Green electronics: ELEC 3202 – 6
Micro grid and storage

Dr Frederic Gardes
University of Southampton

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Overview

• What is a Micro grid?
• Why the need for simulation?
• Modelling and Simulation Rationale
• Renewable Generator Models
• Load Models
• Scenarios and Testing
• Storage
• Conclusions
What is a Micro grid?

- A Micro grid is a small-scale power supply grid or network that is designed to provide power for a small community.

- A key concept that differentiates this approach from a conventional power utility is that the generators are distributed and in close proximity to the loads.

- Potential sources of energy are a mixture of conventional generators (Diesel, Gas, Coal Fired Generators) but it is desirable to include renewable energy sources such as Solar, Wind, Hydro, CHP or Biomass.

- The definition of the “small community” is loose, but may include:
  - isolated rural communities
  - mixed suburban environments
  - academic communities such as Universities or Schools
  - commercial areas or industrial sites.
What is a Micro grid?
Why the need for simulation?

- **Power Balance Analysis**
  - It is essential to understand the overall energy and power balance of the system. This enables the correct mix of generators to be assigned to the load taking into account the prevailing environmental conditions (wind speed, solar characteristics etc).

- **Dynamic Behaviour Analysis**
  - If solar panels and wind turbines are used, for example, then the behaviour will change potentially very rapidly and radically depending on the weather conditions.
  - Simulation can be used to predict the instantaneous power and electrical characteristics across a wide range of scenarios.

- **Detailed Generator Analysis**
  - Simulation is an essential tool in understanding the detailed performance characteristics of motors, generators, power electronics and loads.
Modelling and Simulation Rationale

• The main requirement for the development of the Micro grid library of models was to be able to simulate the power balance behaviour of a variety of generators, with a variety of loads in a dynamic context.

• It was not necessary at this stage to implement detailed models of power electronics elements such as inverters or converters – these are well understood.

• It was also important to have more details than was perhaps available in previous simplistic models, to ensure that realistic weather conditions could be taken into account.

• While the models may be simple at this stage, by taking an integrated multi-level approach, it could be easily extended to include detailed component models of generators, or loads, or power electronics modules.
Modelling Generators

• In a Microgrid, there are a variety of potential sources of energy including Solar Panels, Wind Turbines, CHP (Combined Heat and Power) or Biomass, to name a few.

• These can co-exist alongside the ‘conventional’ utility supply

• In this work it was proposed to investigate the potential for utilising Solar and Wind generation on a small scale domestic level, because:
  – CHP has been relatively well understood for some time and is still dependent on a (non-renewable) Gas supply
  – Solar and wind power are totally dependent on prevailing weather conditions
  – The domestic situation is a small dynamic load, with a wide range of operation
  – The philosophy of the Microgrid in this project is to make small incremental improvements over a large number of locations to make a big difference in emissions and renewable energy usage
Modelling Photovoltaics

- Using the irradiance (power density) of sunlight, the basic output of a photovoltaic (PV) panel can be estimated:

\[ \text{Power}_{\text{solar}} = \text{Area} \times \text{Irradiance} \times \text{Efficiency} \]

- This assumes a linear efficiency, whereas in fact the efficiency varies according to the irradiance. This can be estimated using a function of the form:

\[ \eta = \eta_{\text{max}} \left(1 - e^{-kp}\right) \]
Modelling Photovoltaics

- This enables a useful non-linear model of the panel to be created that models the basic power behaviour of the PV cell with reference to the irradiance.

- While more detailed electrical models do exist, and can be used, they do not give much more information in this context than the behavioural model proposed here.

- In the model library, therefore, both models are included.
Using the PV Model

• The PV array model can be characterised for a specific device, either from performance data, or by simulating a detailed electrical model.

• The test results are shown below for a typical daily solar cycle in the UK.
Wind Turbine Generator Modelling

- Wind turbines have commonly been modelled as machines (Induction or PM or even DC), with a synchronous output. This is useful for analysing the machines detailed behaviour.
- In this project, it is more useful to understand the macroscopic behaviour, so a simpler model has been used, based on the basic aerodynamic equation for a wind turbine:

\[ P_w = 0.5C_p \rho V^3 A \]

- Where \( C_p \) is the turbine power coefficient, \( P_w \) is the output power of the turbine, \( V \) is the wind velocity (m/s), \( A \) is the swept area of the rotor (m\(^2\)) and \( \rho \) is the density of air (1.225 kg/m\(^3\)).
  - In practice, the turbine power coefficient is variable depending on the wind speed, and the power is also limited by a maximum rated speed of the turbine, and the rotor will either be limited to a maximum speed, or will shut down in the event of dangerous high winds.
Modelling the Power Coefficient

Using behavioural models, the power coefficient can be modelled using the tip speed (ratio of blade tip speed $\omega$ (rotational velocity in rad/s) to wind speed $v$):

$$\lambda = \frac{\omega}{v}$$

The resulting variation is modelled approximately thus:-
Load Modelling

• The domestic loads were estimated from the daily usage of a typical family dwelling, with the power demands from electrical appliances monitored over a 24 hour period.
• There are obvious peaks in demand in the morning and early evening.
• This is averaged data, and will depend on the time of year and prevailing weather and light conditions.
• Different load profiles can be obtained for different family groups and usage patterns.
Scenarios and Testing

• In this basic scenario, the domestic load is supplied in addition to the existing utility, by a bank of PV cells and a small wind turbine
• The system also includes a limited amount of battery storage to help even out the supply and demand variations
• Simulations were carried out to investigate the characteristics of this configuration under realistic weather conditions and load profiles
Scenarios – Generated Power

- The total generated power over a typical 24 hour period was as shown.

- It is interesting to note that the bulk of the generated power is obtained from the middle of the day, and there is little overlap with the load profile.

- Scenario Configuration:
  - PV area = 20 m$^2$
  - Wind Turbine Area = 5 m$^2$
  - Storage = 2400 Wh
Scenarios – Energy Balance

• By comparing the generated and load power & energy over the period, the nett energy usage can be calculated.

• It is clear that for the initial configuration, there is an energy deficit.

• The simulation results can be used to assist in sizing the system, checking whether the approach is economically viable, and testing the reliability of the system under weather extremes (such as no sunlight or wind for long periods).
Conclusion

- Configurations and conditions can be evaluated quickly and simply
- The modelling approach has allowed the integrated simulation of high level behavioural and detailed component models
- The open, transferable and extendable nature of the models make the approach useful across a wide range of similar scenarios and configurations
## Energy storage: electrochemical

<table>
<thead>
<tr>
<th></th>
<th>Lead acid</th>
<th>Nickel cadmium</th>
<th>Sodium sulphur</th>
<th>Lithium ion</th>
<th>Sodium nickel chloride</th>
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</thead>
<tbody>
<tr>
<td><strong>Achieved/demonstrated upper limit power</strong></td>
<td>Multiple tens of MW</td>
<td>Tens of MW</td>
<td>MW scale</td>
<td>Tens of kW</td>
<td>Tens/low hundreds of kW</td>
</tr>
<tr>
<td><strong>Specific energy (Wh/kg)</strong></td>
<td>35 to 50</td>
<td>75</td>
<td>150 to 240</td>
<td>150 to 200</td>
<td>125</td>
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<tr>
<td><strong>Specific power (W/kg)</strong></td>
<td>75 to 300</td>
<td>150 to 300</td>
<td>90 to 230</td>
<td>200 to 315</td>
<td>130 to 160</td>
</tr>
<tr>
<td><strong>Cycle life (cycles)</strong></td>
<td>500 to 1500</td>
<td>2,500</td>
<td>2,500</td>
<td>1,000 to 10,000+</td>
<td>2,500+</td>
</tr>
<tr>
<td><strong>Charge/discharge energy efficiency (%)</strong></td>
<td>~80</td>
<td>~70</td>
<td>up to 90</td>
<td>~95</td>
<td>~90</td>
</tr>
<tr>
<td><strong>Self discharge</strong></td>
<td>2 to 5% per month</td>
<td>5 to 20% per month</td>
<td>#</td>
<td>~1% per month</td>
<td>#</td>
</tr>
</tbody>
</table>
Energy storage: electrochemical

Capital cost ($)

Energy (kWh) x Life (cycles) x Efficiency

Rated Power (MW)

Discharge Time (h)
Energy storage: Pumped storage

- Pumped Storage is a “conventional” energy storage mechanism, widely used in reservoirs
- The main issue in general is the scale required for meaningful energy storage

- How much energy stored?
- Simple: Potential energy based on volume (mass) and height
- 1 cubic meter of water = 1000Kg
- Potential energy = m\times g \times h
  - M = mass
  - G = gravity
  - H = height
Energy storage: Pumped storage

• Consider a cubic meter, 100m high
• \((1000 \text{ kg})(10 \text{ m/s}^2)(100 \text{ m}) = 10^6 \text{ J}\), or one megajoule.
• This has a stored energy of \(\sim 0.277 \text{kWh}\)

• Compare this to a single Lead Acid Battery
  – Storage = 100Ah
  – Voltage = 12V
  – Energy = 1.2kWh
Energy storage: Mechanical Flywheel

- Mechanical Flywheels are used to store energy in smaller scale systems
- The principle is the speed it takes to rotate an inertia, and this results in stored energy

$$E_k = \frac{1}{2} \cdot I \cdot \omega^2$$
Energy storage: Mechanical Flywheel

- For example, consider a flywheel of mass 100Kg.

- If this is running at 20000rpm, with a diameter of 600mm,
- Inertia \( I = m(100\text{kg}) \times R (0.3\text{m})^2 \)
- then the resulting energy storage is 5.48 kWh
Energy storage: Mechanical Flywheel
Energy storage: Summary

Electricity Storage Technologies

- Compressed Air
- Pumped Storage Hydro
- Batteries
- Long Duration Flywheels
- High Energy Capacitors
- High Power Capacitors
- High Power Flywheels
- Superconducting Magnetic Storage

Worldwide installed storage capacity for electrical energy:

- Compressed Air Energy Storage: 440 MW
- Sodium-Sulfur Battery: 316 MW
- Lead-Acid Battery: ~35 MW
- Nickel-Cadmium Battery: 27 MW
- Flywheels: <25 MW
- Lithium-Ion Battery: ~20 MW
- Redox-Flow Battery: <3 MW

Over 99% of total storage capacity

Source: Fraunhofer Institute, EPRI
Conclusion

• Storage is a current issue of debate in the renewable energy field

• Hydroelectric storage is the most common source of storage today but this is only possible for large scale storage

• Battery storage is still the most useful and manageable form for micro grid and household environment, and as such is the one in common use today.