- 5G Smart Grid -
5G Programmable Networks ELEN 6771
Project Presentation

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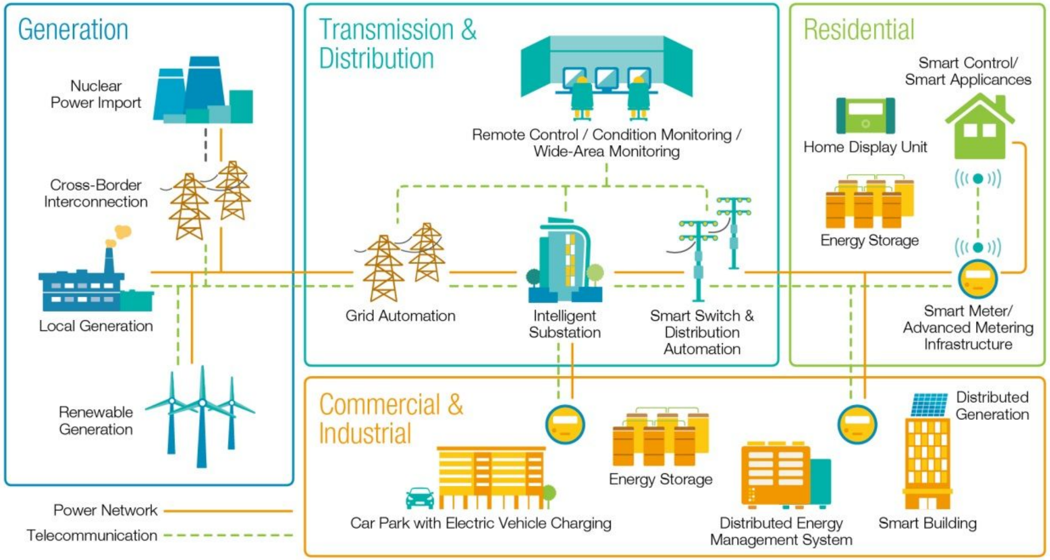
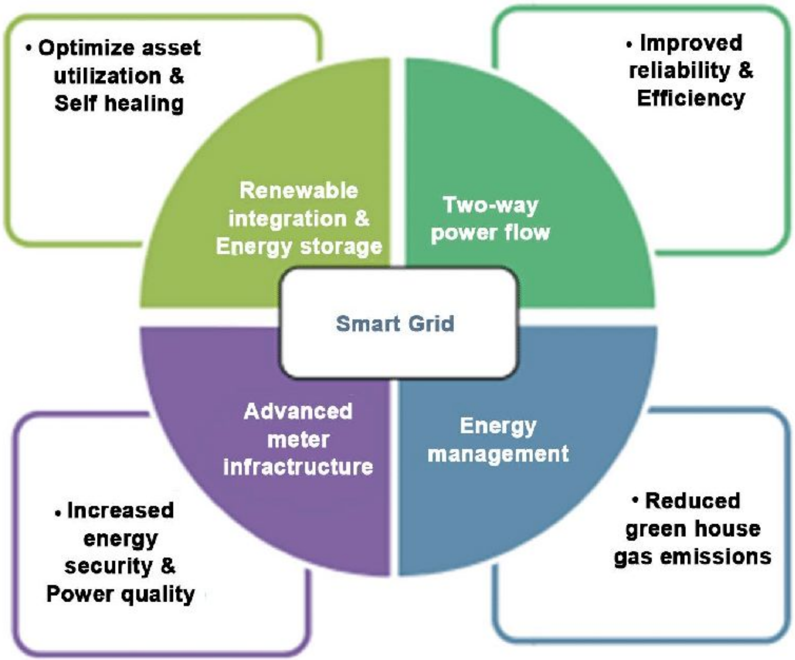
Smart Grid Overview

“Smart grid” refers to a two-way communication network for electricity grid, where wirelessly connected devices

- remotely detecting the status of electricity generations and transmission lines/substations;
- monitoring consumption of user electricity usage;
- adjusting the power consumption of household applications;
- conserve energy and reduce the overall energy losses.



Smart Grid Benefits



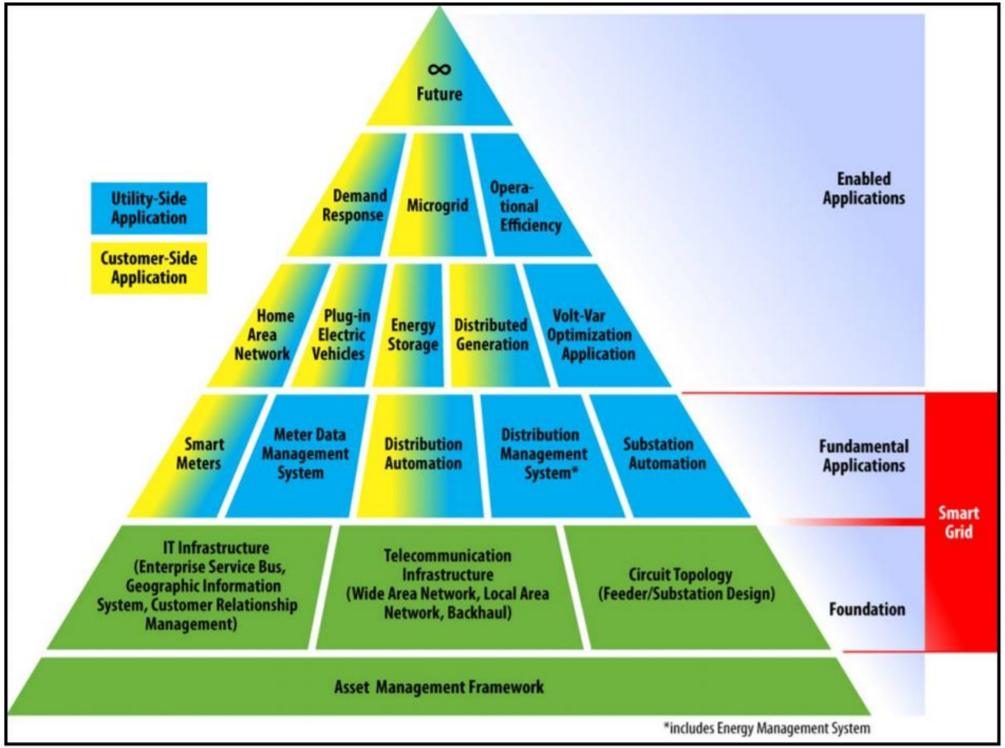
Smart Grid Components

According to Federal Energy Regulatory Commission:

- Wide Area Situational Awareness
- Demand Response
- Electric Storage
- Electric Transportation

Added by National Institute of Standards and Technology:

- Advanced Metering
- Distribution Grid Management
- Cyber Security
- Network Communications



Current State

Intelligent Automation:

- 2-way power-communication exchange - smart metering
  - Smart meters in smart homes can communicate with appliances within the homes, and home appliances can benefit from the knowledge of smart meters.
  - For example, appliances such as an icemaker can function only during off-peak hours of energy use. This two-way communication enables users to be more mindful of their energy consumption.
- Customer-engagement
  - Tesla Solar Roof and Tesla Powerwall
    - Store up power during the day and use the stored power as needed to power the home at night
    - Provide backup power in the event of a utility power outage.
  - In addition, customer-owned power generators can produce power to the grid when it is not available from utilities.

4G/LTE For Smart Grid

Cellular Overcomes Shortcomings of Short-range Communications

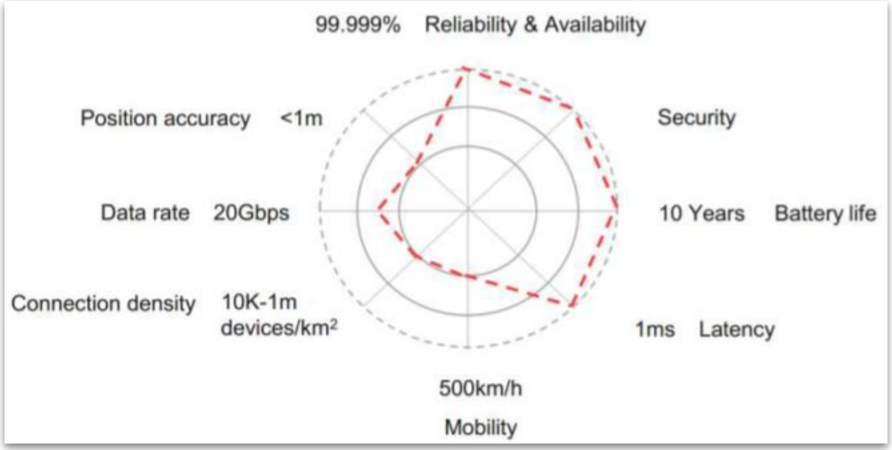
There are three benefit for the adoption of LTE in smart grid:

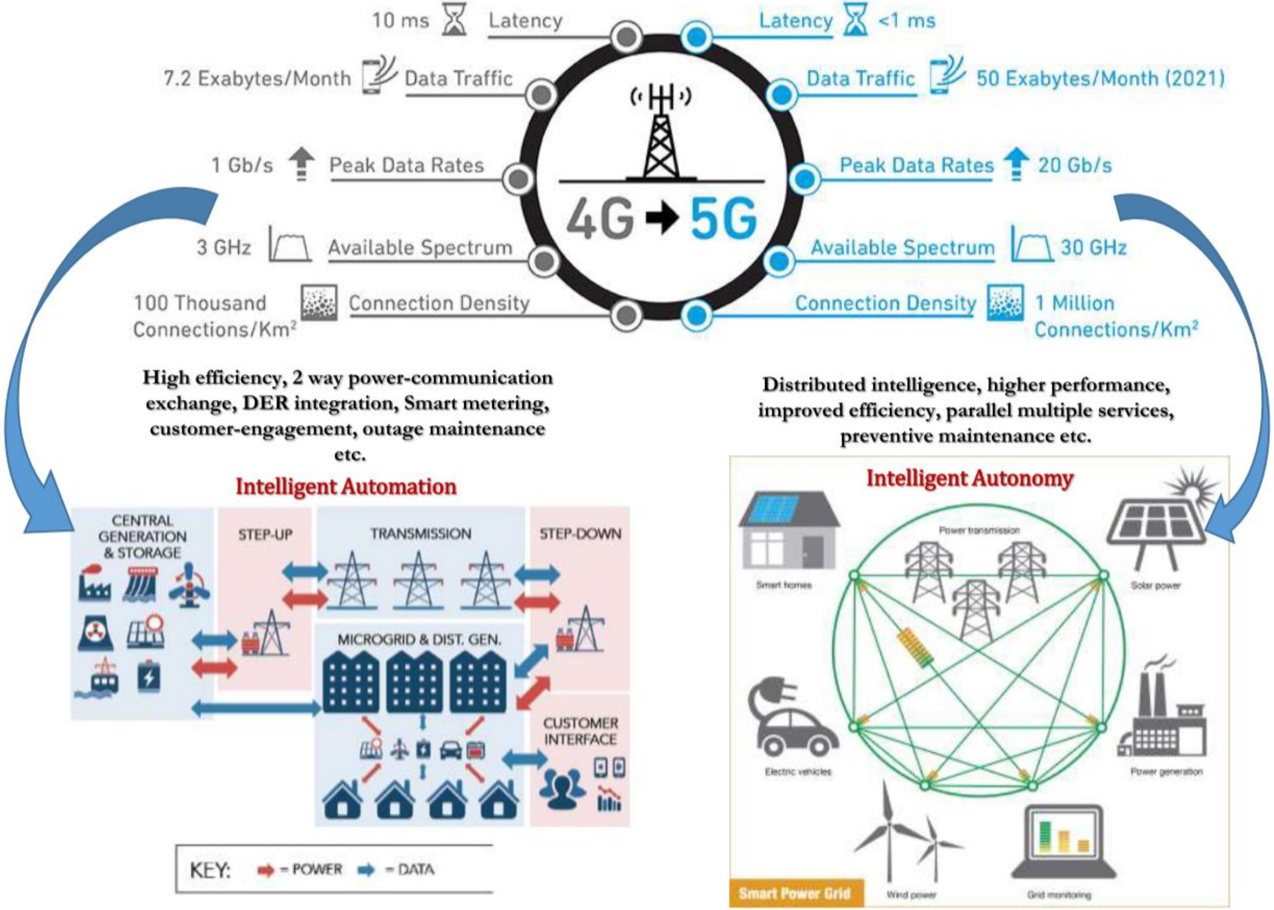
- Long-term usability;
  - LTE offers long-term reliability - reliable for at least the next decade, remain effective well into the 2020s.
- Spectral efficiency;
  - M2M applications such as smart metering require smaller amounts of data transmission, LTE offers much better spectral efficiency, meaning many more smart meter endpoints can be serviced on a given chunk of spectrum.
- Investment of mobile network operators.
  - Huge investments by MNOs in launching 4G LTE networks in smart metering connections and Internet of Things (IoT) applications.

‘Smarter grids’: 5G KPI

The key requirements of smarter grids for communications networks are as follows:

- Massive access: millions of to tens of millions of terminals
- Low latency:
  Distributed power supply management system includes
  - uplink data collection
  - downlink control (very low latency)
- High reliability: 99.999%
- High security
- Extended battery life




10 ms Latency
7.2 Exabytes/Month Data Traffic
1 Gb/s Peak Data Rates
3 GHz Available Spectrum
100 Thousand Connections/Km²
Connection Density
4G → 5G
Latency <1 ms
Data Traffic 50 Exabytes/Month (2021)
Peak Data Rates 20 Gb/s
Available Spectrum 30 GHz
Connection Density 1 Million Connections/Km²
High efficiency, 2 way power-communication exchange, DER integration, Smart metering, customer-engagement, outage maintenance etc.
Intelligent Automation
CENTRAL GENERATION & STORAGE
STEP-UP
TRANSMISSION
STEP-DOWN
MICROGRID & DIST. GEN.
CUSTOMER INTERFACE
KEY: = POWER = DATA
Distributed intelligence, higher performance, improved efficiency, parallel multiple services, preventive maintenance etc.
Intelligent Autonomy
Power transmission
Smart homes
Solar power
Electric vehicles
Power generation
Wind power
Grid monitoring
Smart Power Grid

5G Impact on Smart Grid

5G comes at just the right juncture to enable the energy sector's ongoing evolution to meet the emerging challenges of a "smarter" grid.

Some opportunities and benefits for the next generation smart grid includes

- Rapid detection and response to spikes in demand
  - by for example, mass charging of electric vehicles (EVs)
- Provision of more dynamic energy pricing based on real-time demand
- 5G Network Slicing for Smart Grid

‘Smarter’ Grid: Multi-Slice Architecture

The diversity of power grid services requires a flexible and orchestrated network, high reliability requires isolated networks, and millisecond-level ultra-low latency requires networks with optimal capabilities.

On the 4G network, all services are running on the same network with the same network functions, therefore services may directly affect one another, which does not meet the service isolation or diversified service requirements of the power grid.

5G network slicing addresses these problems and can meet the diversified network connection requirements of the power grid. 5G network slicing is designed to handle specific service requirements, meets differentiated service level agreements (SLAs), and automatically builds isolated network instances on demand.

5G Network Slicing for Smart Grid

On-demand deployment
Network functions are customized according to service requirements.

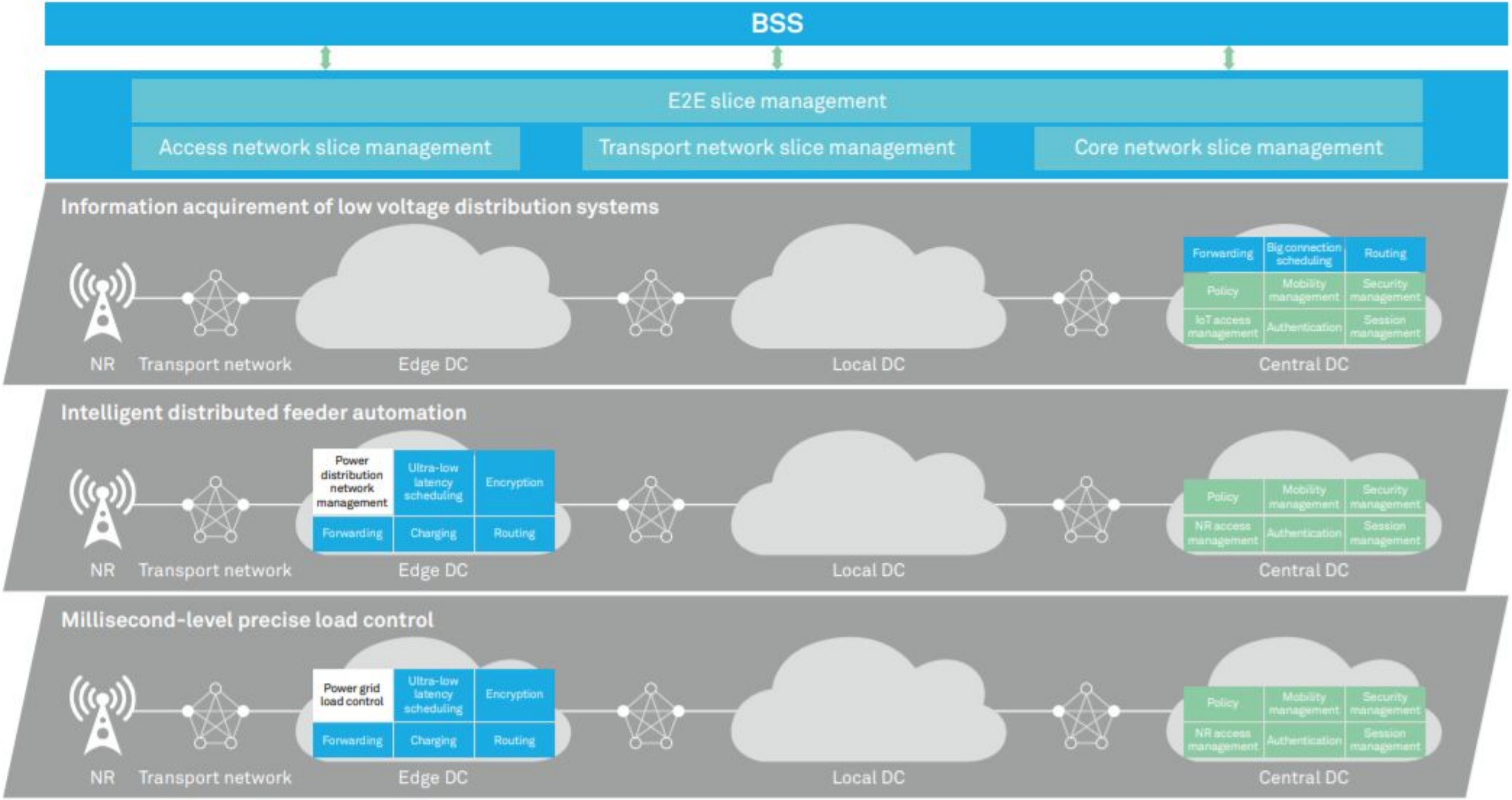
E2E SLA assurance
5G network slicing provides E2E millisecond-level low-latency guarantee.

Network slicing

Isolation
Logically isolated dedicated networks are constructed on the shared telecom infrastructures.

Automation
Shared infrastructures, automatic deployment, and automatic O&M reduce costs.

- Distribution automation
- Power consumption data collection
- New energy vehicle
- Distributed power supply
- Precise load control


BSS
E2E slice management
Access network slice management
Transport network slice management
Core network slice management
Information acquirement of low voltage distribution systems
Forwarding
Big connection scheduling
Routing
Policy
Mobility management
Security management
IoT access management
Authentication
Session management
NR
Transport network
Edge DC
Local DC
Central DC
Intelligent distributed feeder automation
Power distribution network management
Ultra-low latency scheduling
Encryption
Forwarding
Charging
Routing
Policy
Mobility management
Security management
NR access management
Authentication
Session management
NR
Transport network
Edge DC
Local DC
Central DC
Millisecond-level precise load control
Power grid load control
Ultra-low latency scheduling
Encryption
Forwarding
Charging
Routing
Policy
Mobility management
Security management
NR access management
Authentication
Session management
NR
Transport network
Edge DC
Local DC
Central DC

‘Smarter’ Grid: Benefits

By being more responsive to real-time demand and supply fluctuations, smart grids would support the wide scale adoption of EVs, by providing and distributing the extra capacity needed for charging them. This could result in an extra 1.3m EVs on the road by 2025.

According to a report, 5G connected smart grids driving dynamic pricing, enabling two-way communication and allowing citizens to choose where they buy their energy could lead to a 12% reduction in household energy use.

Other savings identified include a possible 3.4B saving annually by mitigating the loss of productivity caused by blackouts and brownouts.

Smart Grid Simulation

A project that simulates a power grid and analyze the power cost related to open circuit, spikes in demand situations at the load line and compare the cost between using 4G and 5G network.

pandapower - an Open Source Python Tool for Convenient Modeling, Analysis and Optimization of Electric Power Systems based on PYPOWER and pandas

Optimal Power Flow - *pandapower* allows solving AC and DC optimal power flow (OPF) problems, which determining the best operating levels for electric power plants in order to meet demands given throughout a transmission network, with the objective of minimizing operating cost.

Simulation Grid Architecture

Grid Connection

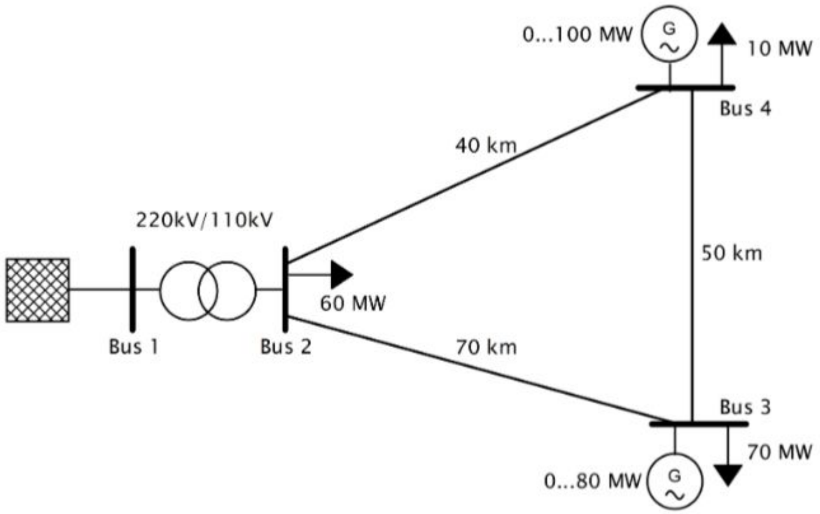
Transformer: 200kV/110kV

Buses: 1,2,3,4

Lines: 40km, 70km, 50km

Loads: 60mW, 10mW, 70mW

Generators: 80mW, 100mW

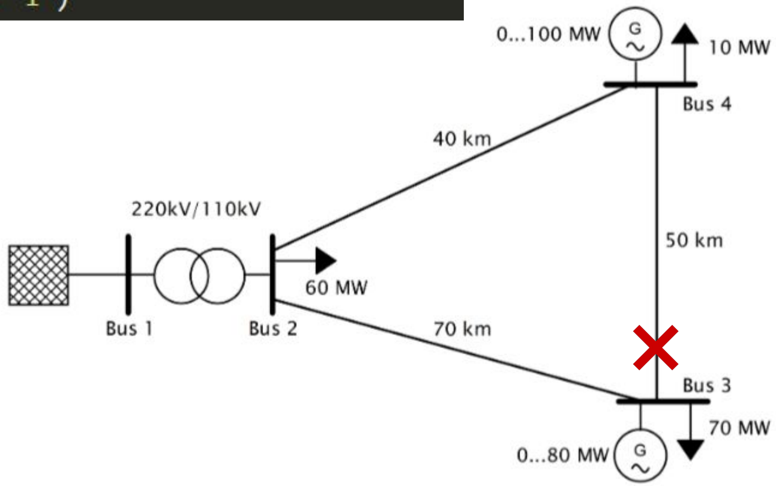


```python
#create buses
bus1 = pp.create_bus(net, vn_kv=220.)
bus2 = pp.create_bus(net, vn_kv=110.)
bus3 = pp.create_bus(net, vn_kv=110.)
bus4 = pp.create_bus(net, vn_kv=110.)

#create 220/110 kV transformer
pp.create_transformer(net, bus1, bus2, std_type="100 MVA 220/110 kV")

#create 110 kV lines
li = pp.create_line(net, bus2, bus3, length_km=70., std_type='149-AL1/24-ST1A 110.0')
pp.create_line(net, bus3, bus4, length_km=50., std_type='149-AL1/24-ST1A 110.0')
pp.create_line(net, bus4, bus2, length_km=40., std_type='149-AL1/24-ST1A 110.0')

#create loads
lo = pp.create_load(net, bus2, p_mw=60, controllable=False)
pp.create_load(net, bus3, p_mw=70, controllable=False)
pp.create_load(net, bus4, p_mw=10, controllable=False)

#create generators
eg = pp.create_ext_grid(net, bus1, min_p_mw=-1000, max_p_mw=1000)
g0 = pp.create_gen(net, bus3, p_mw=80, min_p_mw=0, max_p_mw=80,  vm_pu=1.01, controllable=True)
g1 = pp.create_gen(net, bus4, p_mw=100, min_p_mw=0, max_p_mw=100, vm_pu=1.01, controllable=True)
```

Open Circuit Scenarios

Create a switch on line 2 at bus3, set the switch to be open, compare the power from the grid before and after running optimal power flow

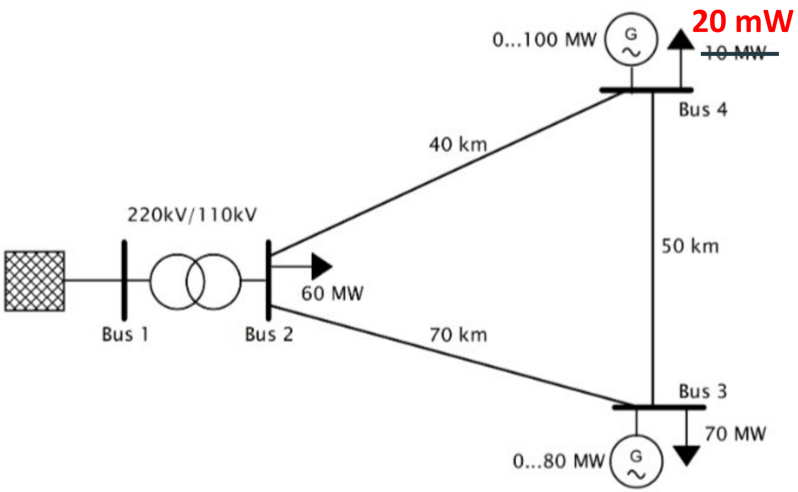
```
li = pp.create_line(net, bus3, bus4, length_km=50., std_type='149-AL1/24-ST1A 110.0')
s1 = pp.create_switch(net, bus3, li, closed=False, et = "l")
```



Spikes in Demand Scenarios

Assume the load at one location increases from 10 mW to 20 mW

```
pp.create_load(net, bus4, p_mw=10, controllable=False)
                          ↓↓
pp.create_load(net, bus4, p_mw=20, controllable=False)
```



Simulation Result

Assuming 40ms (ideal latency when a 4G network is lightly loaded) latency on 4G and 1ms latency on 5G

	Loss on 4G (J)	Loss on 5G (J)	Improvement (J)
Open Circuit	445.5	11.1	434.4
Spikes in Demand	1979.4	49.5	1929.9

5G Smart Grid Challenges

Fiber Optic Infrastructure:

- The high data rate requires a broadband communication infrastructure which means a large amount of upfront investments. Additionally, wireless broadband communication technologies should be implemented where wiring can not be established.

Security:

- Security mechanisms to provide integrity and authenticity are of great importance whereas encryption is applicable and also in cases like metering.

Latency and reliability:

- Smart grid requires low communication latency and high reliability. The standard for the cellular domain changes from ‘average latency’ into ‘worst case latency’ represents the main challenge for 5G development.

Conclusion

Smart grid, as a combination of distributed electric power network and advanced communication and information technologies, places real and diverse challenges on 5G technologies. The power grid nowadays is evolving to mitigate outages and support more renewable sources of energy in the grid. The evolving 5G standard has the potential to become a key enabler for this transformation as it will support a wider area of communication, lower latency, higher security, more reliable and scalable communication, while other communication technologies such as 4G/LTE, fiber optic, WiFi, ZigBee, etc. have been applied to and will remain effective in the current smart grid.

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