Prototype

Pablo de Juan Vela [1]
[1]eRoots, Barcelona, Spain

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1 Grid Definition

We chose a modified version of the IEEE39 [1] to demonstrate the capabilities of COLMENA. The original grid consists of 39 buses, 10 synchronous generators and 19 loads. In order to better demonstrate the capabilities of COLMENA we switch the generators to converters that can be operated in GFM(mode) or GFL(mode). The converter in GFM mode simulates a spinning mass mirroring the behavior of a generator. We define the grid as a dynamic system that evolves over time.

1.1 Grid Dynamics

Changes in the Grid's topology

This type of changes are the ones directly affecting the connection status of an electric device. For example, switching a generator off or having a line failure.

Change in Modes

A change in mode changes the internal definitions and states of the device. Although the power exchanges in the bus stay similar just after the change the control logic behind it can be completely changed.

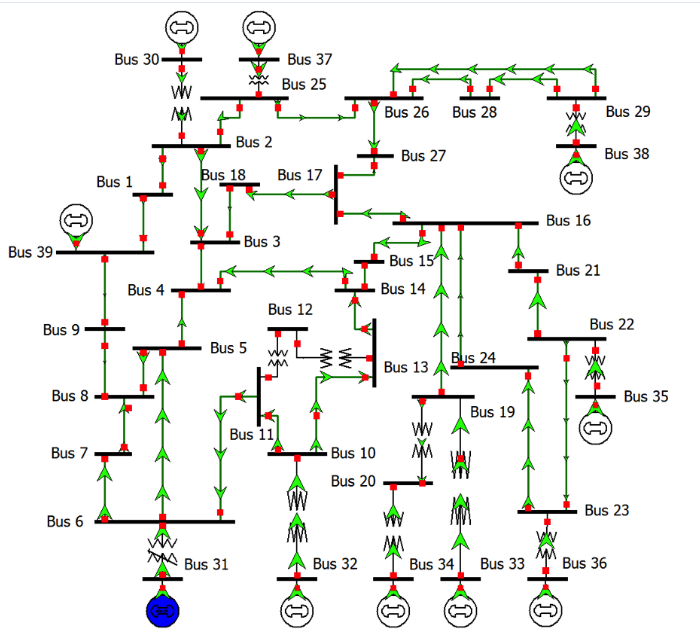

Figure 1: Your caption here

Change in devices Set Points

Here the control logic is not directly changed but some of the reference values that describe the desired steady state values. For example a reference voltage value for a converter.

2 Roles & Agents

2.1 Agents

In the simulation we consider 6 different agents. Specifically, three of the agents are coupled to converter devices, two of them are coupled to generators and one of them is coupled to a load. At initialization, the agent receive their coupled device data from Andes. The pairings are defined before the simulation starts. We define the agents with the following hardware tags:

- **Generator Compatible**

- **Converter Compatible**
- **Load Compatible**

We use this different hardware so that an agent monitoring a specific type of device can only execute the roles of compatible with that device. For example, the LoadSheddingRole only makes sense if executed in a agent thats monitoring a Load device. Therefore, adding both the hardware to the agent definition and the requirement to the role definition ensures that the roles activated in that agent are compatible with the device.

2.2 Roles

For this simulation use case we include different roles that participate in the frequency response. The different roles govern the agent's behaviors during the simulation. It is also through these roles that the agents can modify the grid.

Role	Requirement	Behavior	KPI
Monitoring	None	Monitors its device's data	NA
Load Shedding	Load Compatible	Reduces the device's load	$\omega \notin [\omega_{min}, \omega_m ax]$
Automatic Secondary Response	Generator or Converter Compatible	Activates automatic response	$\omega \notin [\omega_{min}, \omega_m ax]$
GFM	Converter Compatible	Activates the GFM Role	$\omega \notin [\omega_{min}, \omega_m ax]$

Table 1: Summary of Roles

Monitoring Role

This role runs persistently in every agent that is paired with a physical device. When this role initializes it stores the initial values of the devices states. Then it sends periodic requests to the ANDES simulation to keep the stored values updated. Additionally, it publishes the key metrics that are important for the service in COLMENA. In this case the published metrics are the voltage of the bus the device is connected to and the generator's frequency if the agent monitors a generator. We aim to run this run continuously, this would mean syncing the stored data with a high frequency. In order to run the role continuously is executed in agents with the "EAGER" politic.

Automatic Generation Control

This role is activated when the frequency is seen by the agent is out of the admissible interval. This role is only compatible with devices injecting power to the grid such as generators and converters. The rol defines a PI controller with a feedback loop that adjust the power delivered by the device. The role reads the frequency value from the agent data and then sends the change in power to the device as a change of parameter.

GFM Role

This role changes the operation mode of GFL converters to GFM to converters. It is activated when the frequency seen by the device is out of the admissible interval. When the role ends its execution the agent changes the mode of the converter back to GFM.

Load Shedding Role

This role is engaged when the frequency is out of the admissible interval and the Automatic Generation Response has been running in a nearby generator for at least 30 seconds. When activated the agent reduces the consumed load linearly, when the role is disengaged the change is reversed.

3 Grid Simulation

3.1 Andes Interaction

The grid is simulated through the ANDES package. The Grid is initialized with the values from the power flow results. Afterwards Andes is deployed in a port where the different agents can request information from it.

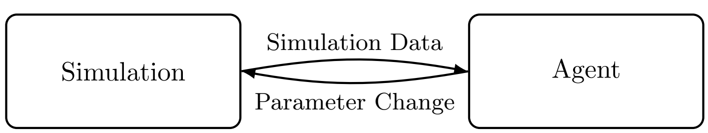

Figure 2: Interaction between the simulation and agent.

In this use case the agents only receive data from the device their paired to and they only change the parameters of the same device. This is a constraint that comes from the agent-device pairing that we envisioned in the beginning.

Algorithm 1 Grid Simulation

```
Initialize grid states x to x_0 with the Power Flow results.
for agent in Agents do
    for device in controllable devices do
        if device is not controlled then
            Pair agent to device
        end if
    end for
end for
while not Stop do parallel do {
    }Receive Parameter Changes
    Run Simulation Online
end while
Finalize the result.
```

3.2 Simulation

The grid simulation starts from a steady-state solution that was computed before. In order to model the dynamic changes in the grid we introduce multiple changes. These changes are variable loads simulating the variability of the consumption in electric power and also line failures. These changes introduce perturbations to the grid and force the agents to respond. The objective is to showcase the different actions that the agent will perform to the grid to maintain the grid's frequency stability. The simulation runs for 70s and observe the different transient responses compared to the simulation with just the automatic response.

Perturbation	Device	Change
Line Failure	Line 2	Line disconnected at $t = 2$s
Load Reduction	Load 1	Load increases 5% from $t = 10$s to $t = 20$s
Load Increase	Load 2	Load decreases 5% from $t = 20$s to $t = 30$s

Table 2: Table of non-agent induced changes in the grid

Results