Hochschule
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Energy management in a hybrid power system

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Agenda

- Reasons for expansion of renewable energy on Barbados
- Background information of Barbados
- Challenges to maintaining grid stability
- Controller structure of different power plants
- Structure of the energy management system
- Simulation results
- Conclusion

Reasons for expansion of renewable energy on Barbados

- 100 % access to electricity but remains over 90 % dependent of imported fossil fuel resources for:
  → electricity generation
  → transportation sector
- Expansion of renewable energy sources will increase the independence of fossil fuel imports
  → current installation capacity of 30 MW
- Cost savings from utilizing domestic renewable energy resources
- Lower carbon emissions

Background information of Barbados

Solar Resource:

- **average daily solar insolation of 5.7 kWh/m²**
- **irradiance peaks during April through August**
- **cloudy to partly cloudy skies during August to December**
- **needed installation capacity for 100 % renewable energy system ranging between 200 – 270 MW**

Background information of Barbados

Wind Resource:

- **wind speed range between 4.8 and 8.0 m/s at 10 m hub height**
- **lowest wind speed between August and September**
- **472 MW of wind turbines may be installed**

Pumped-storage power plant:

- **installed capacity: 190 – 300 MW**
- **storage capacity: 1 to 5 GWh**
- **one area with an altitude drop: 240 – 270 m**

Background information of Barbados

- **Diesel generators:**
  - → **Spring Garden: 155 MW**
  - → **Garrison: 13 MW**
  - → **Seawall: 73 MW**

  Sum = 241 MW
- **Peak demand: 159 MW**

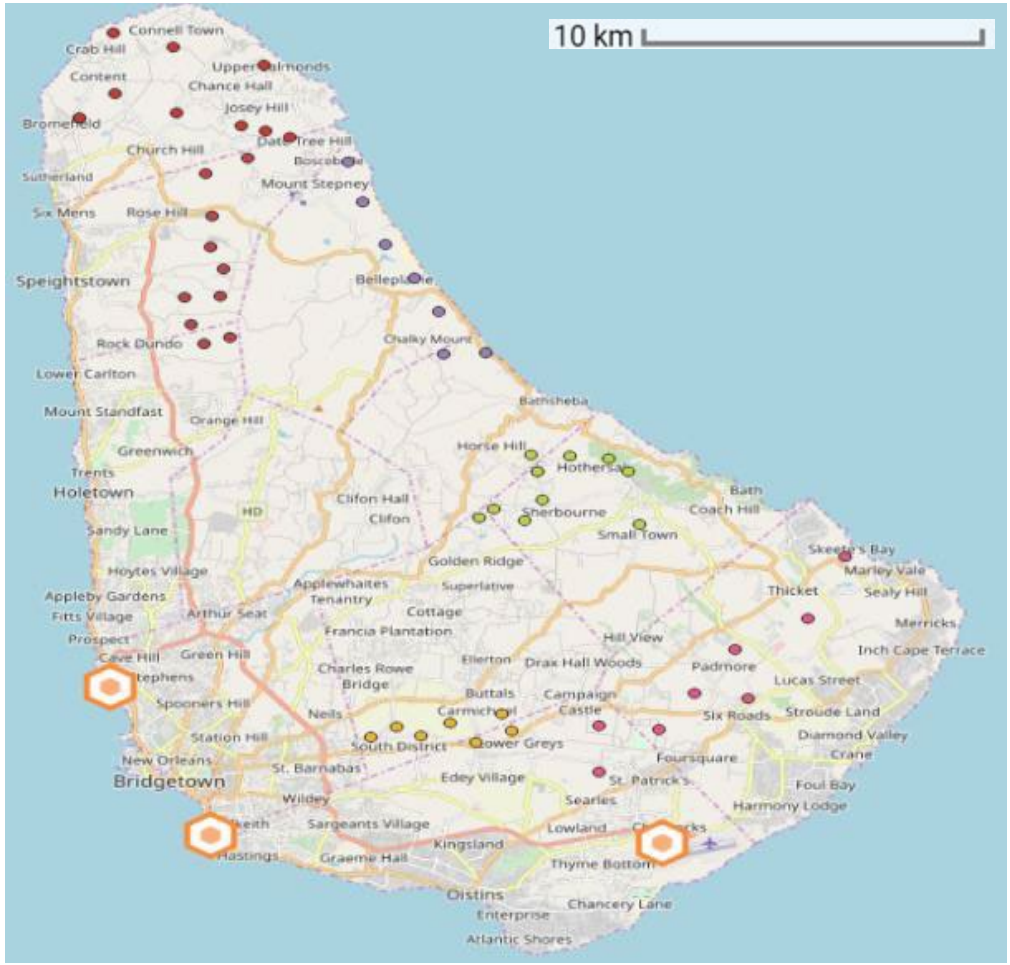

Figure 1. The island of Barbados

Challenges to maintaining grid stability

- **There are 4 different generating plant:**
  - **→ Photovoltaic**
  - **→ Wind turbines**
  - **→ Pumped-storage power plant (storage)**
  - **→ Diesel generators (backup-system)**
- **Control of grid frequency and voltage in case of:**
  $P_{PV} + P_{wind} \geq P_{load}$
- **Photovoltaic and wind turbines have to change from PQ to VF control mode**

Challenges to maintaining grid stability

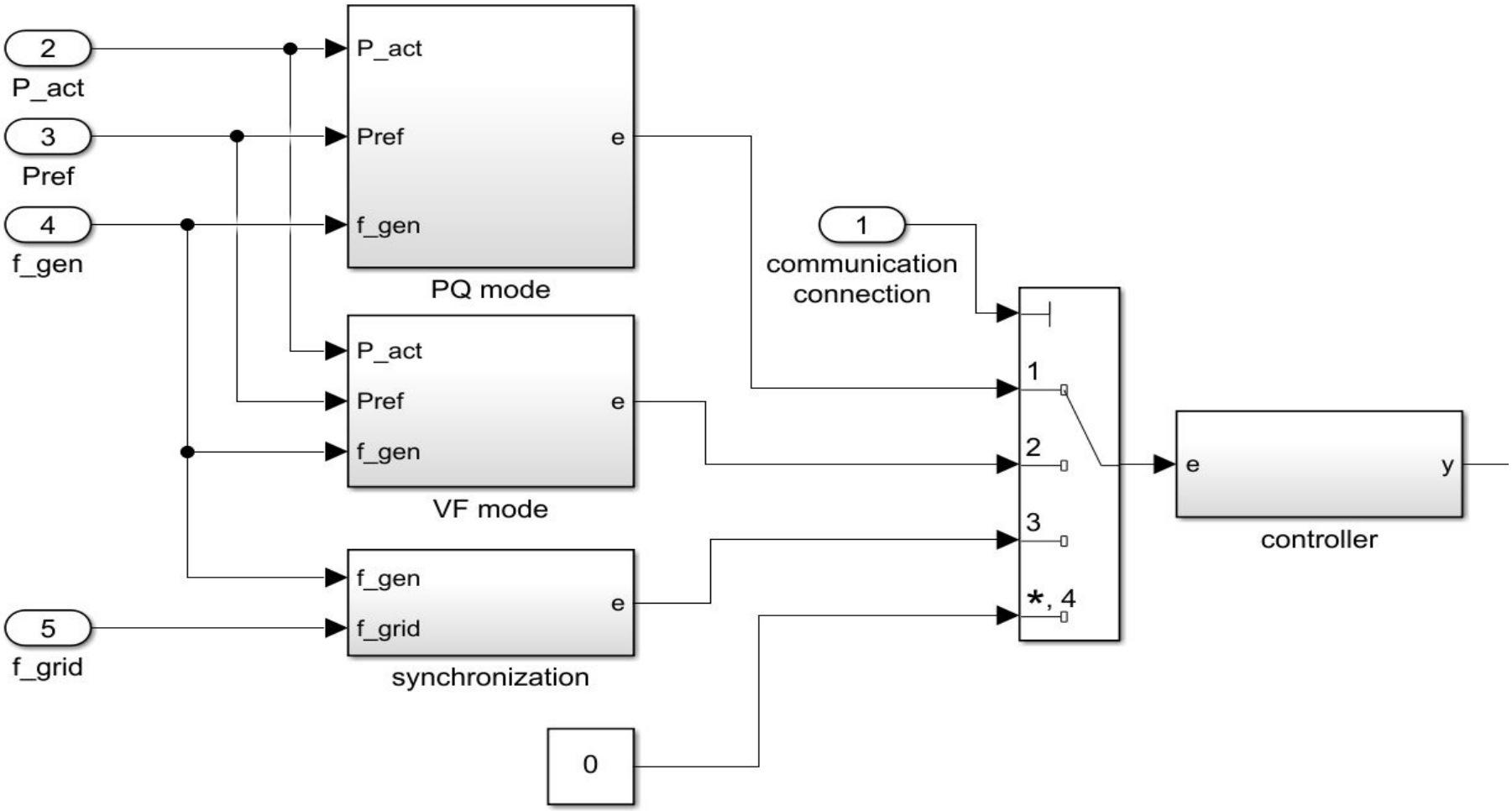

Figure 2. Controller structure of renewable energies

Challenges to maintaining grid stability

PQ control mode:

- Determination of maximum possible feed-in power P_{max}
- Droop characteristics for f → P and U → Q
- Secondary control
- Feed-in power correction by the EMS

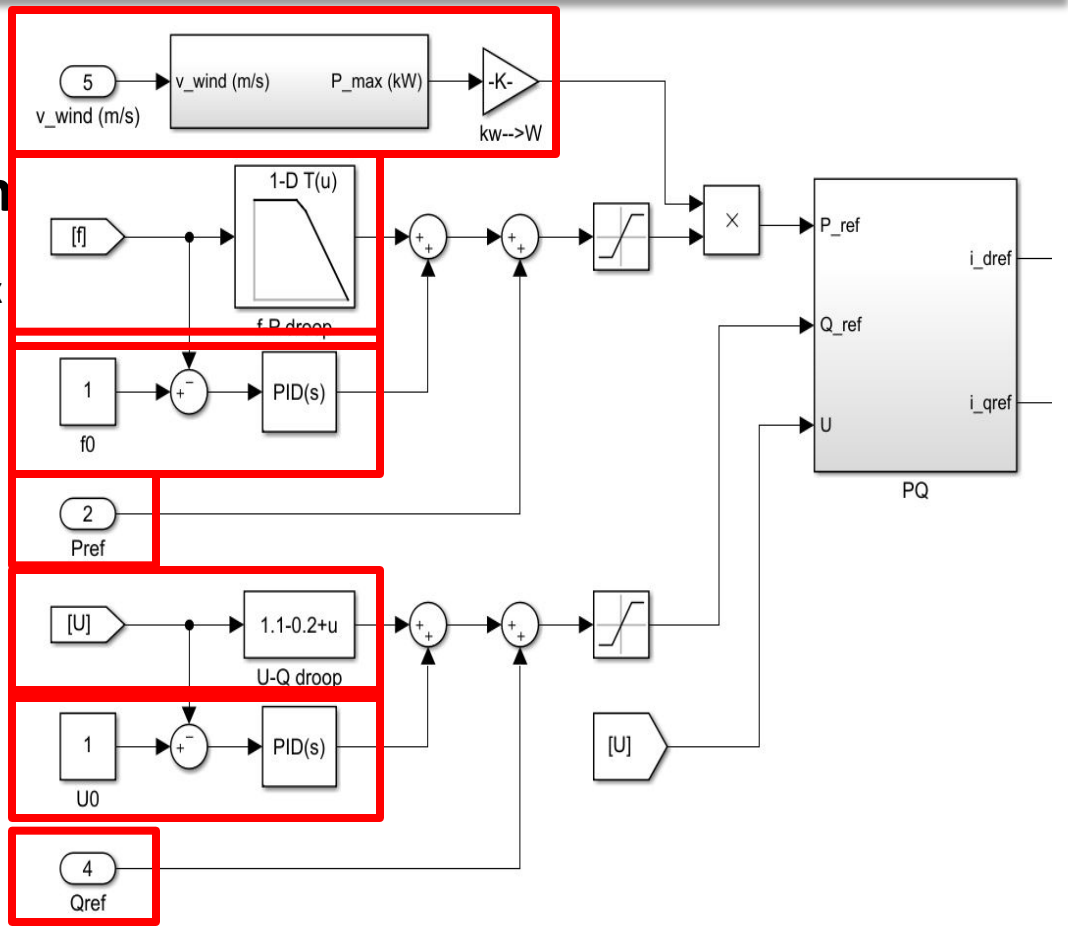

Figure 3. PQ control mode of photovoltaic and wind turbines

Challenges to maintaining grid stability

VF control mode:

- Determination of maximum possible feed-in power P_{max}
- Droop characteristics for P → f and Q → U
- Secondary control
- Feed-in power correction by the EMS

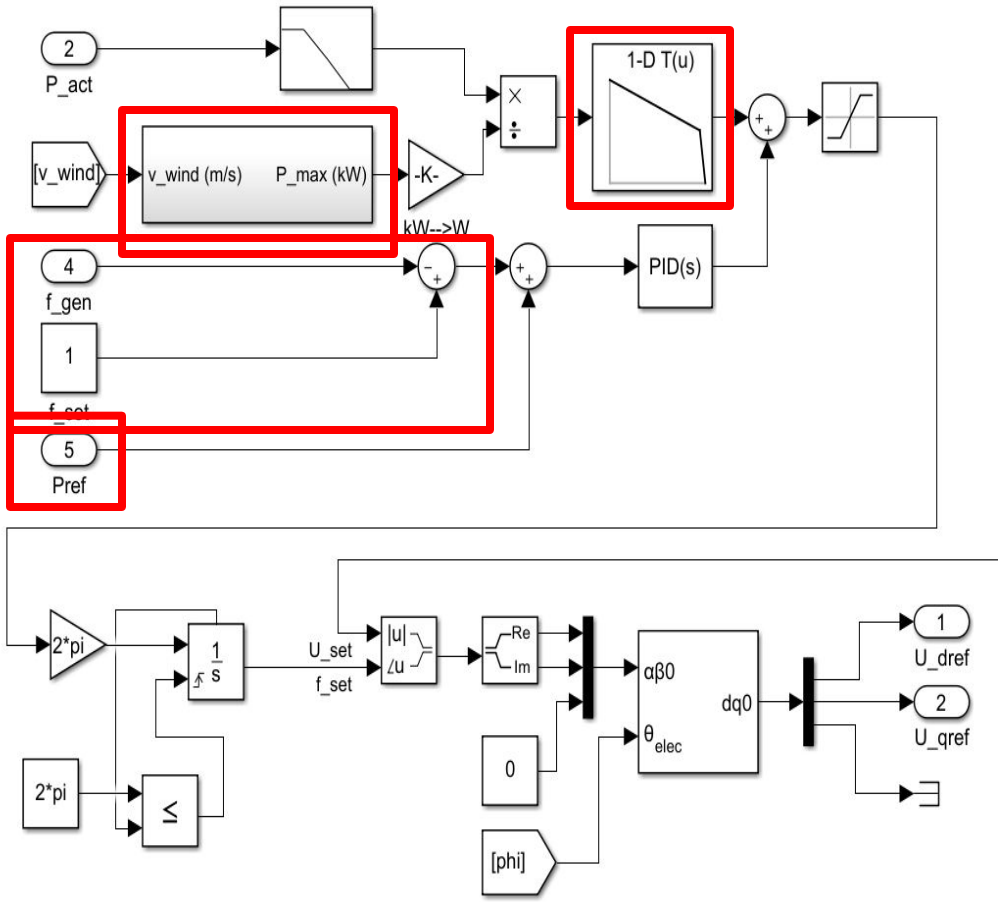

Figure 4. VF control mode of photovoltaic and wind turbines

Controller structure of different power plants

Primary control:

- Droop characteristic
- first stabilization of fgrid and Vgrid
- no communication link required

Secondary control:

- setpoints f_0 and V_0
- correct the feed-in power to reach f_0 and V_0
- using a PI-controller
- no communication link required

Controller structure of different power plants

Tertiary control:

- **Correct the feed-in power of generating plants to reach an optimal economic operation point (EMS)**
- **communication link required**

Structure of the Energy Management System

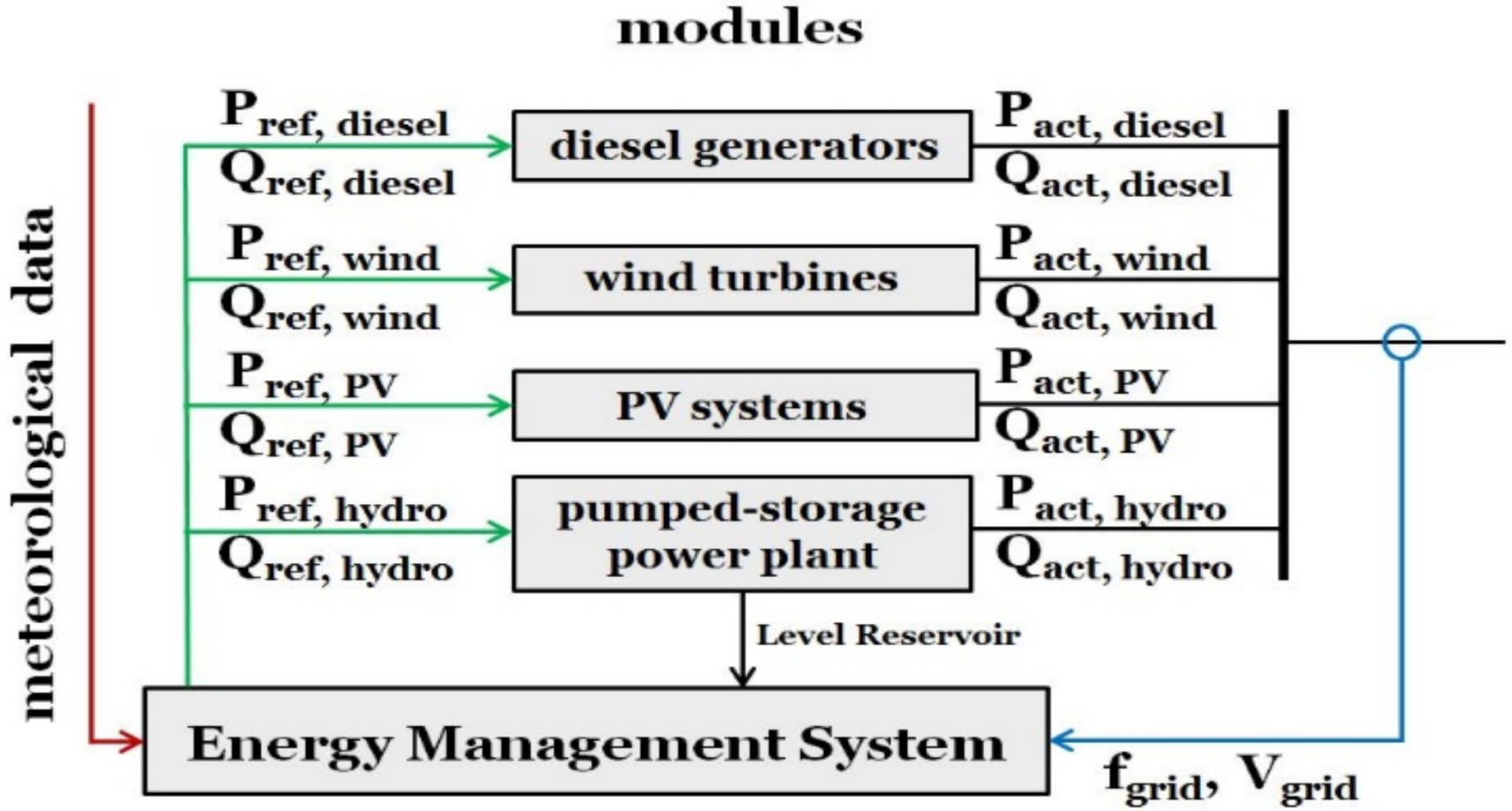

Figure 5. Structure of the EMS

Inside view of the Energy Management System

EMS increase the feed-in power ($f < f_n$):

1. Increase the feed-in power of the photovoltaic systems
2. Increase the feed-in power of the wind turbines
3. Increase the feed-in power of the pumped-storage power plant (turbine mode)
4. Increase the feed-in power of the diesel generators

Figure 6. Increase feed-in power by EMS

Inside view of the Energy Management System

EMS decrease the feed-in power ($f > f_n$):

1. Decrease the feed-in power of the diesel generators
2. Decrease the feed-in power of the pumped-storage power plant (turbine mode)
3. Increase the pumping power of the pumped-storage power plant (pumping mode)
4. Decrease the feed-in power of the photovoltaic systems
5. Decrease the feed-in power of the wind turbines

Figure 7. Decrease feed-in power by EMS

Model of different generating plants

Pumped-storage power plant:

- Model for P_{mech} in turbine or pumping mode
- Model for V_f in turbine or pumping mode
- EMS corrects power setpoint over input Pref and Qref

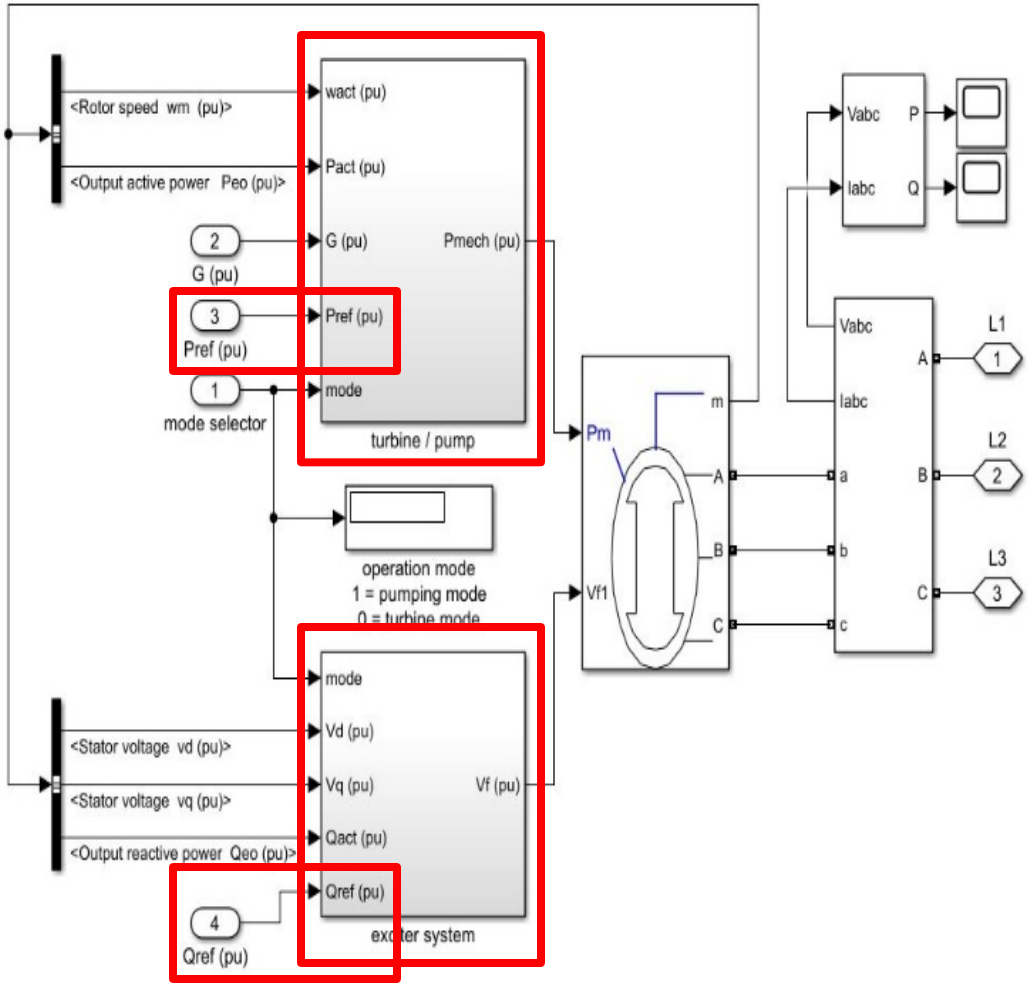

Figure 8. Pumped-storage power plant model

Model of different generating plants

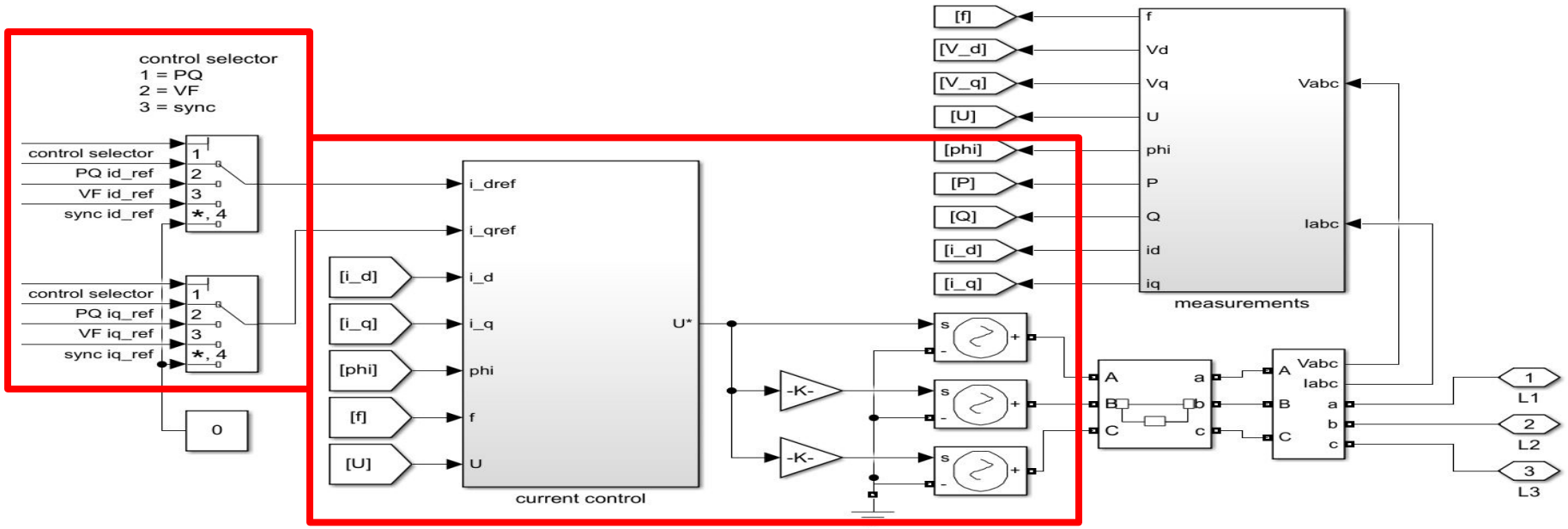

Figure 9. Selection of reference values for i_{dref} and i_{qref}

Photovoltaic system and wind turbines:

- **Determining i_{dref} and i_{qref} from subsystem PQ regulator , VF regulator or synchronization**
- **Determining necessary three phase voltages to feed-in i_{dref} and i_{qref}**

Model of different generating plants

Diesel generator:

- Model for P_{mech}
- Model for V_f
- EMS corrects power setpoint over input Pref and Qref

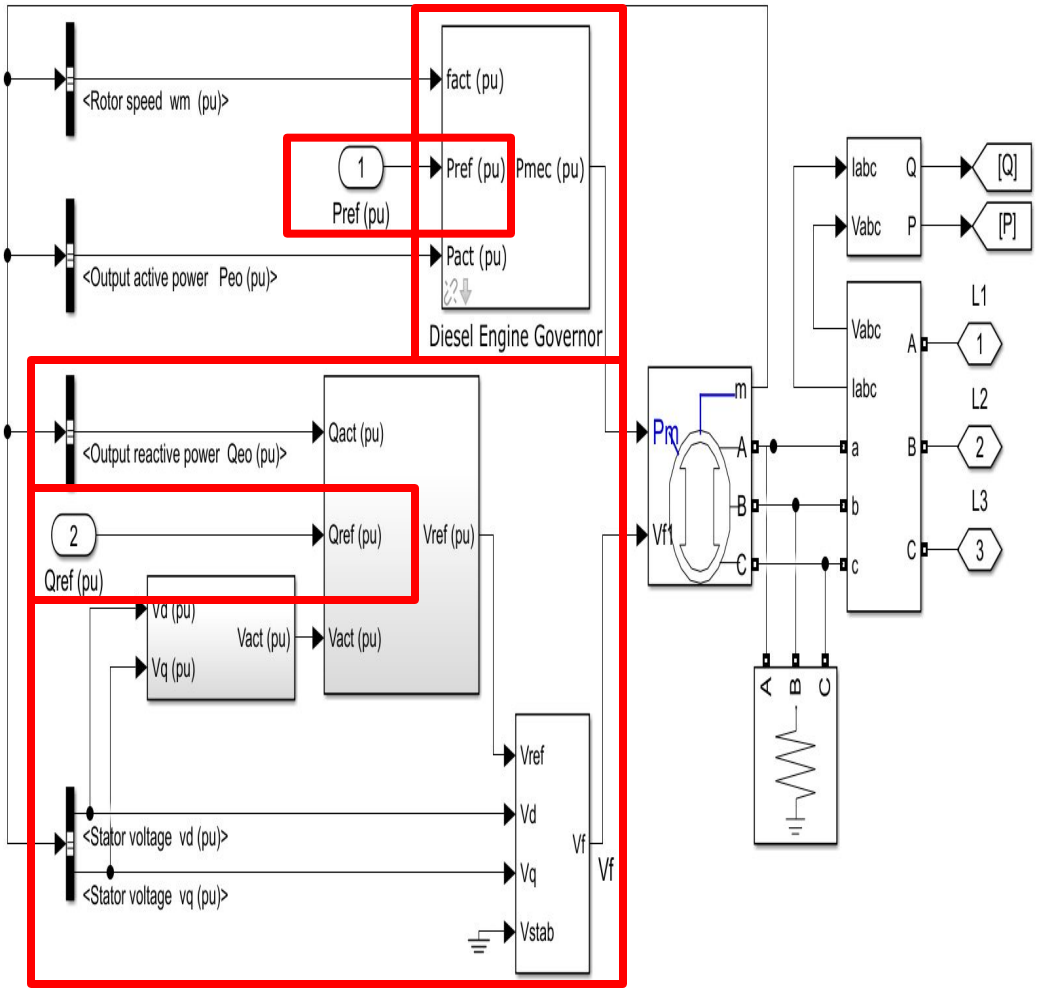

Figure 10. Diesel generator model

Simulation results for a selected scenario

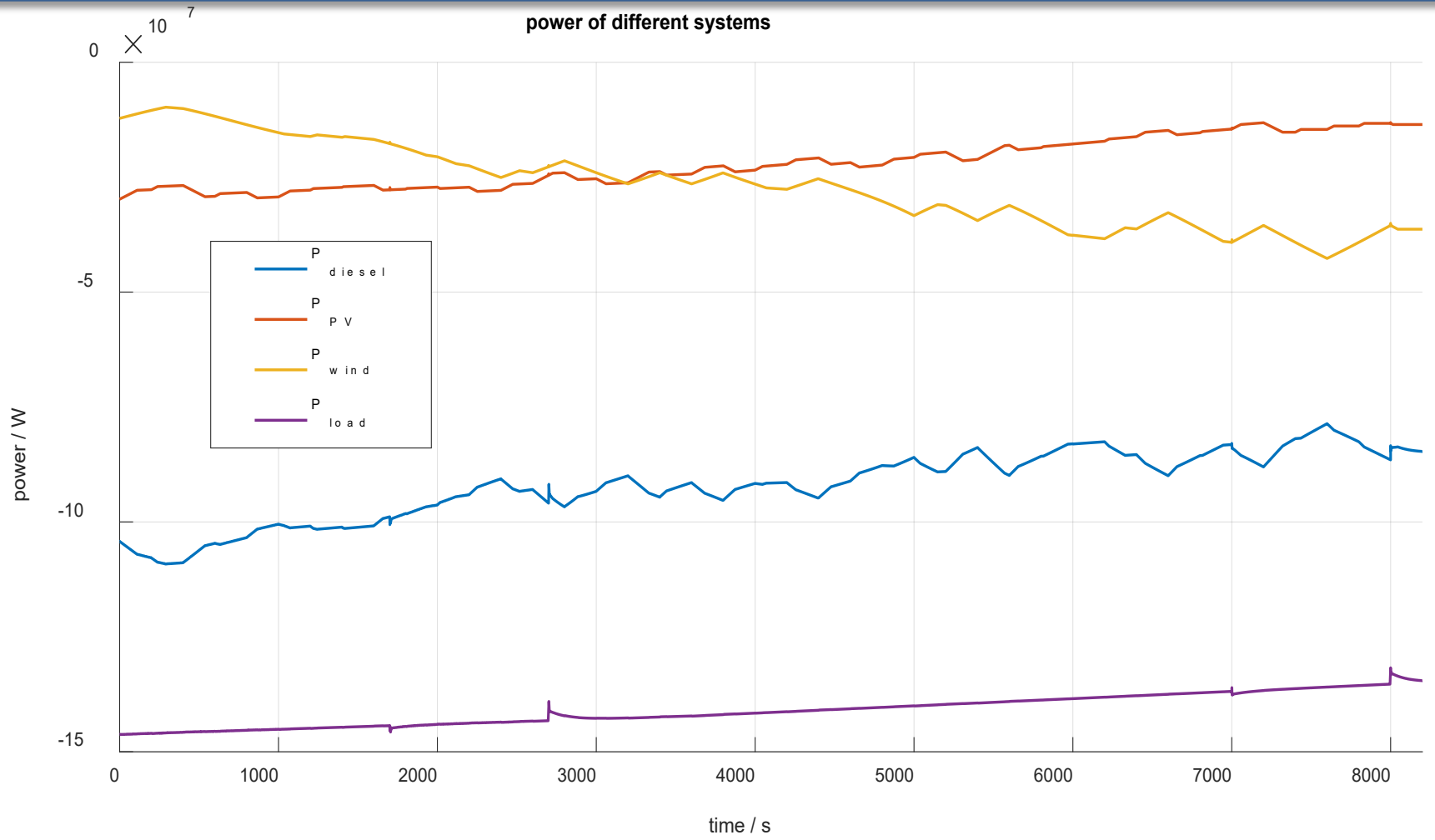

Figure 10. power of different systems

Simulation results for a selected scenario

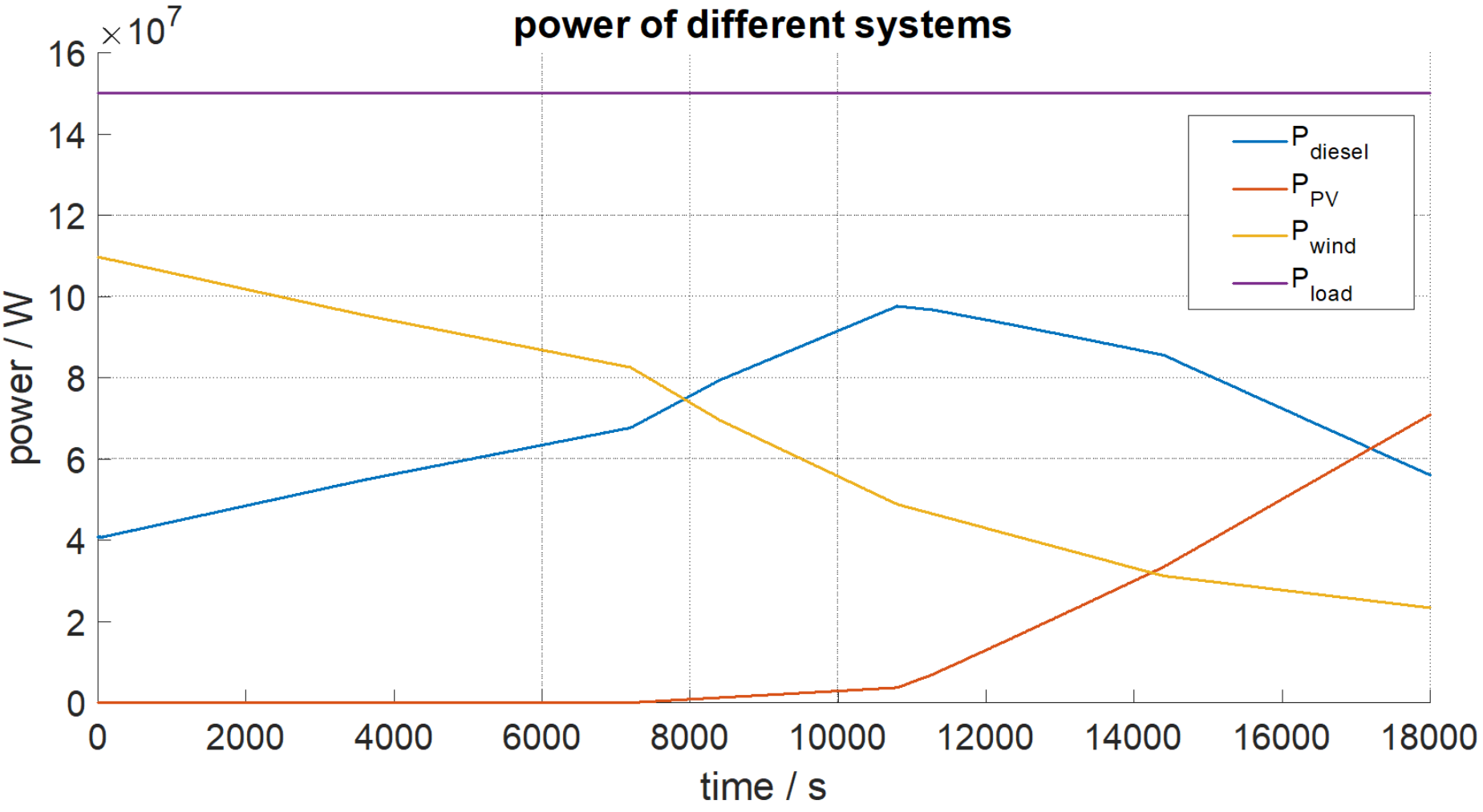

Figure 11. power of different systems

Conclusion

- **Barbados is 90 % dependent on fuel imports → high costs for electricity and transportation sector**
- **An EMS can help to operate the different power plants economically**
- **Increase installation capacity of renewable energies → lower costs for these sectors**
- **Integration of volatile renewable energies by switching the control algorithm (PQ ←→ VF)**
- **Saving CO_2 emissions by using renewable energies**
- **The Government of Barbados has committed to a 100 % renewable energy system by 2030**

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Thank You

Questions?

Alexander Kroggel