Floating Point Functions

Simulation result of 3-phase current controlled inverter

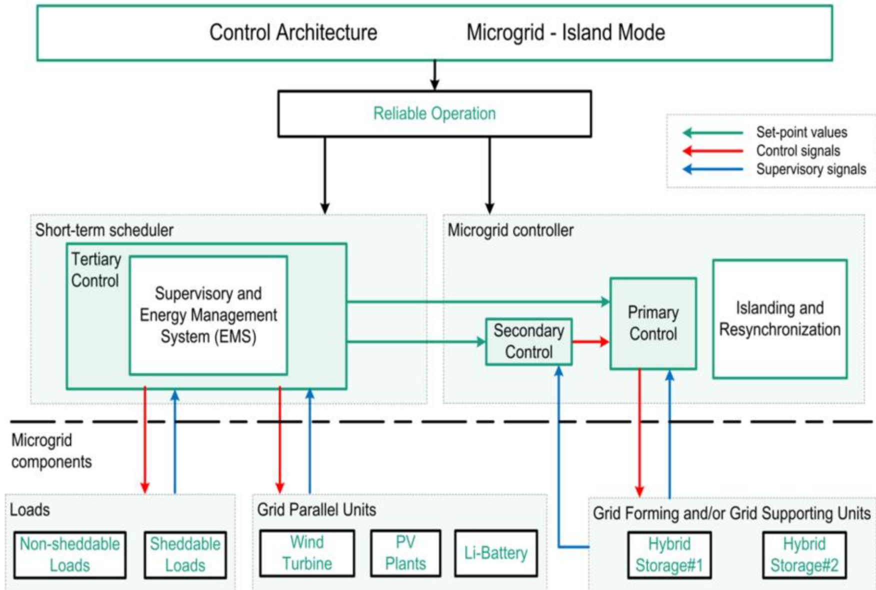


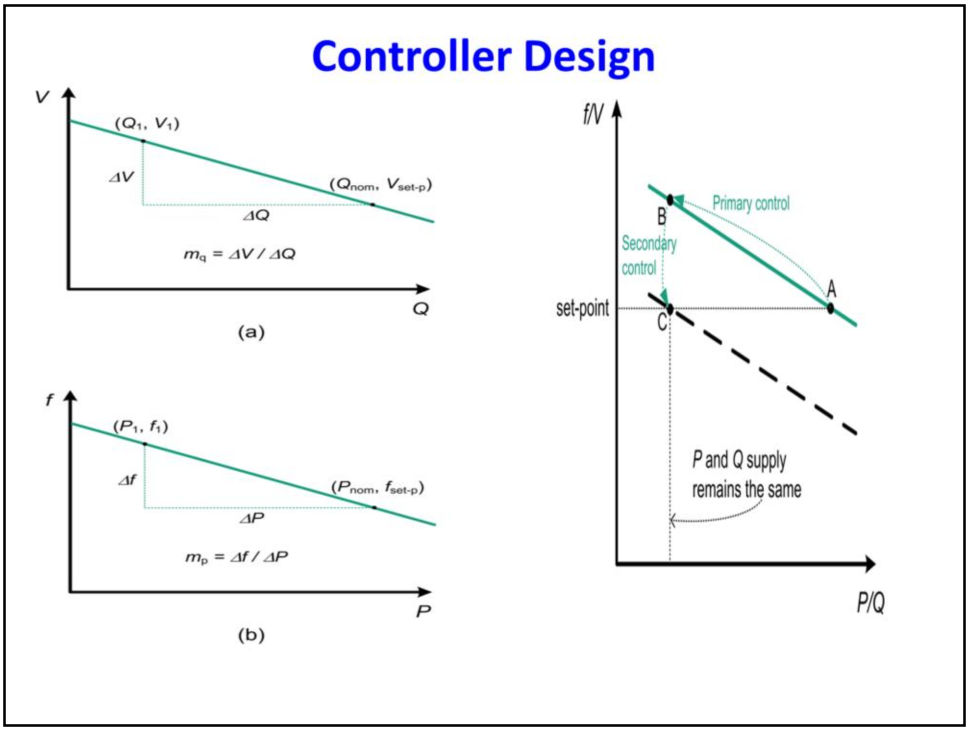


- Fig for three phase current control circuit: Inverter Current in A, Power Output in kW, Comparator and Conversion of Idq to Iabc, Synchronous PI Control Output.
- Fig for booster circuit: boosting current in A, output voltage in V, comparator ratio.

- Modelling of PMSG WT has been completed for UWM.
- An FPGA-based controller for power electronics has been implemented on an Altera Stratix II FPGA.
- The use of an FPGA for this purpose provides hardwired parallel operation, and functional isolation of multiple operations.
- In addition, HDL based power electronics controller has been developed using Altera's DSP Builder technology.
- 3-phase Grid Tie Inverter for WT has been designed and Implemented.
- Simulation result has been verified experimentally.

Controller Design



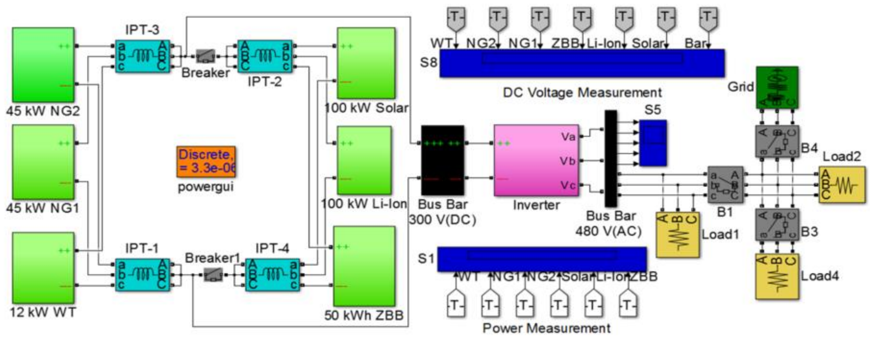


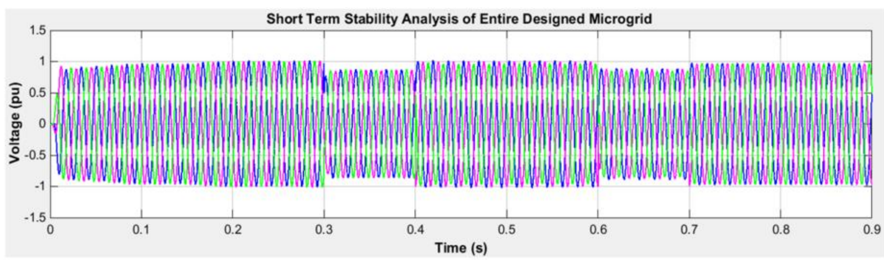
The primary control is found in the lowest layer of the control architecture of the Microgrid, it is mainly used for load sharing among controllable and dispatchable fast-response units. The most widely used primary control strategy is droop control, which is shown in Figure 2

Secondary control is the middle level control at the microgrid, it is used to eliminate frequency and voltage deviations caused by lower control layers (primary control)

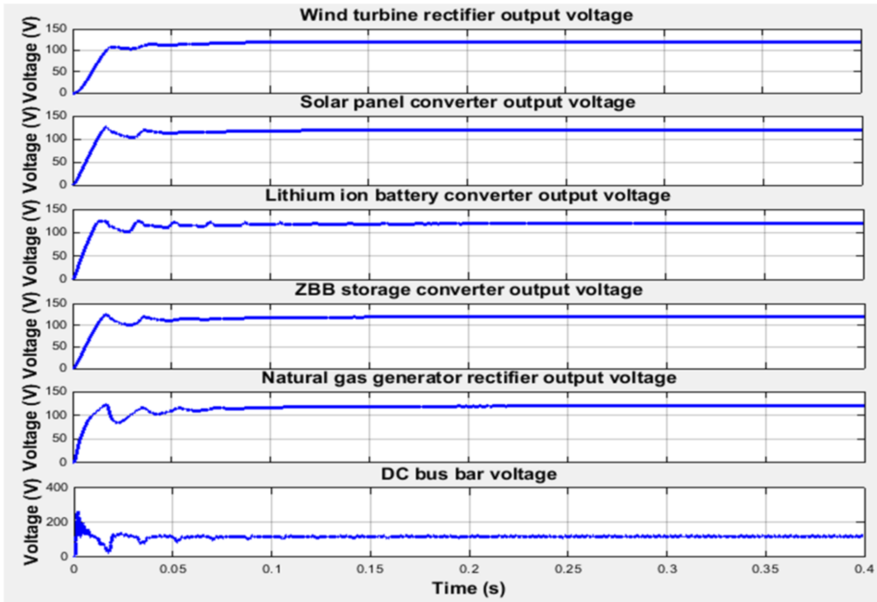
Tertiary control is the upper most level of the control system; it ensures the optimal operation of the microgrid by determining the set points of generation

Entire Microgrid Simulation

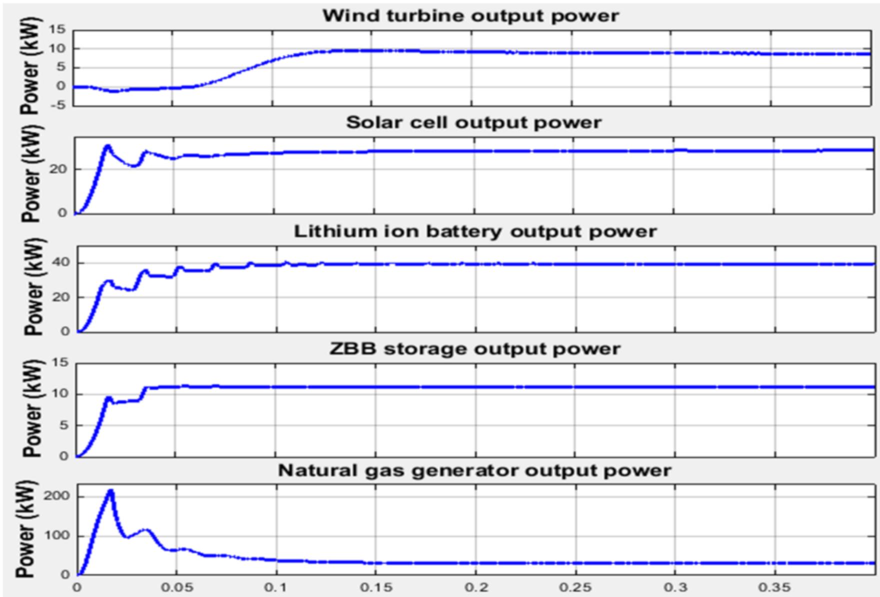




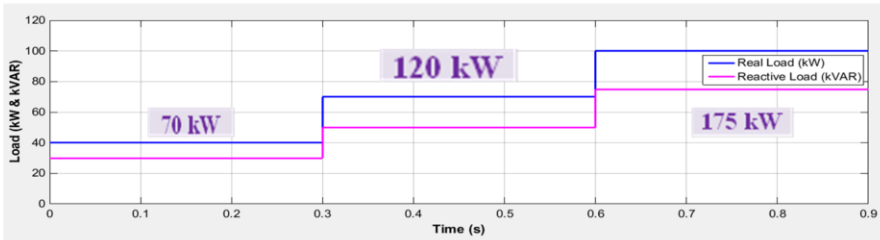
Simulation Result

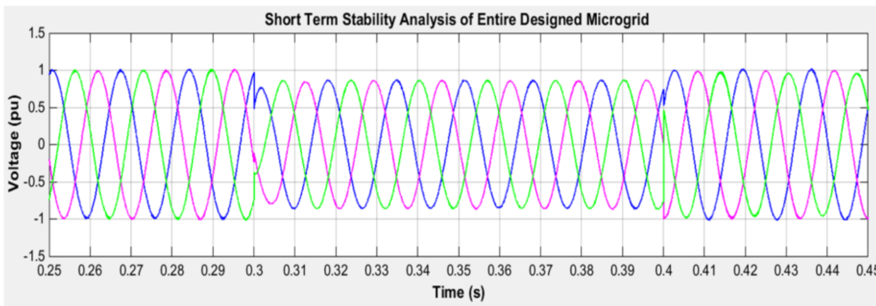


Simulation Result

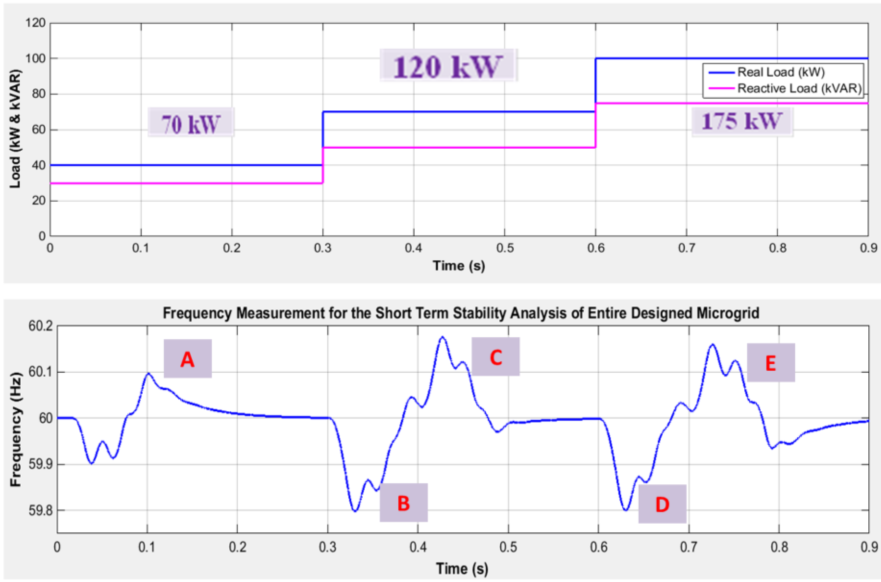


Simulation Result

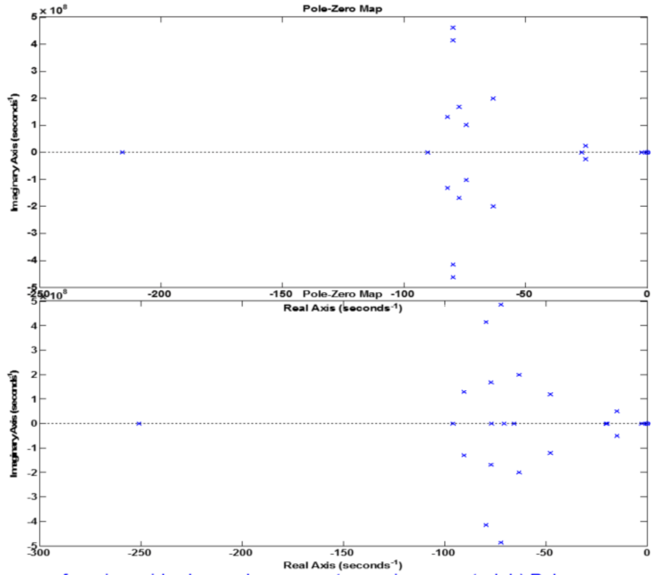




Simulation Result



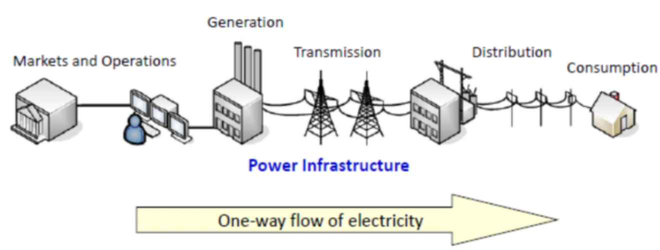
Stability Analysis of the Microgrid



a) Pole-zero map for microgrid, when only energy storage is connected. b) Pole-zero map for microgrid, when energy storage and renewables are connected

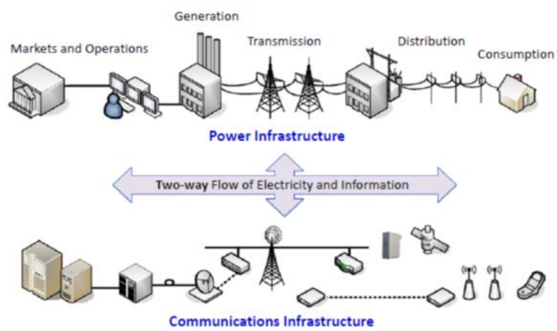
Communication needs

- However, distributed structure of this system including fuel cells, photovoltaic systems, wind turbines, micro turbines, synchronous generators and energy storage elements arises the problem how the measurement and control information receive and transmit between the control center and the field elements.



Communication needs

- Since the SCADA system developed for centralized and decentralized system has not this type of ability, a communication and automation networks need to be established.



May 6, 2018

Thank you for your attention

Questions&Answers