Modeling vehicle to grid system for frequency regulation in a microgrid

SEC Autumn School

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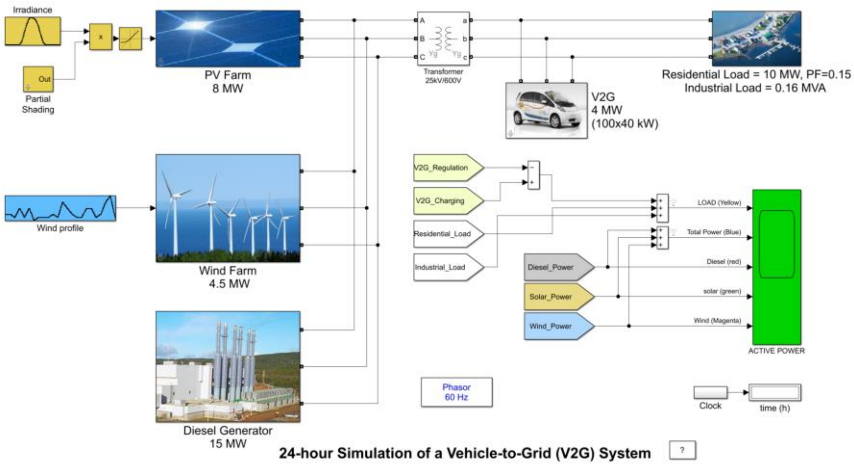


Goals:

- Run a Matlab Simulink model which simulates a microgrid during one day.
- Observe the power profiles of power production and consumption, electric vehicles (EVs) charging and power frequency regulation.
- Recognize and analyze the contribution of each generation system.
- Run different scenarios by changing the input parameters to investigate different power profiles and the impact of the Vehicle-to-Grid system on peak regulation.

Requirements: Matlab Simulink version 2018b or newer.

Instructions: Students can work in pairs. Mixing electrical engineering students with students having a different background is recommended but not necessary. Follow the steps A to C described below and briefly answer and discuss within your group the questions in orange. When you come to a new "Figure" you can save a screenshot on your computer to be able to compare the results from different scenarios. At the end on the lab (Step D) you will investigate further the model by creating new scenarios according to your personal interest and/or following the suggestions.

Let's get started!

Step A – Get acquainted with the model components

Open Matlab and run *power_V2G* in the Command Window. The Simulink model will automatically open.

Look at the different parts of the model. The microgrid is divided into four parts:

1. Diesel generator, acting as the base power generator;
2. Renewable energy generation source, which combines a PV farm with a wind farm;
3. Grid load, which has approximately the size of a community of a thousand households during a low consumption day in spring or fall;
4. A V2G system of 100 electric vehicles by default.

1. Diesel Generator

The diesel generator balances the power consumed and the power produced by the renewable sources. More specifically, it balances the grid frequency by controlling how much active power is injected into the grid. The control is implemented with a PI controller of the rotational speed of the generator.

2. Renewable Energy

There are two sources of renewable energy in this microgrid.

First, a PV farm produces power proportional to three factors: the size of the area covered by the PV farm, the efficiency of the solar panels and the irradiance data. A partial shading due to cloud coverage, for example, has been introduced around 12:00 (after time step 43000) for the duration of 5 minutes.

Second, a simplified model of a wind farm is simulated to produces electrical power. When the wind reaches a nominal value, the wind farm produces the nominal power. The wind farm disconnects from the grid when the wind speed exceeds the maximum wind value, until the wind gets back to its nominal value.

3. Load

The load is composed of a residential load and an asynchronous machine that is used to represents the impact of an industrial inductive load (like a ventilation system) on the microgrid. The residential load follows a consumption profile with a given power factor.

4. Vehicle-to-Grid

The V2G has two functions: Controls the charge of the batteries connected to it and uses the available power to regulate the grid when an event occurs during the day. The block implements five different car-user profiles:

Profile #1: People going to work with a possibility to charge their car at work. They are employed from 8 to 4pm, and drive their EVs for 2 hours during this period with available charging stations near offices and homes. They represents 35 % of the total EVs.

Profile #2: People going to work with no possibility to charge their car at work. They are employed from 8 to 4pm, and drive their EVs for 2 hours during this period without available charging stations near their offices. They represent 25 % of the total EVs.

Profile #3: People going to work with a possibility to charge their car at work but with a longer ride. They are employed from 8 to 4pm, and drive their EVs for 3 hours during this period with available charging stations near offices and homes. They represent 10 % of the total EVs.

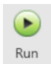
Profile #4: People staying at home. They do not drive their EVs thorough out the day and their cars are connected to the grid for 24 hours. They represent 20 % of total EVs.

Profile #5: People working on a night shift and with no possibility to charge their car at work. They work from 20pm to 4am, and drive their EVs for 2 hours during this period without available charging stations near offices. They represent 10 % of the total EVs.

More information about each block and sub-block is available at the top of the window that opens when double clicking on the block.

Step B – Run the model without EVs

The first simulation you are asked to run, will not consider the contribution of the EVs. Double click on the V2G block and remove the check on box *V2G on*. The EVs are now disconnected from the grid during the entire simulation. In other words, we assume that there are no electric vehicles interacting with the microgrid.

Run the model by clicking the 

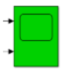
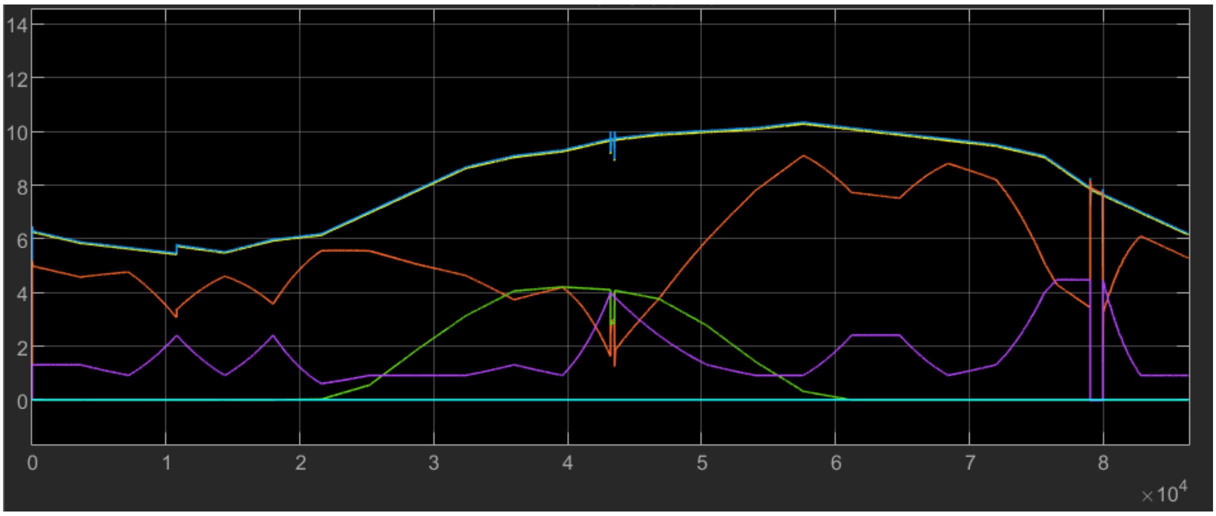
bottom and look at the *scopes*  . The scopes are blocks that will allow you to visualize the input and output by means of graphs. In particular, open the scope that shows the *Active Power*. Note that the simulation lasts 24 hours, however, the horizontal axis shows you the time steps in seconds. You can add a legend by clicking on *View -> Legend* to help you recognize each profile.

Figure 1 – Open and look at the Active Power scope. In the example below: MW on vertical axis – seconds on horizontal axis.



Consumption

- The consumption (yellow) follows a typical pattern similar to a normal household consumption.

Did you expect such profile? Can you describe how a typical patter looks like then?

Production

- The diesel generator (red) balances the power consumed and the power produced. Note the kick-off of the asynchronous machine early at the third hour.
- The solar intensity follows a normal distribution where the highest intensity is reached at midday (green). A partial shading at noon affects the production of solar power.
- The wind (violet) varies greatly during the day and has multiple peaks and lows. Note: when the wind speed reaches the maximal value (15 m/s), the wind farm disconnects from the grid. When the wind speed is between the nominal speed (13.5 m/s) and the maximal value, the power is fixed to 1 p.u.

How is the total power profile (blue) calculated?

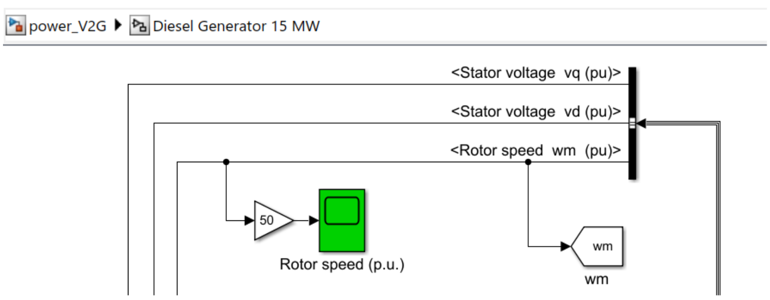
What is the power peak for this day, approximately?

What happens at midday? Zoom in and discuss what happens during the fault. What production facility is affected and how?

Grid frequency

Let's now look at what happens to the grid when the PV farm experiences the disturbance at midday. We can determine the frequency deviation of the grid by looking at the rotor speed of its synchronous machine. You can find the scope inside the block called *Diesel Generator*.

You can multiply the rotor speed (p.u.) with a factor of 50 using a gain in order to get the frequency in Hz of the grid, like in the suggestion below:



According to some standards, an acceptable frequency variation in the power grid should stay in the interval [49.9 50.1] Hz. We will keep this interval as a reference to evaluate the differences between the scenarios.

Figure 2 – Open the Rotor speed scope and zoom close to the unbalances experienced at midday. Does the unbalance in the grid stay in the acceptable range?

Step C – Change the inputs to activate the V2G regulations and evaluate the new outputs

Scenario 1

Activate the V2G function by opening the V2G block and clicking on the *V2G on* checkbox. In order to visualize the results in a more complete way, add profiles of *Regulations* and *EV charging* as shown below.

To do so, bring the cursor on the scope, wait until you see a plus sign (+, which indicates that you can add an input or port), click and drag the wire till the *V2G_Regulation* and *V2G_Charging*. If you Simulink version does not show the plus sign, you can right click on the block, select *Signals and ports -> Number of input ports* and add a port. To visualize the name on the wire, double click the wire and insert the text.

If you feel confident with the Simulink tool, you can create subplots to show the production and consumption curves separately: this will help you to visualize the results and to be able to keep the same horizontal axis when zooming in.

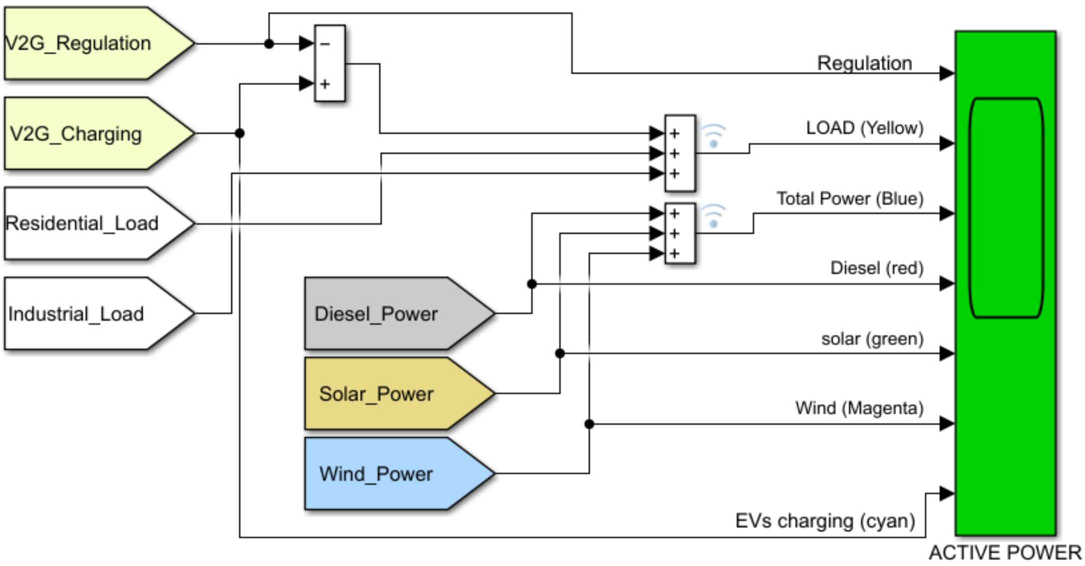


Figure 3 – Look again at the Active Power scope.

What is the power peak in this scenario?

At what time does EV charging effect the consumption the most?

Figure 4 – Open the Rotor speed scope and zoom close to the unbalances experienced at midday. Does the unbalance in the grid stay in the acceptable range?

Scenario 2

In the first scenario, there was a 1:10 ratio between the electric cars and the households. The total number of EVs considered was 100. What happens if we increase the penetration of EVs in this microgrid to 200?

To do so, double click on the V2G block and multiply by a factor 2 the number of cars in each profile. Run again the model. If the simulation crashes, you can go to *Model settings -> Solver reset method* and select *Robust* instead of *Fast*.

Figure 5 – Open the Active Power scope.

What is the power peak in this scenario compared with the scenario 1?

Figure 6 – Go to the Rotor speed scope and zoom close to the unbalances experienced at midday. Does the unbalance in the grid improved compared to scenario 1?

Step D – Change the inputs as you wish! And discuss within your group or with the class.

Now that you got acquainted with the model, feel free to change the inputs as you wish. If you are interested, you can look at the different blocks to better understand the code. Some ideas for further simulations and discussion follow.

1. What happens if you change the number of cars in different profiles? What are the car profiles that contribute to the V2G regulation?

2. If you look at the disturbance created by the loss of wind power around 22:00 (or about 80000 seconds) why are the oscillations bigger than the once at midday?

3. What happens to the frequency if you increase the load power? For example, if you increase the residential load by 30 %.

4. Can we say that V2G is basically an increase in the capacity of frequency regulation? But how much can we rely on that?

5. Assuming that the EVs in our microgrid do not want to participate to V2G, would you be able to simulate their contribution to the load without regulation? If you keep the contribution of the change but neglect the V2G regulation, how does the frequency change? Are the oscillations significantly different?

Try to run the simulations you believe interesting and discuss them with the other students.

Well done, you have reached the end of this lab!