Microrredes Eléctricas

Tema 6 A
Coordination

1. Operation under Islanded mode.

Coordination

1. Coordination

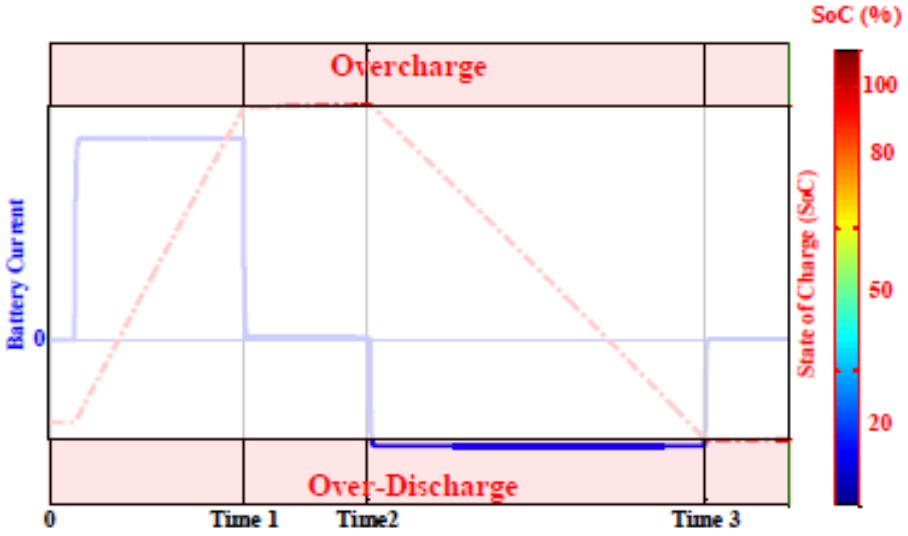
For islanded applications where the autonomy is the key requirement (long-term balance). ESSs based on batteries continue being the most used

The operation and limitations of the Batteries determine the reliability and coordination requirements of the microgrid

1. Coordination

Batteries are voltage limiting devices

The capacity of the batteries is limited, they cannot be operated beyond certain limits.



1. Coordination

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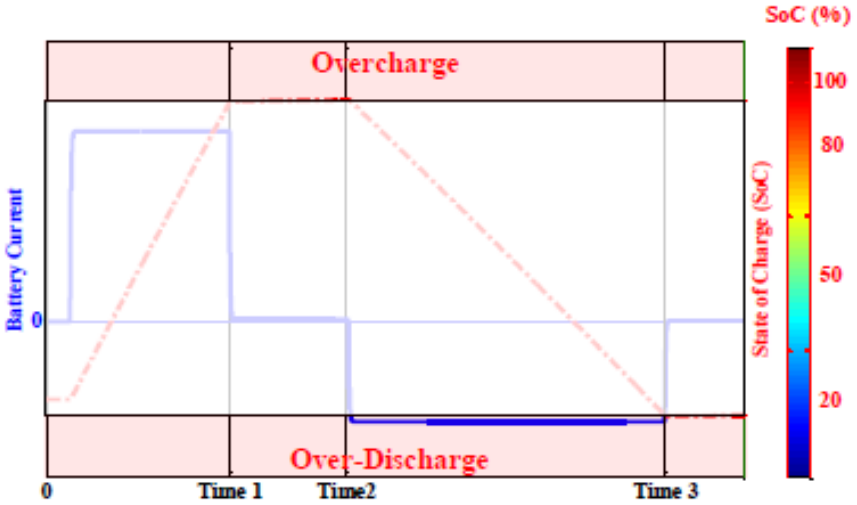
RES

Are expected to deliver their maximum Power (MPPT).



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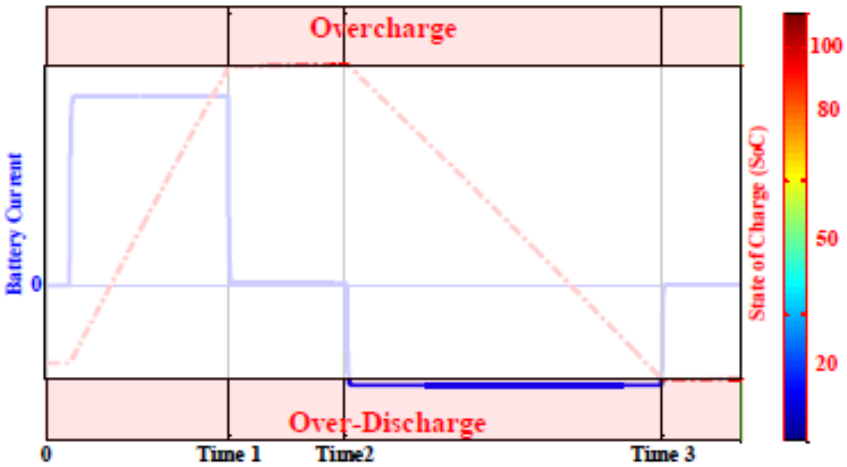

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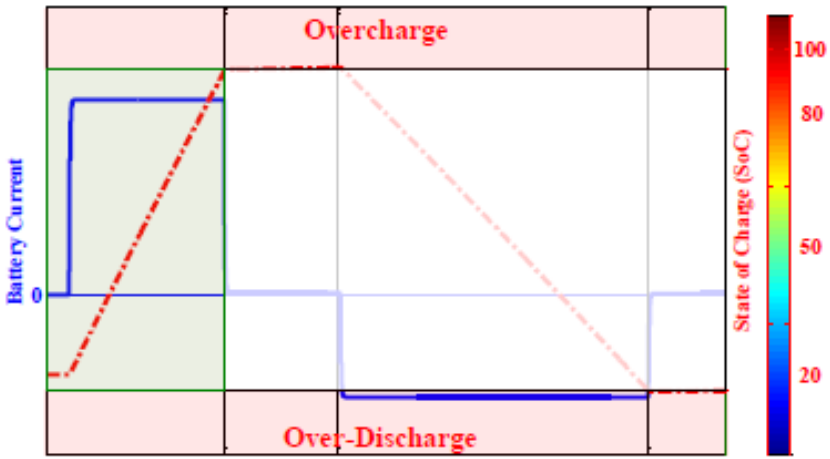
Demand is expected to be met regardless of variability of RESs.

1. Coordination

The capacity of the batteries is limited, they cannot be operated beyond certain limits.

RES

Supply > Demand.



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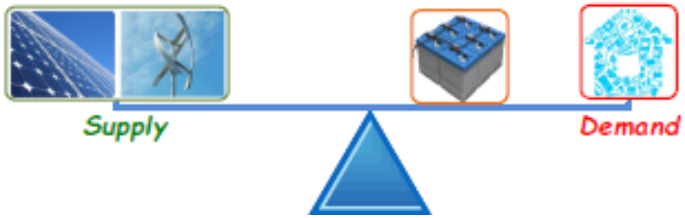
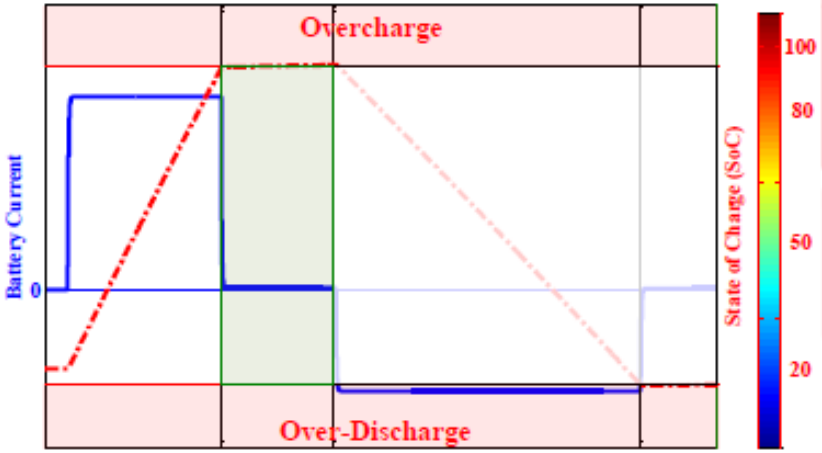


1. Coordination

The capacity of the batteries is limited, they cannot be operated beyond certain limits.

RES

The generation from RESs should be curtailed for avoiding overcharge of batteries.



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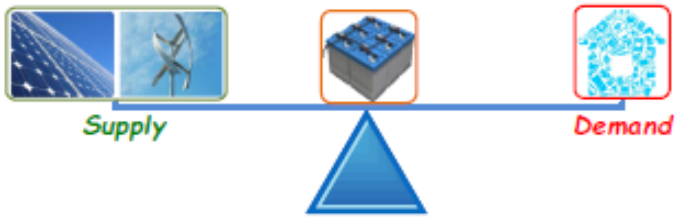

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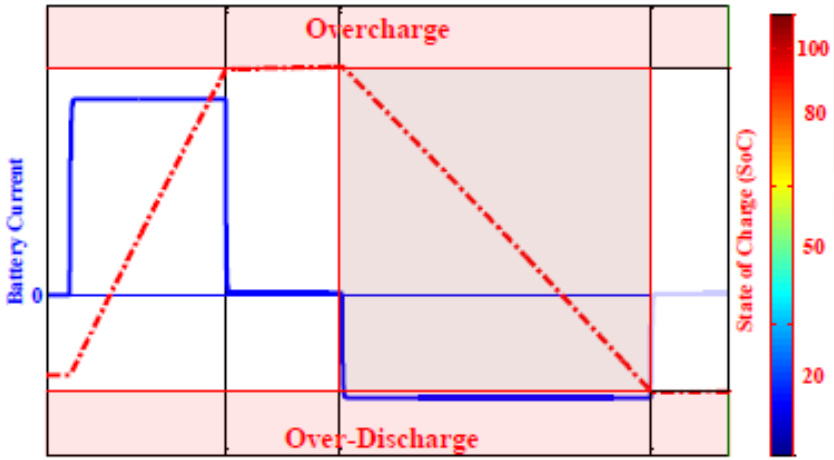

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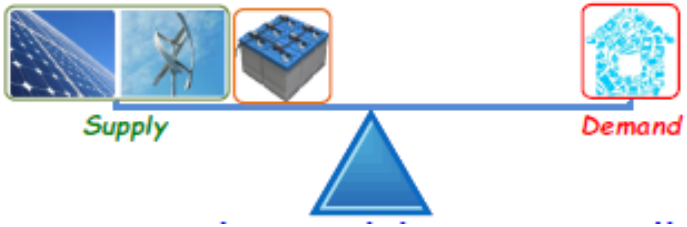
Demand>Supply.



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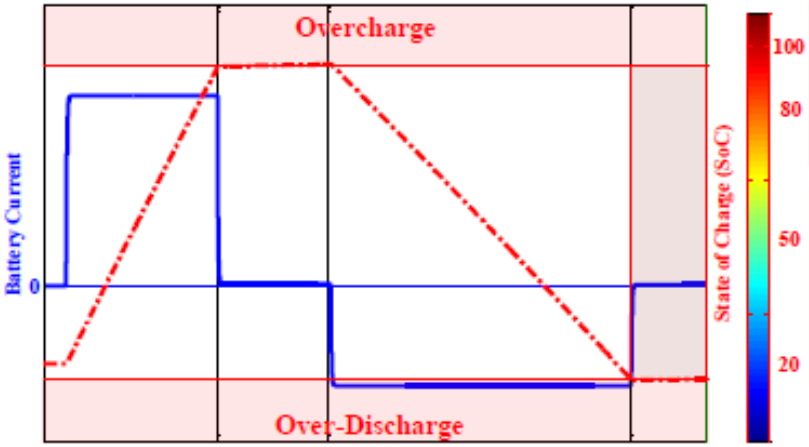

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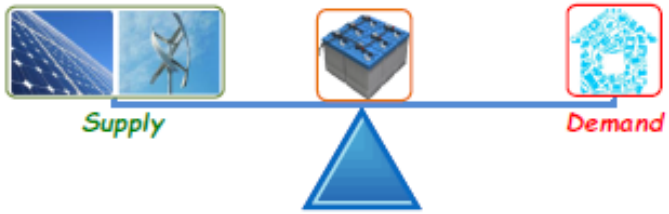
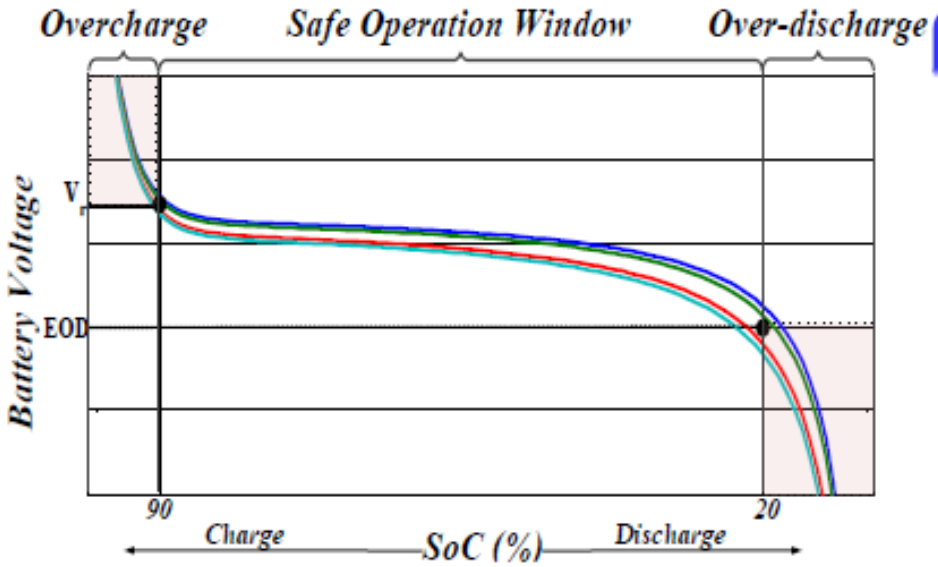
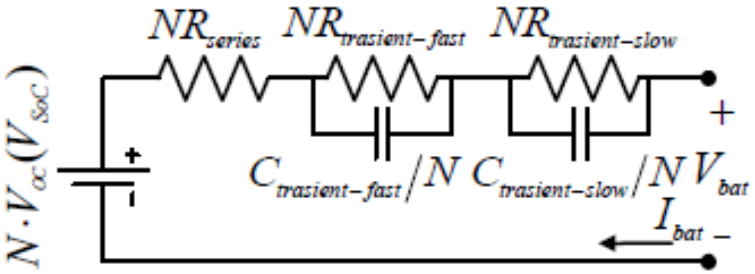
The load should be reduced or shedding for avoiding deeper discharge.



1. Coordination



Electrical Model



$$SoC(t) = SoC(0) - \int_0^t \eta \frac{I_{bat(i)}(\tau)}{C_{bat(i)}} d\tau;$$

The electrical circuit model is relatively accurate to capture the main **I-V** characteristics.[2]

- Terminal voltage.
- Transient response.

[2] T. Kim and W. Qiao, "A Hybrid Battery Model Capable of Capturing Dynamic Circuit Characteristics and Nonlinear Capacity Effects," in IEEE Transactions on Energy Conversion, 2011.

Parameters of the battery model

$$P_{DC} \approx P_{AC}$$

$$P_i = \frac{3}{2}\left(v_{di}i_{di} + v_{qi}i_{qi}\right)$$

$$Q_i = \frac{3}{2}\left(v_{di}i_{qi} - v_{qi}i_{di}\right)$$

If Synchronized

$$P_i = \frac{3}{2}\left(v_{di}i_{di}\right)$$

$$Q_i = \frac{3}{2}\left(v_{di}i_{qi}\right)$$

Then

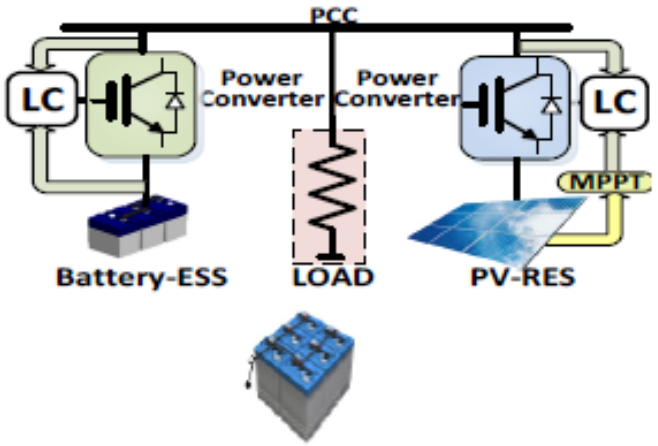
$$I_{DCi} * V_{DC} = \frac{3}{2}\left(v_{di}i_{di}\right)$$

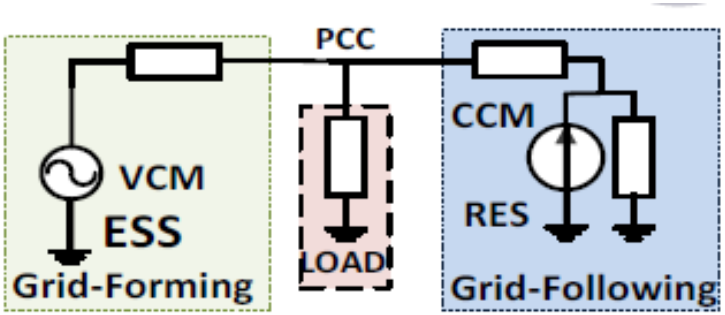
Regarding the Modulation Idex

$$m = \frac{v_{di}}{V_{DC}/2}$$

$$I_{DC} \approx \frac{3}{4} * m * i_{di}$$

1. Coordination

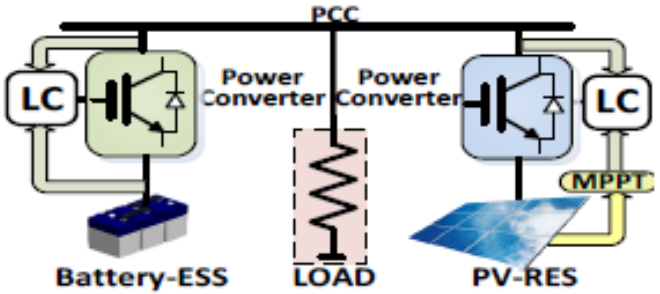




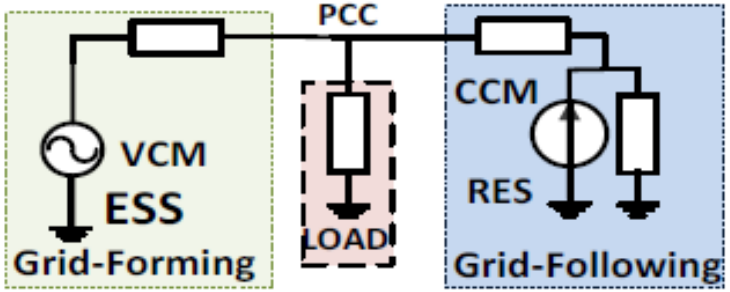
- Commonly, ESSs (Grid-Forming).

- RESs are more likely to operate under MPPT algorithms.
  CCM (Grid-Following).

1. Coordination



- Commonly, ESSs (Grid-Forming).
- A two-stage charge procedure is recommended for batteries.



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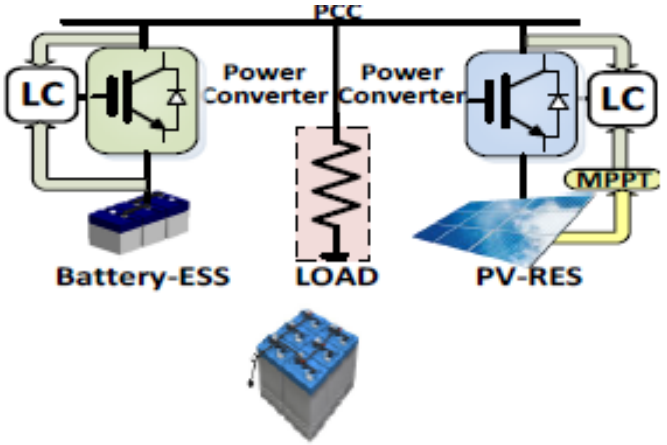

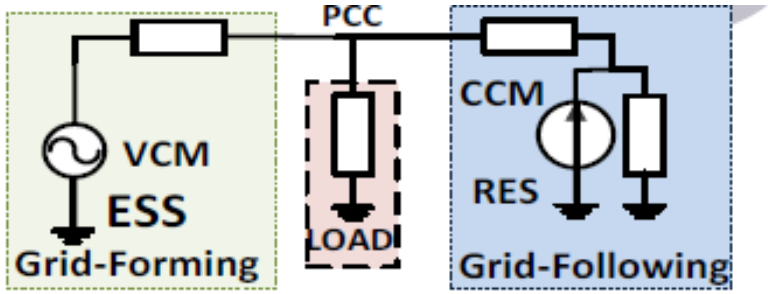

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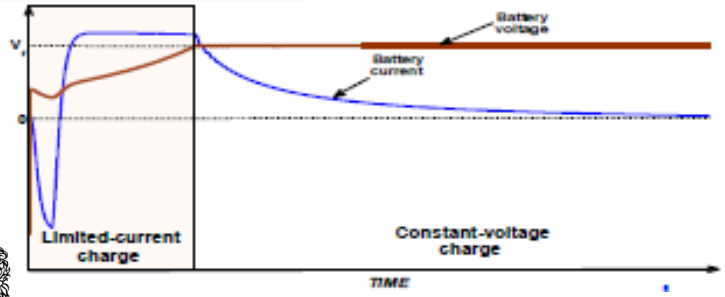
Limited-current
Grid-forming (VCM)



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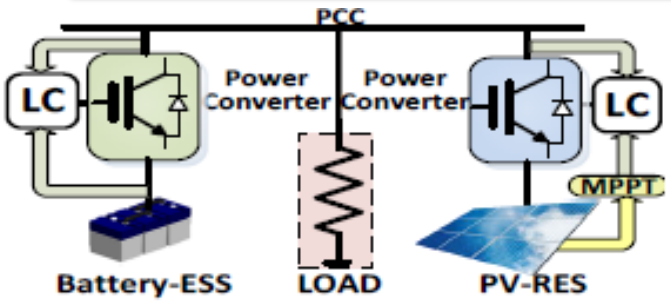

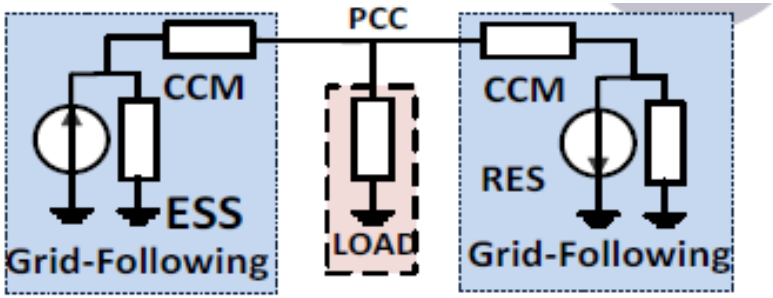

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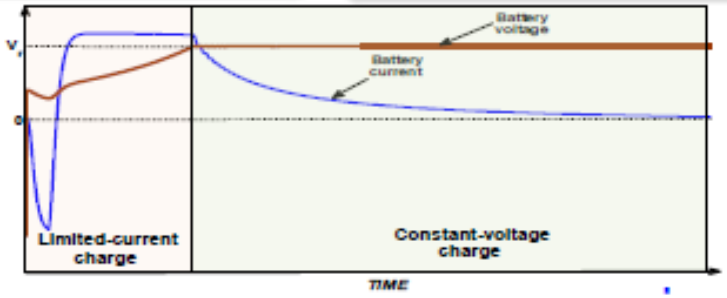
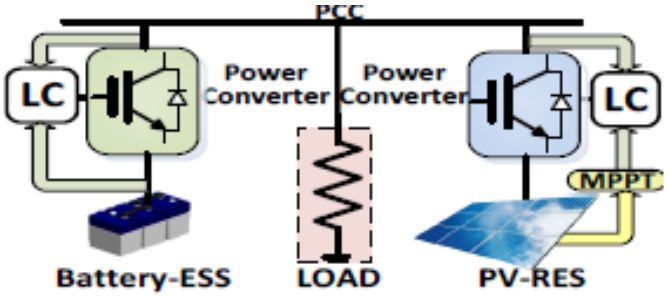
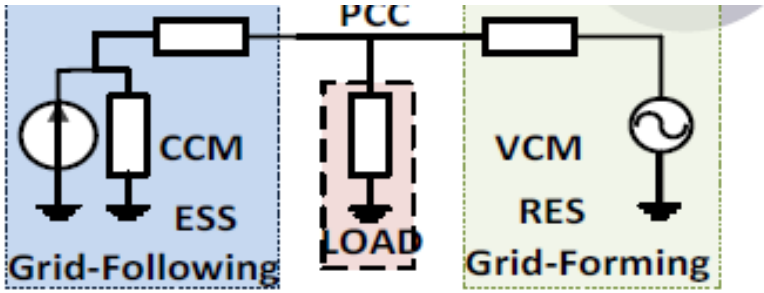
Limited-current	Constant-voltage
Grid-forming (VCM)	Grid-following (CCM)



- RESs are more likely to operate under MPPT algorithms.
  CCM (Grid-Following).
- When ESSs are in Constant-voltage Charge, who will form the power grid?

1. Coordination





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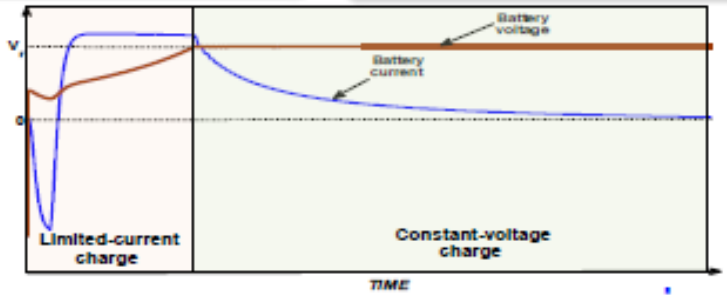
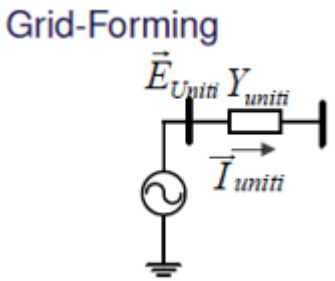
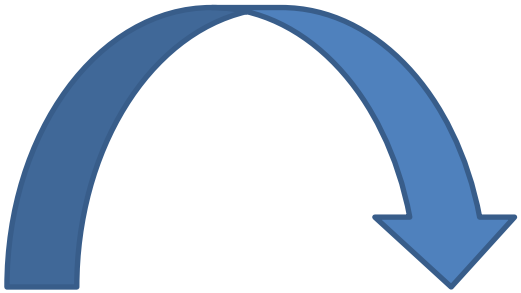
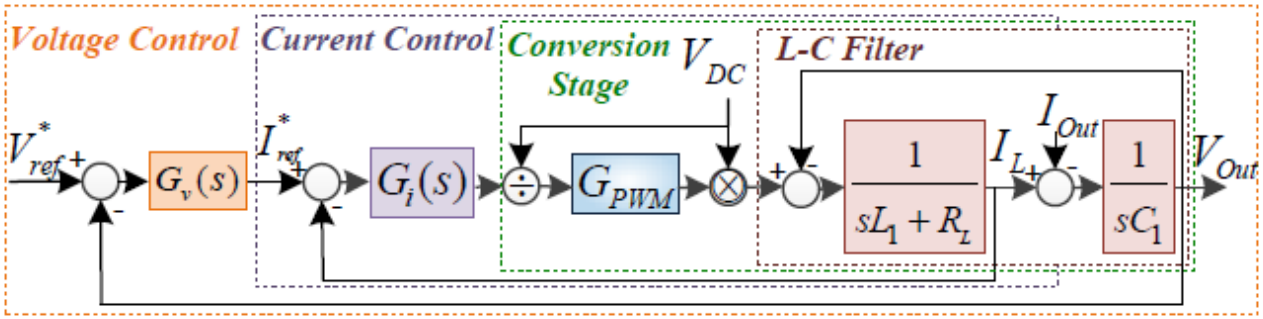


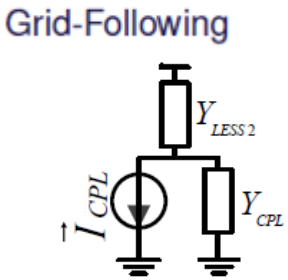
- RESs are more likely to operate under MPPT algorithms.
  CCM (Grid-Following).
- When ESSs are in Constant-voltage Charge, who will form the power grid?
  - RESs may assume the forming role. Grid-Forming (VCM), and the generation should be limited for keeping the power balance.

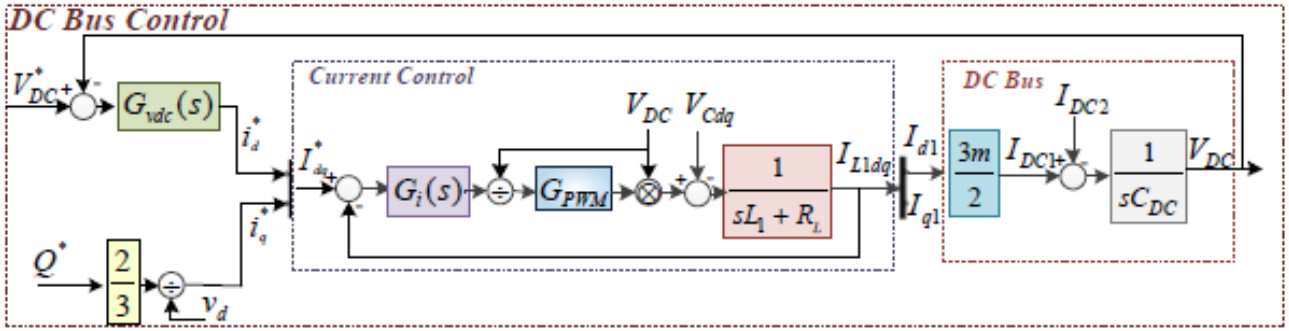
1. Coordination





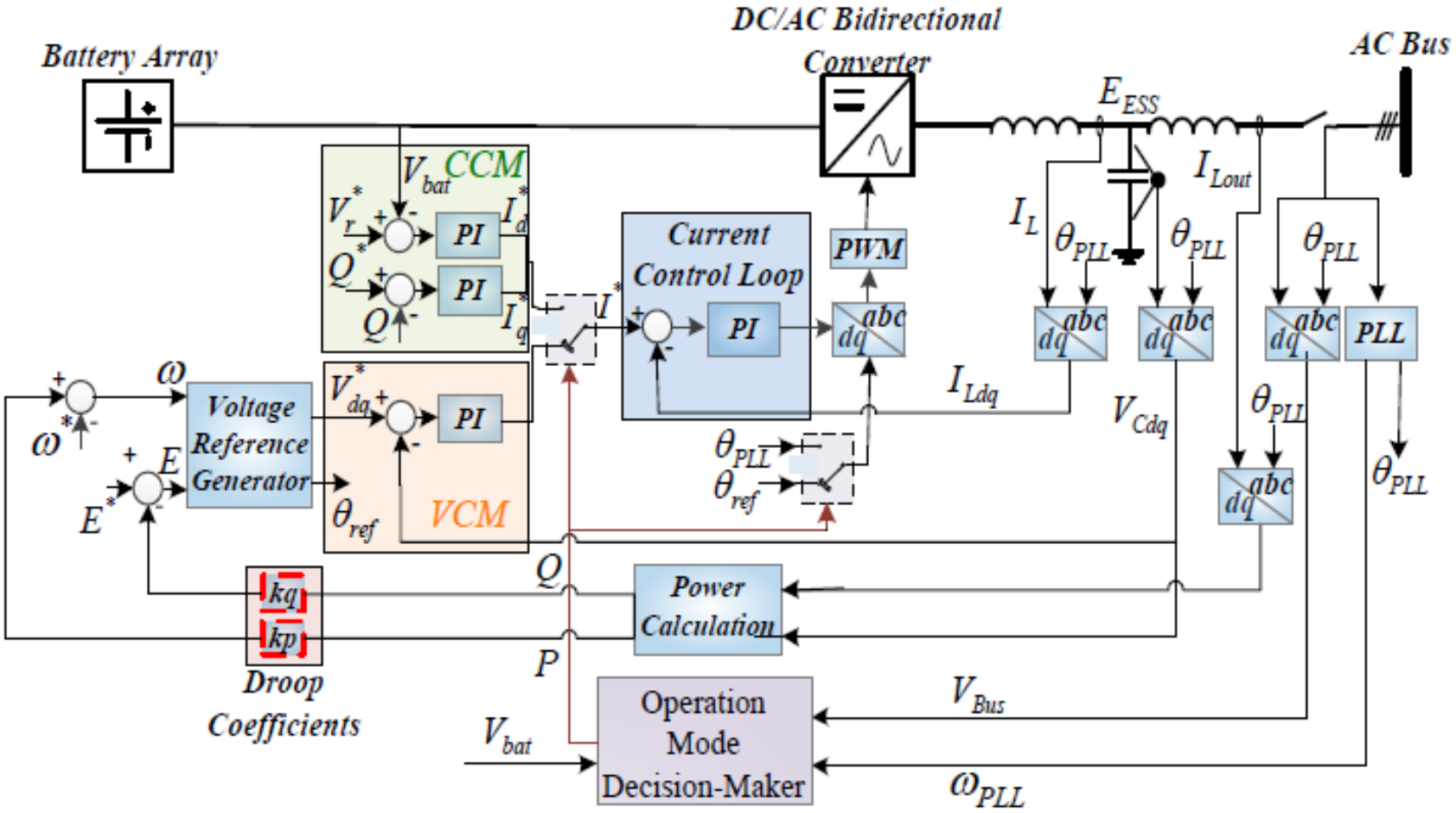






1. Coordination

For the ESS



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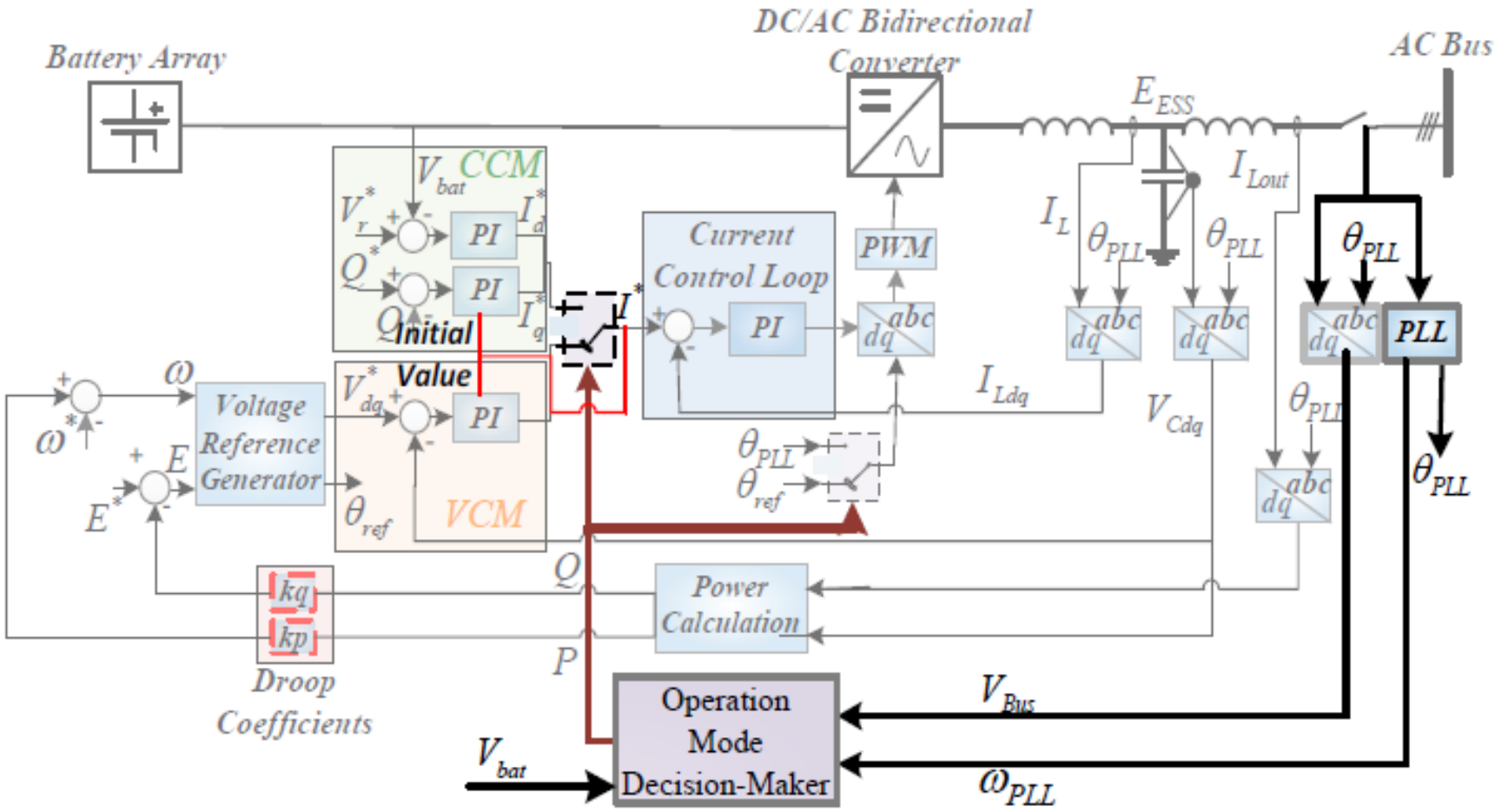
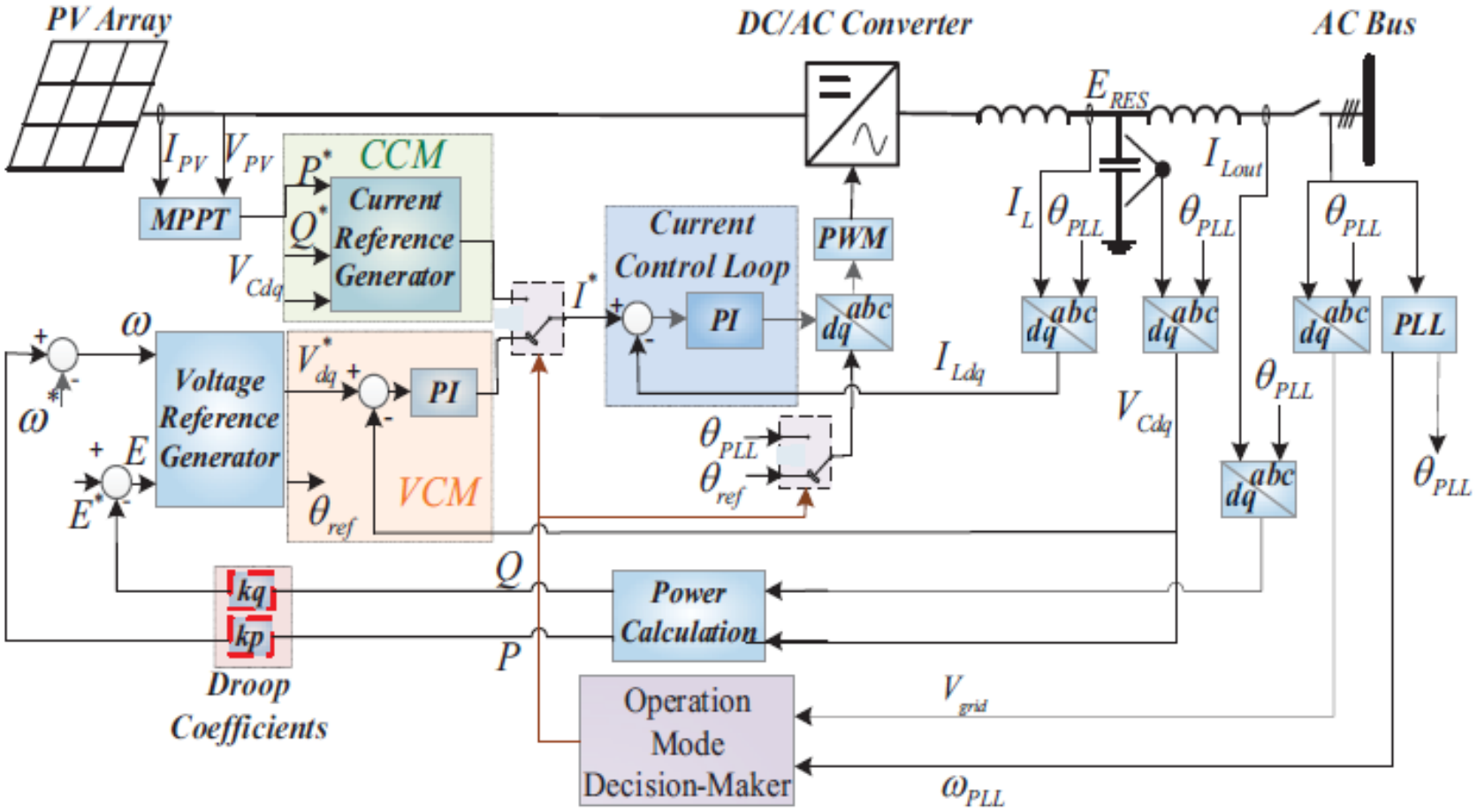


1. Coordination

For the RES



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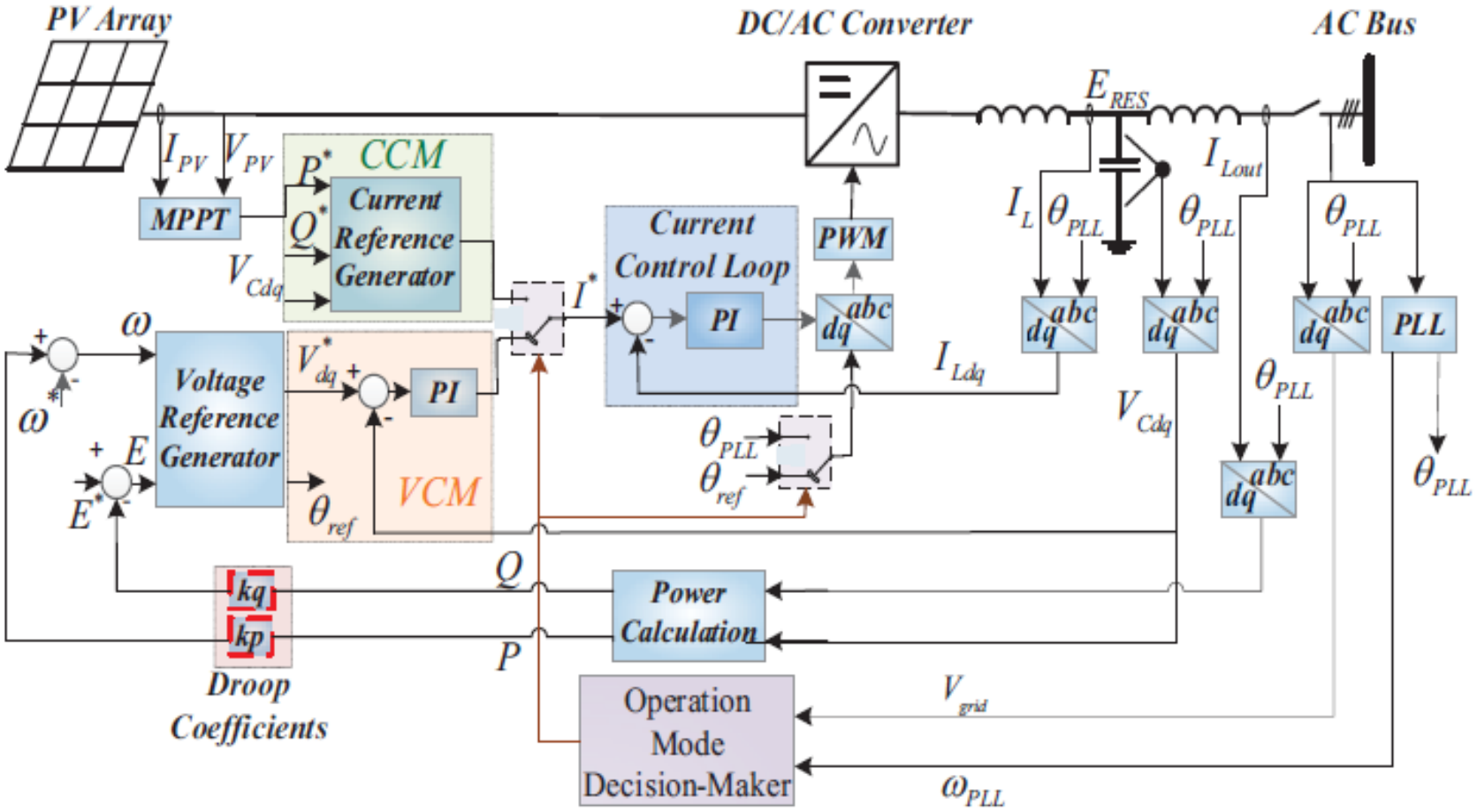
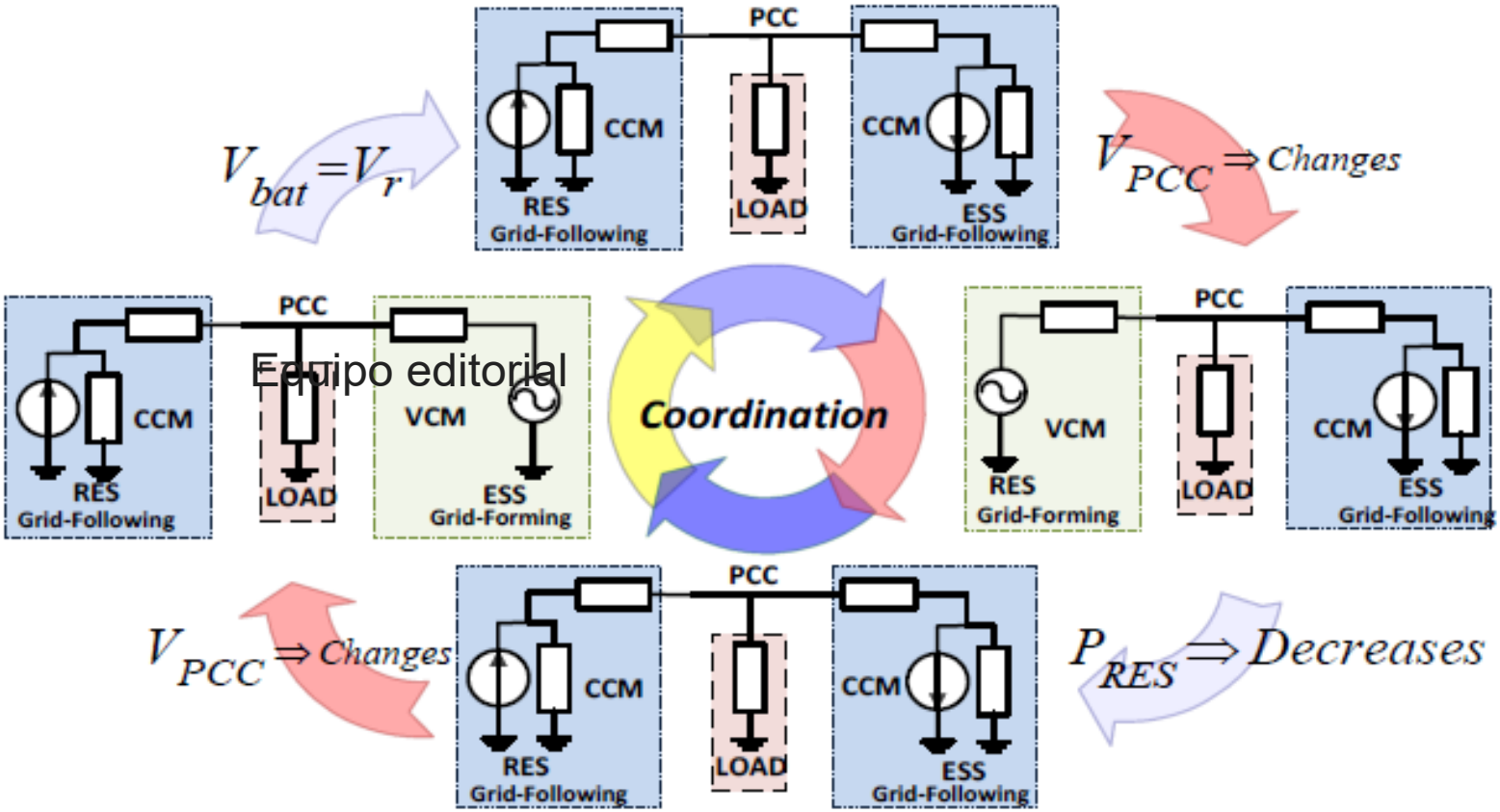


1. Coordination

The transition between operation modes at the DERs are triggered by local events



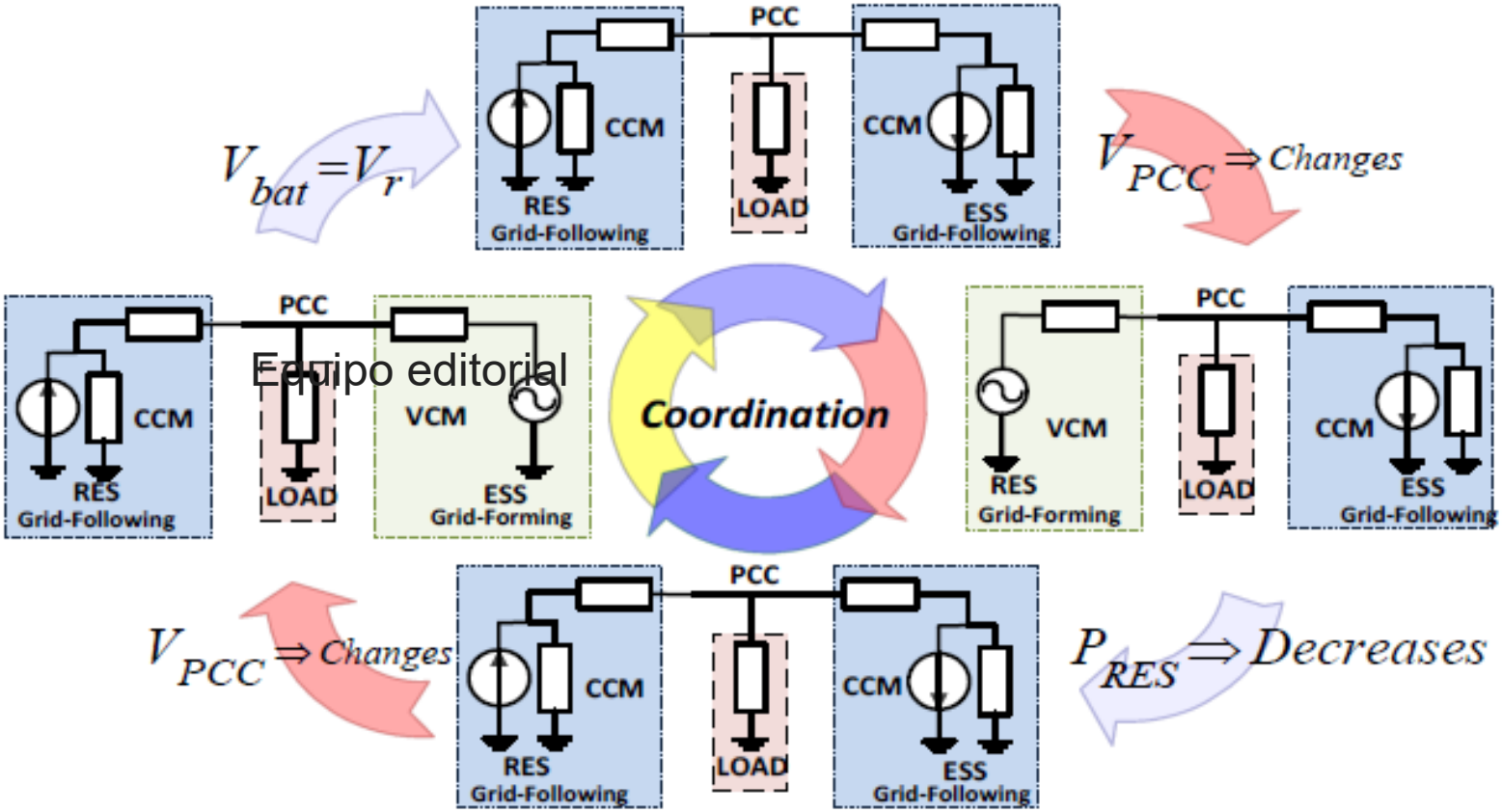
Equipo editorial

Tema 6 B
Coordination

1. Examples.
    1. Distributed Strategy
    2. Centralized Strategy

1. Coordination- Distributed Approach

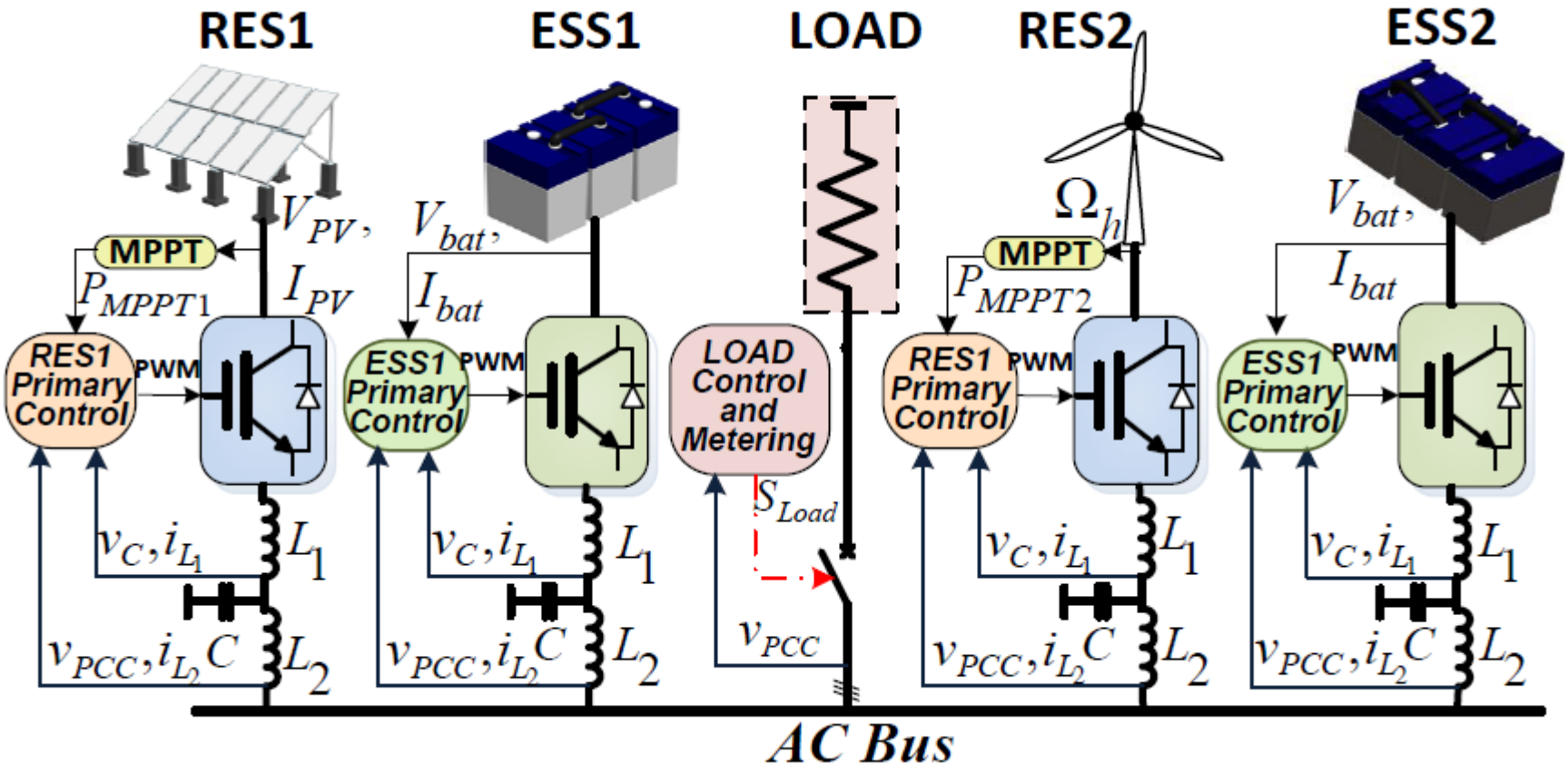
The transition between operation modes at the DERs are triggered by local events



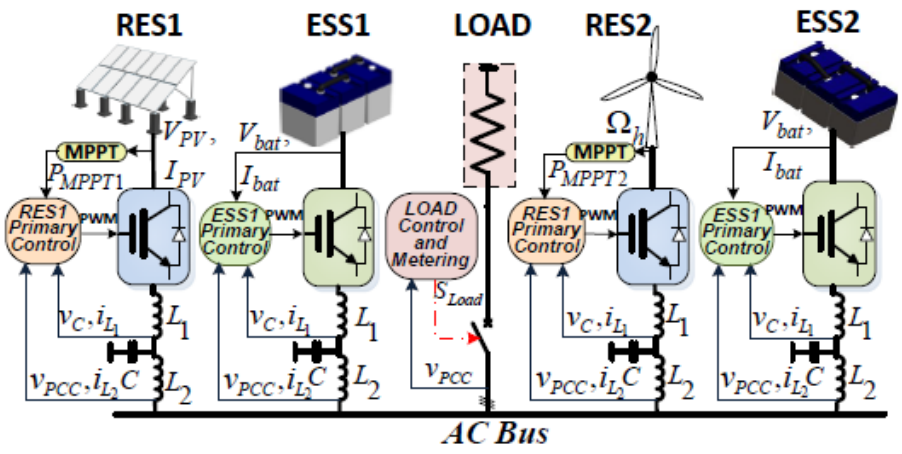
Equipo editorial

1. Coordination- Distributed Approach

Case Study MG



1. Coordination- Distributed Approach



6 possible combinations of 16
4 different TCM

Every DER may operate in any of two control functions

- Grid-Forming (VCM)
- Grid-Following (CCM)

A specific combination at the unit-level defines topological operation modes (TCM) at the system-level.

$$TCM = 2^N$$

Where N is the number of DER.

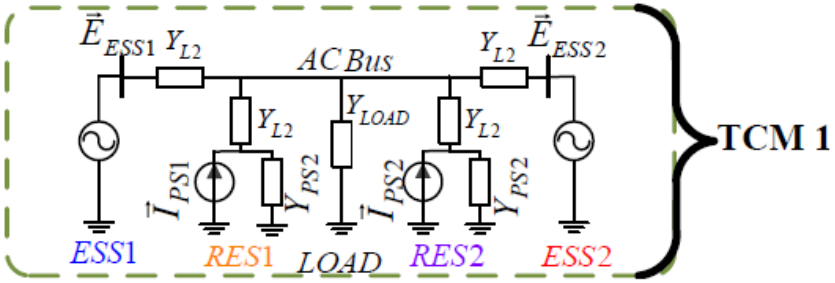
Rules for a reliable and efficient operation

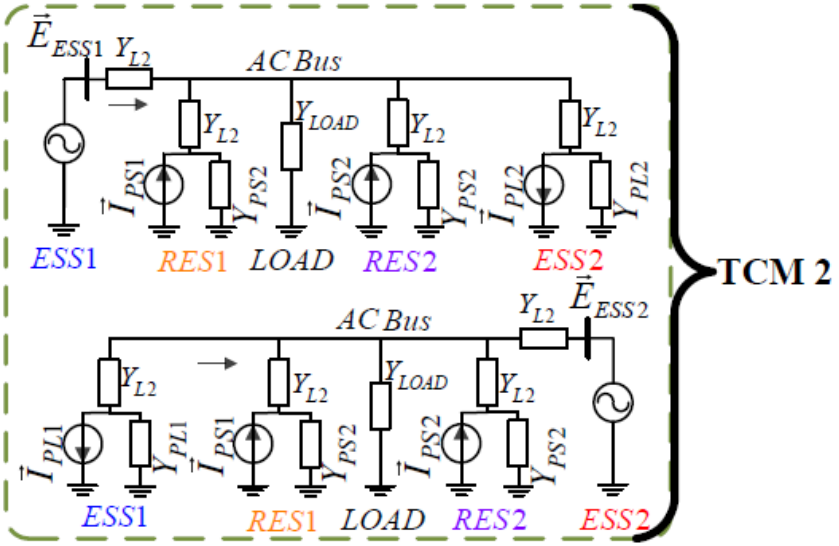
1. At least one of the DERs must assume the Grid-Forming control.
2. RESs assume the Grid-Forming control when ESSs are in constant-voltage charge.
3. RESs and ESSs cannot be Grid-Forming units simultaneously.

1. Coordination- Distributed Approach

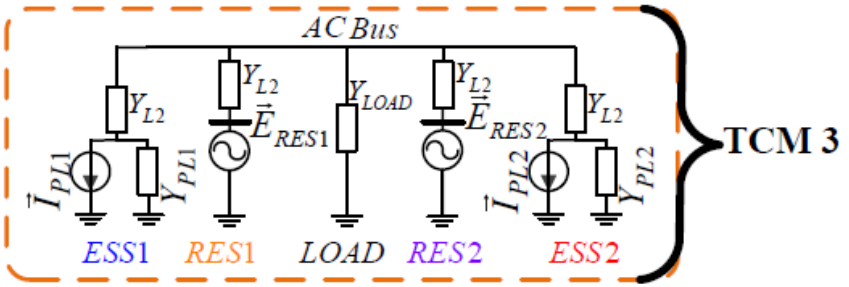
Reliable Operation Modes (TCM)

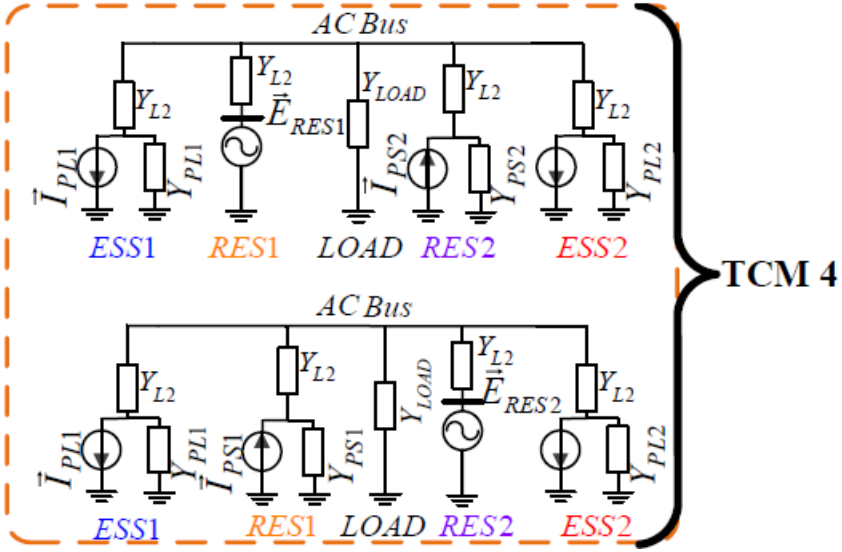
ESSs as Grid-Forming





RES as Grid-Forming

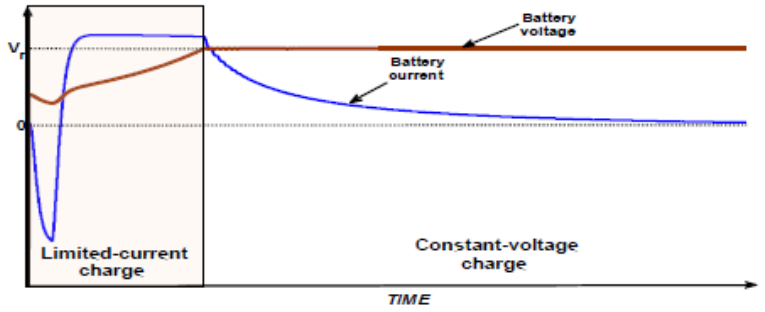




1. Coordination- Distributed Approach

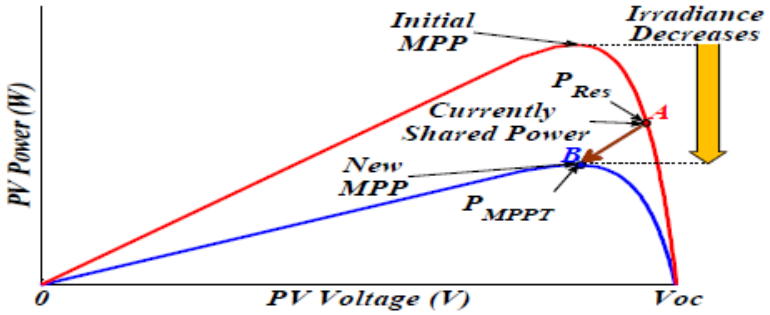
Transition From Grid-Forming to Grid-Following.

ESS

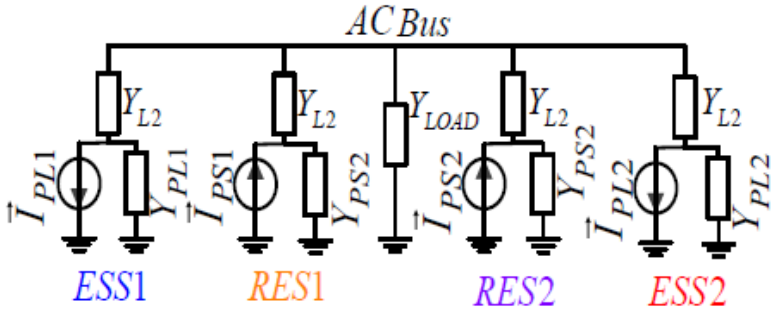


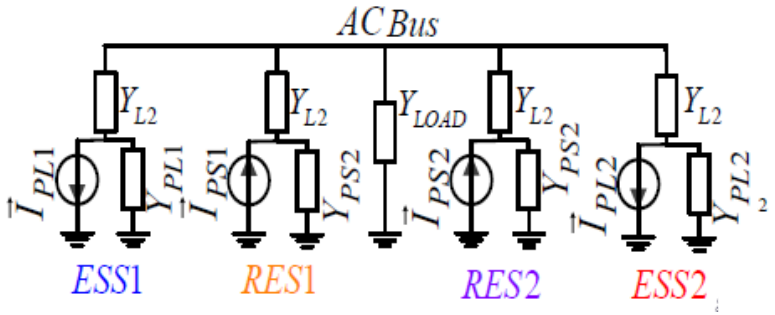
- The transition is defined by the regulation voltage ($V_{Bat} \geq V_r$).

RES



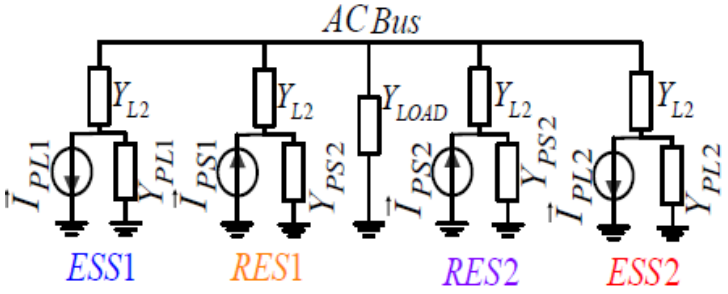
- The transition is defined when the power capacity of the RES is reduced ($P_{MPPTi} < P_{RESi}$).

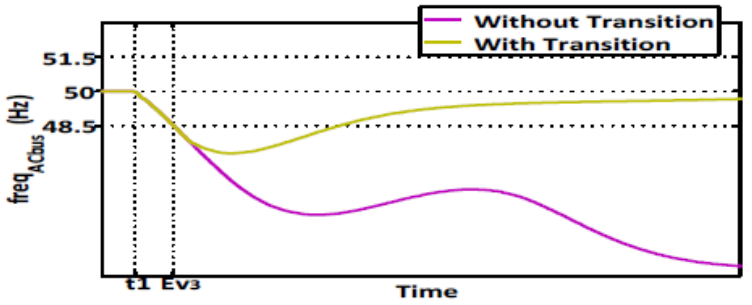




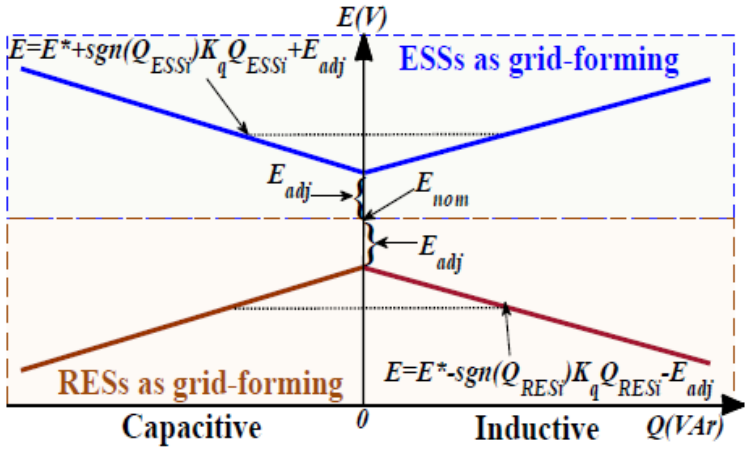
1. Coordination- Distributed Approach

The coordination signal is obtained from the response to the unbalanced grid





A voltage amplitude strategy is proposed based on the reactive droop control loop

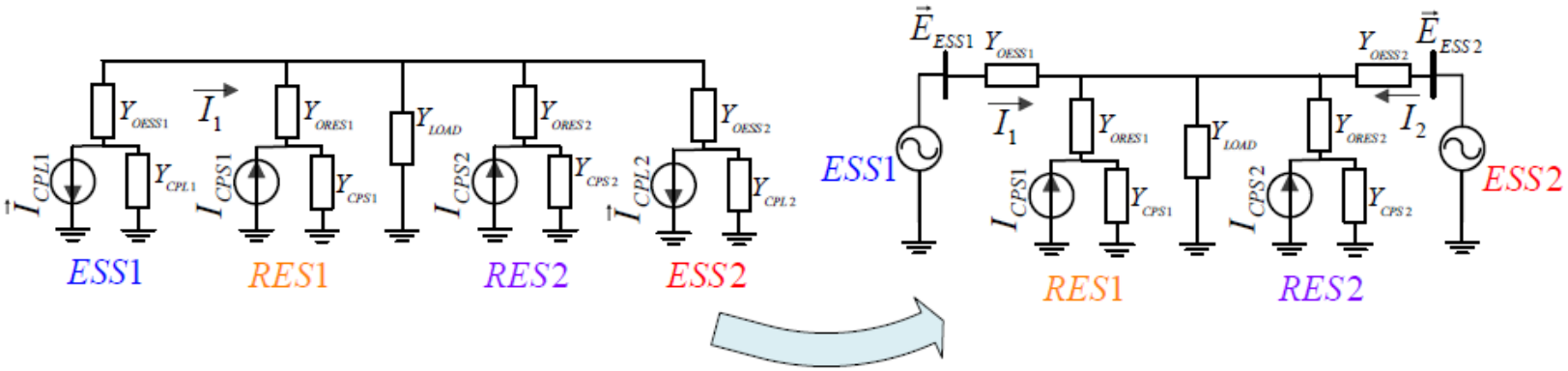


$$E = \begin{cases} E^* + sgn(Q_{ESSi}) \cdot K_q \cdot Q_{ESSi} + E_{adj}, \\ \textbf{When } \textit{ESSs } \textbf{are } \textit{Grid - Forming}; \\ E^* - sgn(Q_{RESi}) K_q \cdot Q_{RESi} - E_{adj}, \\ \textbf{When } \textit{RESs } \textbf{are } \textit{grid - forming}. \end{cases}$$

1. Coordination- Distributed Approach

TRANSITIONS BETWEEN OPERATION MODES

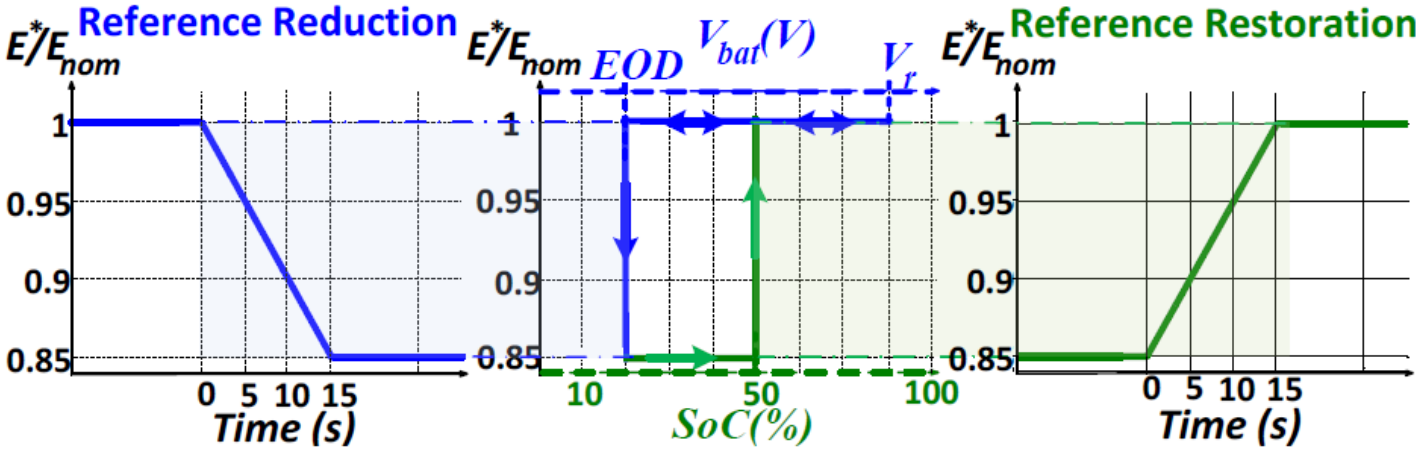
	Current Mode		Next Mode	
Event & Conditions	**ESS**	**RES**	**ESS**	**RES**
(Ev_1) $V_{Bati} \geq V_r$	Grid-Forming	Grid-Following	Grid-Following	Grid-Following
(Ev_3) $freq_{ACbus} \leq frec_t$ & (Co_1) $E \geq E_{nom}$	Grid-Following	Grid-Following	Grid-Following	Grid-forming
(Ev_2) $P_{MPPTi} < P_{RESi}$	Grid-Following	Grid-Forming	Grid-Following	Grid-Following
(Ev_3) $freq_{ACbus} \leq frec_t$ & $(\bar{C}o_1)$ $E < E_{nom}$	Grid-Following	Grid-Following	Grid-Forming	Grid-Following



1. Coordination- Distributed Approach

Load Shedding

Activated for avoiding deeper discharge of the batteries



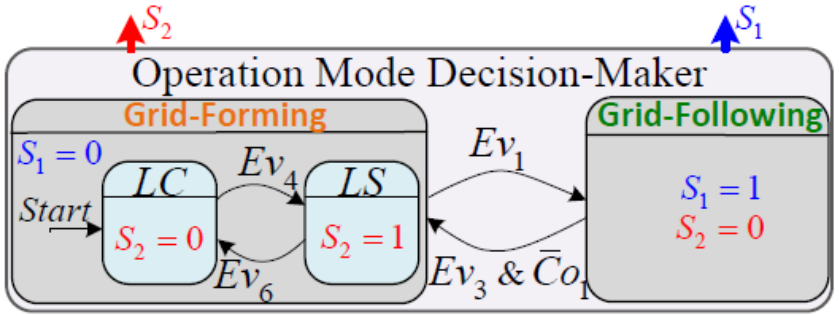
Operation of the Load Shedding

1. When **demand** > **supply**. ESSs are the Grid-Forming.
2. The voltage in the power grid is reduced when the voltage in the battery reaches a threshold value (EOD). (Ev_4)
3. The voltage is restored to the nominal value when (SoC > 50%). (Ev_6)

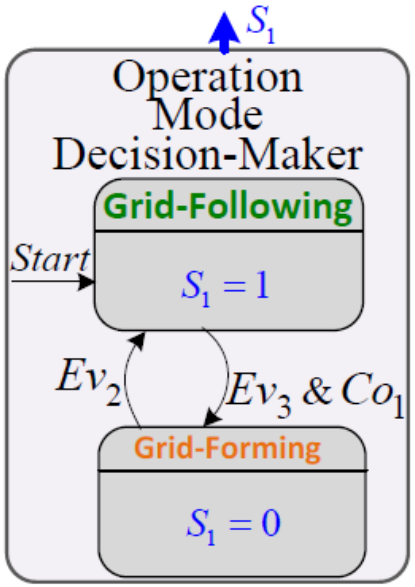
1. Coordination- Distributed Approach

Distributed Decision-Makers

ESS

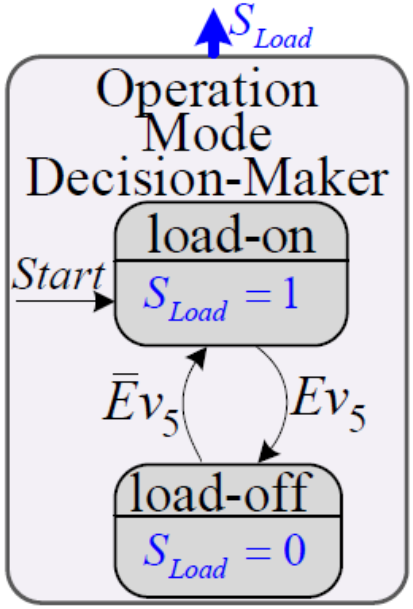


RES



Event/Condition	Description
Ev_1	$V_{Bati} \geq V_r$
Ev_2	$P_{MPPTi} < P_{Resi}$
Ev_3	$f_{ACbus} \notin NDZ$
Ev_4	$V_{Bati} \leq EOD$
Ev_5	$V_{PCC} < 0.9E_{nom}$
Ev_6	$SoC_{bati} < 50\%$
Co_1	$V_{PCC} > E_{nom}$

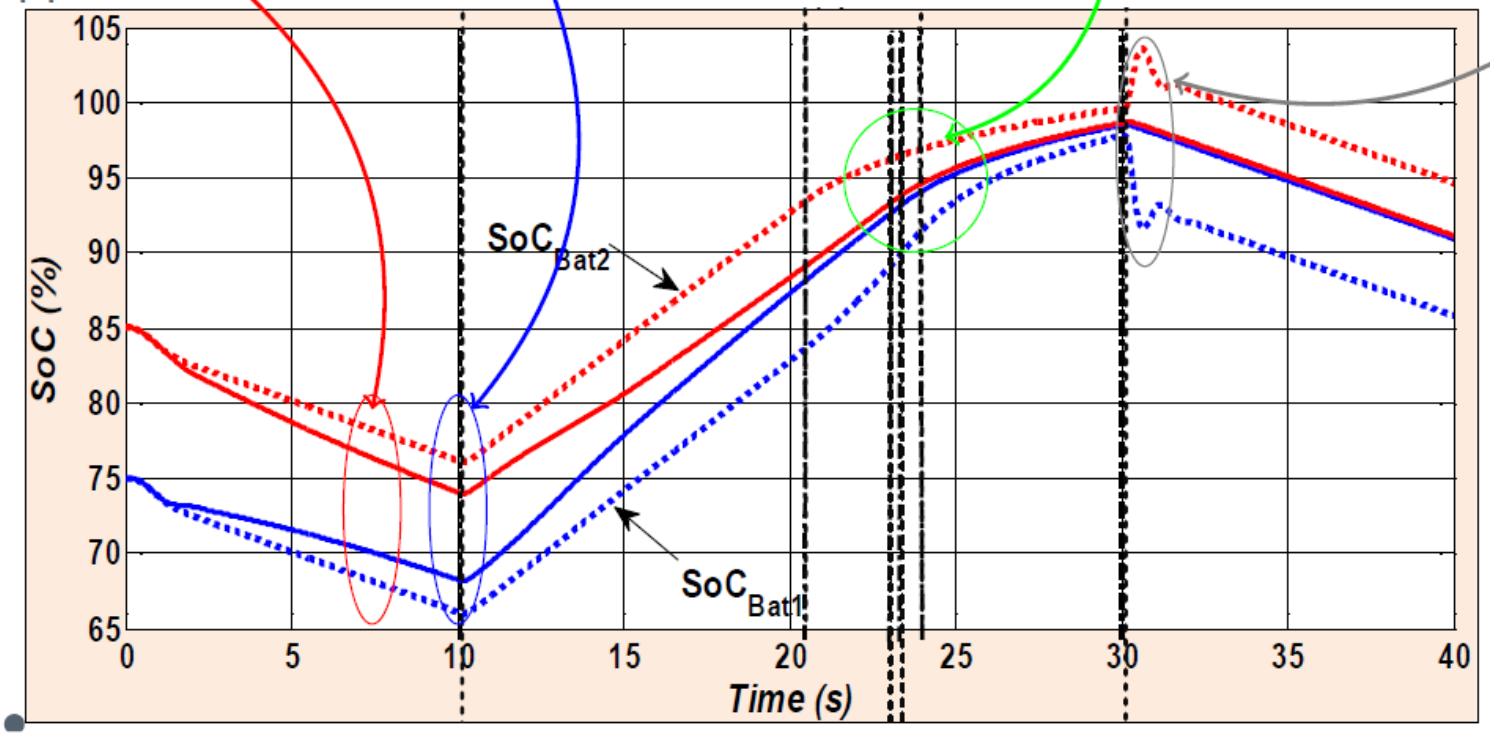
LOAD



1. Coordination- Distributed Approach

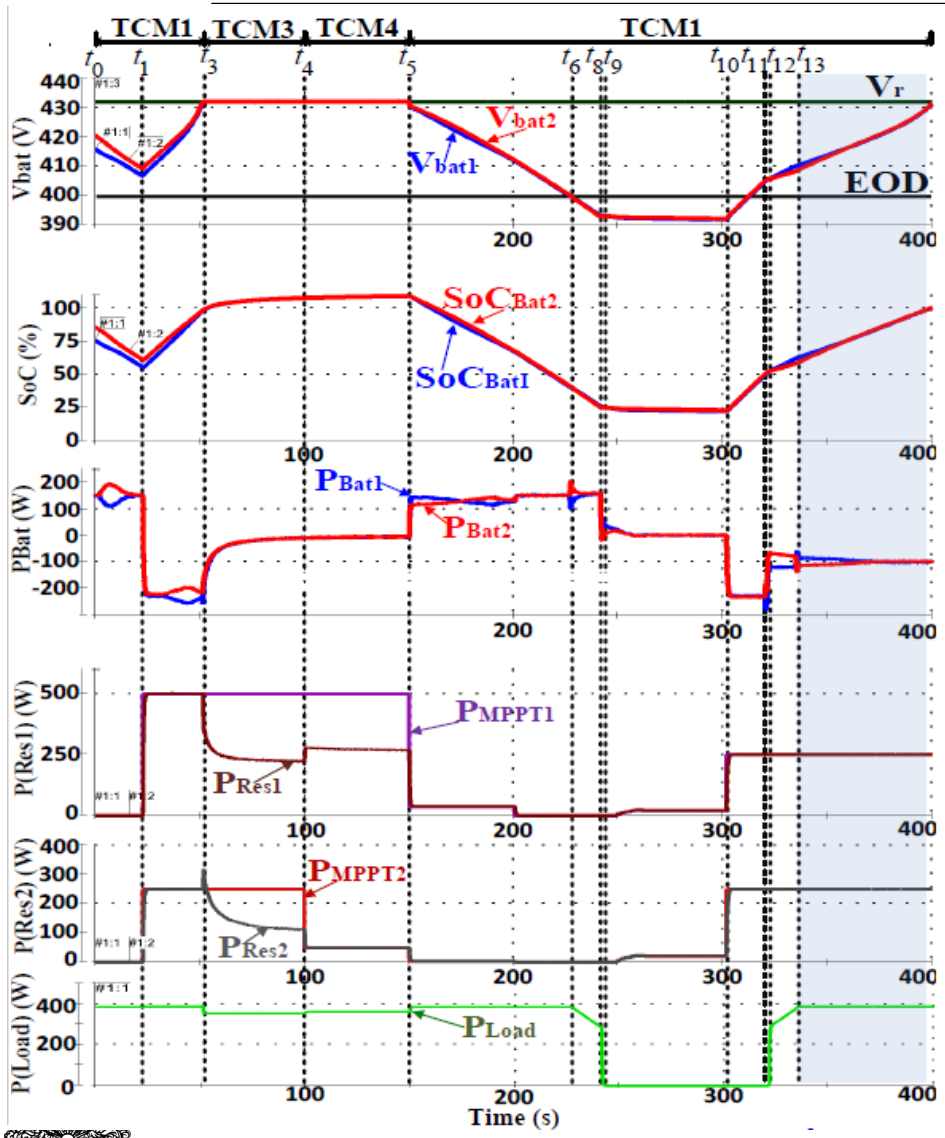
SoC Equaliazation

- Asymptotic Approach.
- Reduction of DoD.
- Less Time for Charging.
- Smooth Transitions.

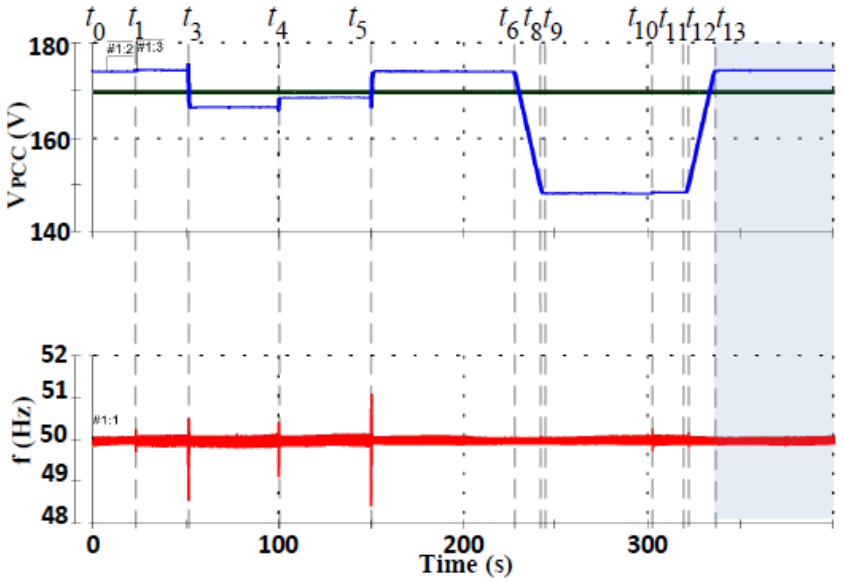


Unify the charging profiles for ESSs based on batteries.

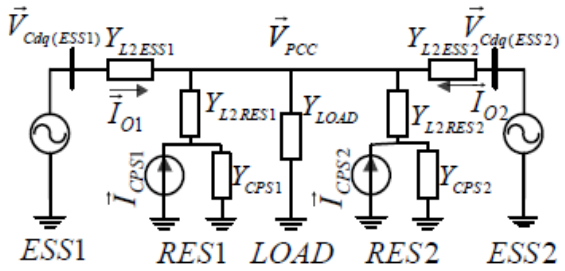
1. Coordination- Distributed Approach



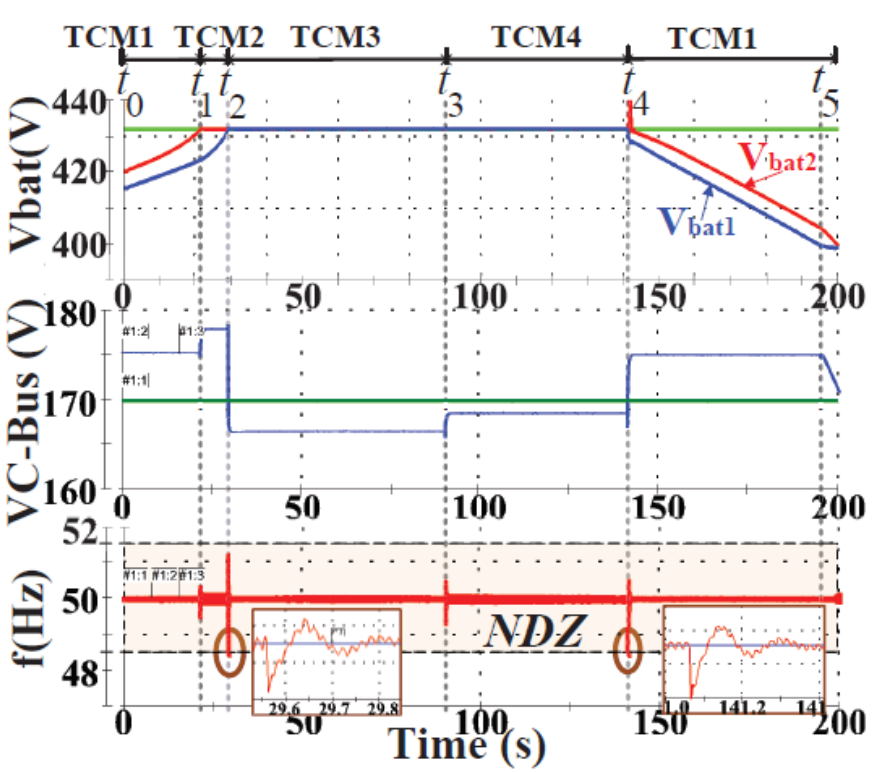
Bus Signalling

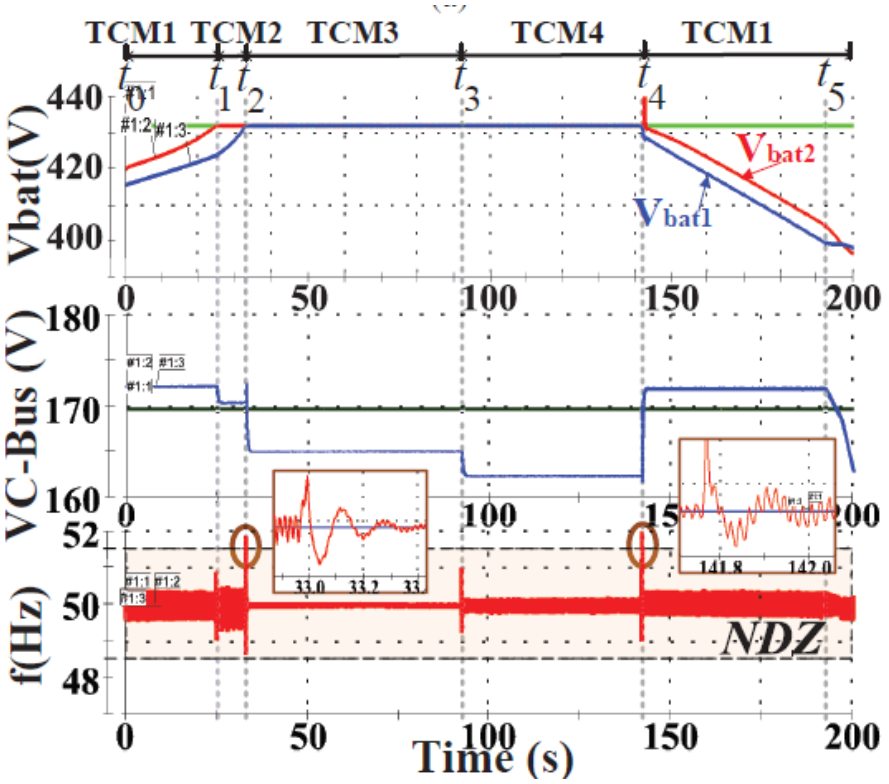


Microgrid Operation Mode



1. Coordination- Distributed Approach

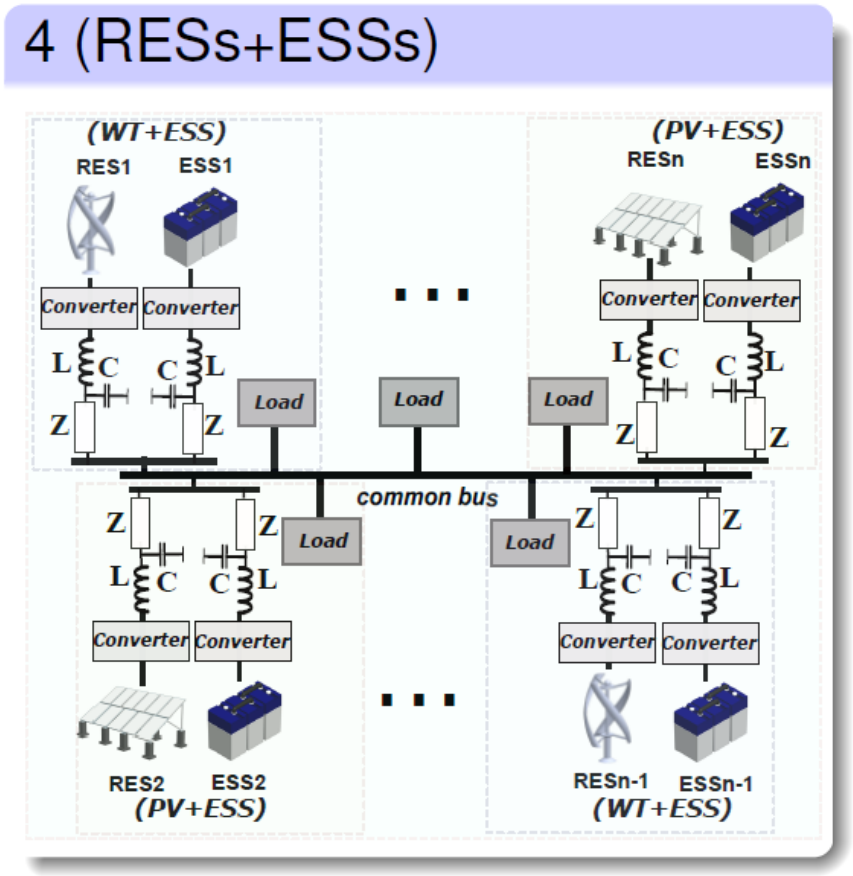


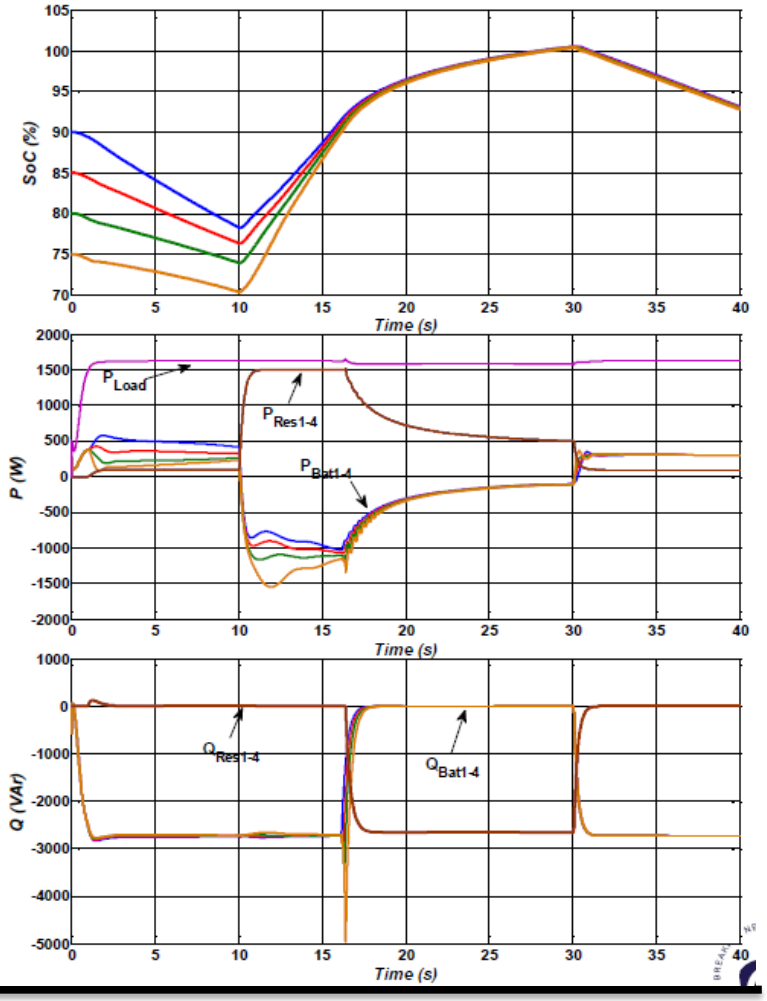


Voltage/Frequency Signalling (a) Capacitive load, (b) Inductive Load.

1. Coordination- Distributed Approach

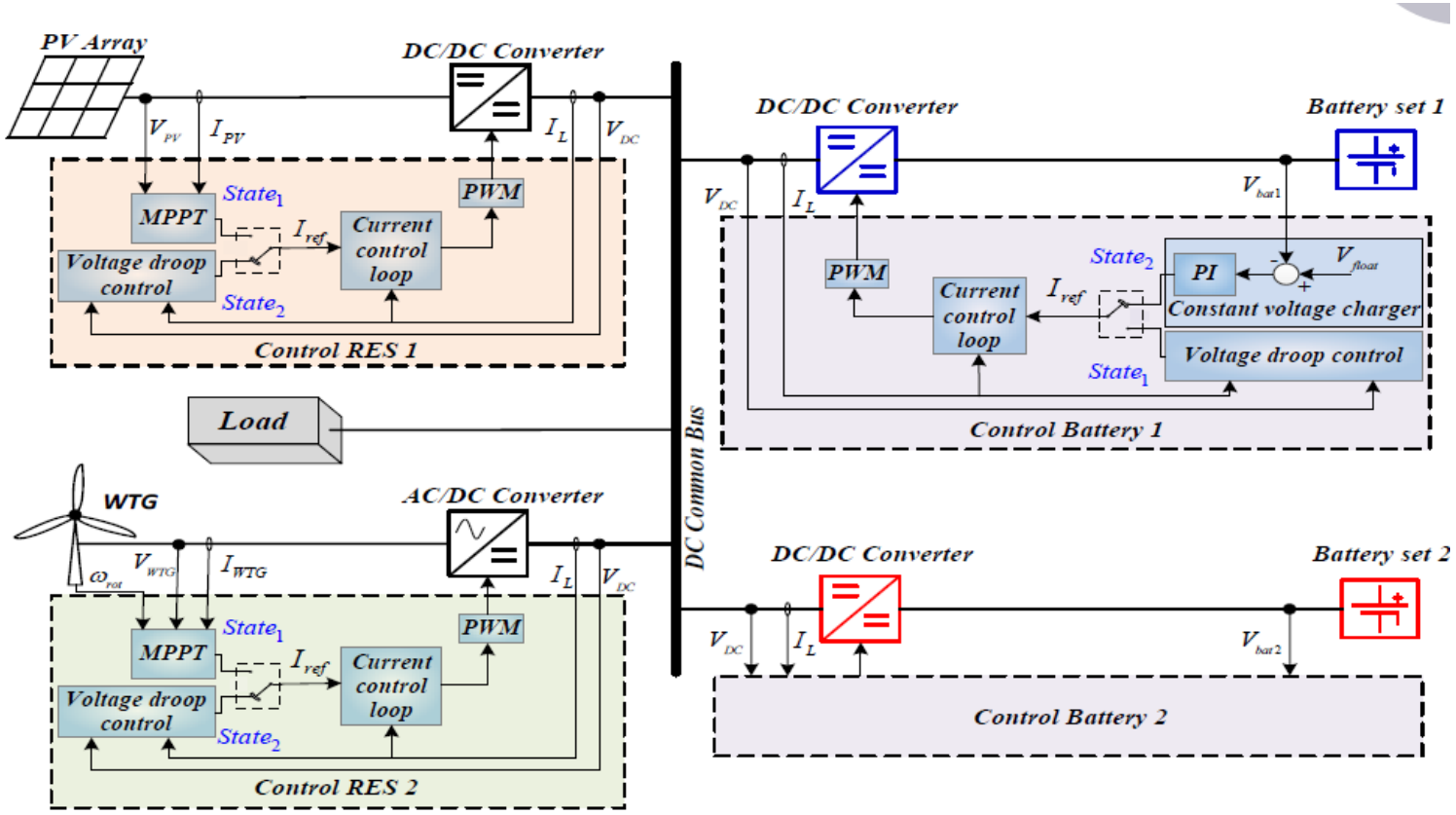
Easy to expand





1. Coordination- Distributed Approach

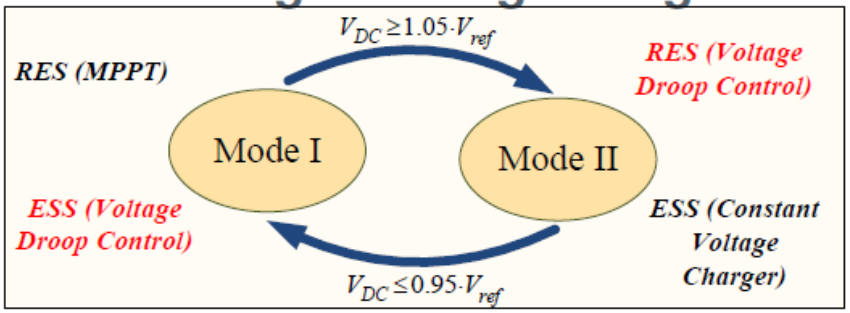
For DC Microgrids



[4]Díaz, N. L., et al, (2014). Intelligent Distributed Generation and Storage Units for DC Microgrids - A New Concept on Cooperative Control without Communications Beyond Droop Control. IEEE Transactions on Smart Grid

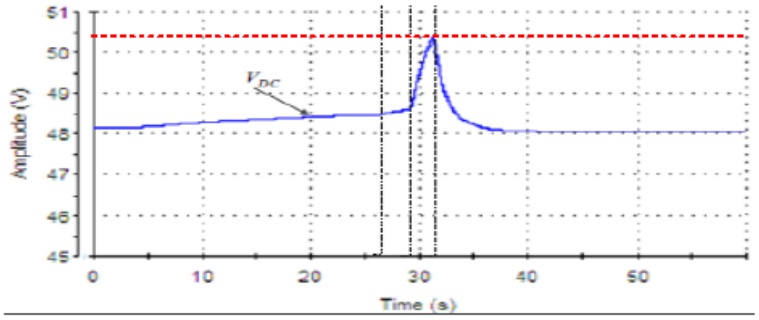
1. Coordination- Distributed Approach

Transitions between Grid-Forming controls are based on DC voltage bus signalling



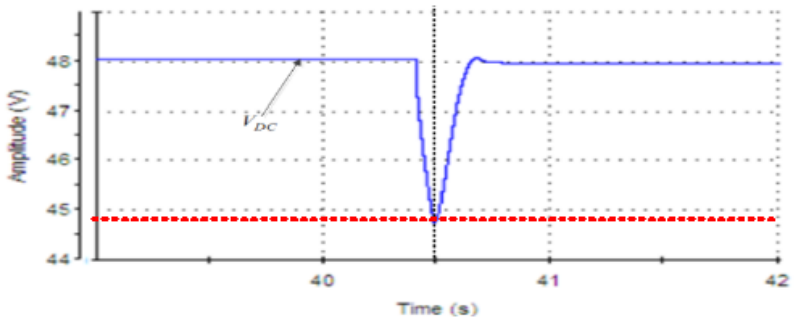
From ESSs to RESs

When The ESSs change to Constant-Voltage Stage.



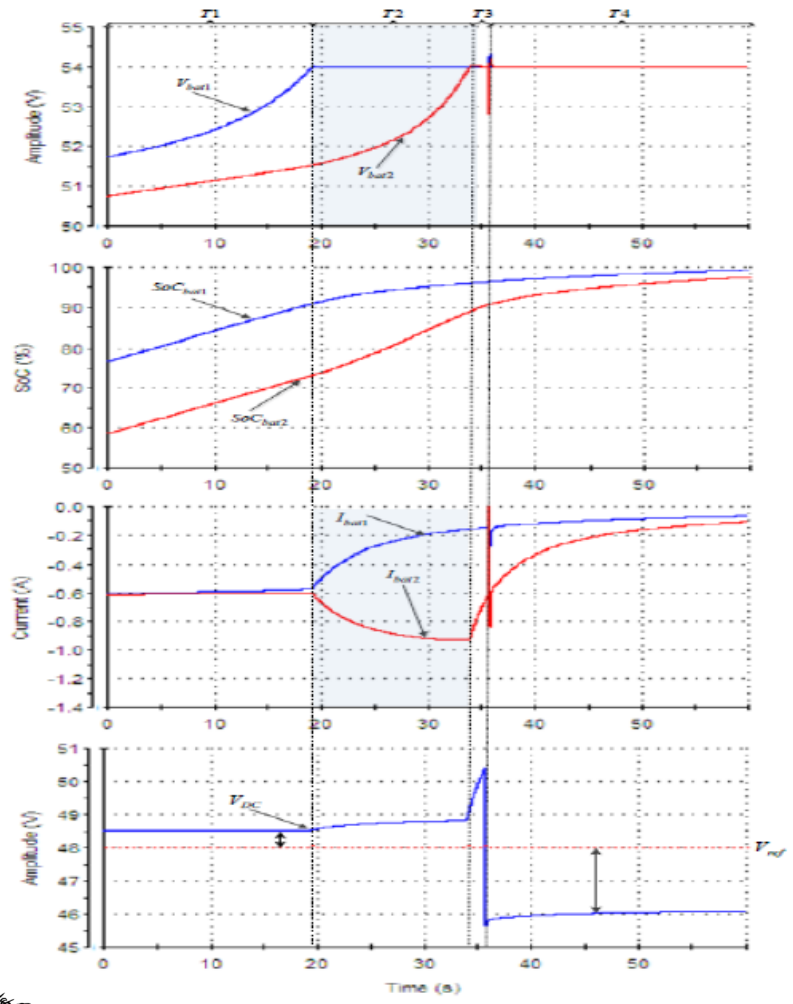
From RESs to ESSs

When available power from RESs is lower than consumption.

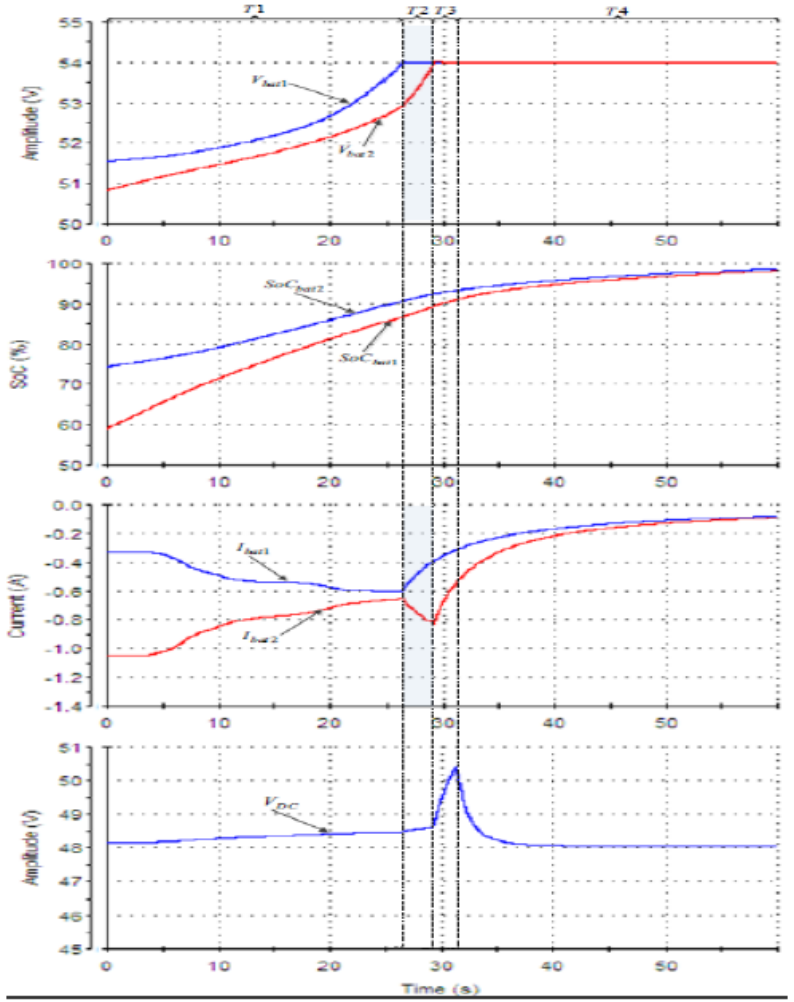


1. Coordination- Distributed Approach

Without Fuzzy function

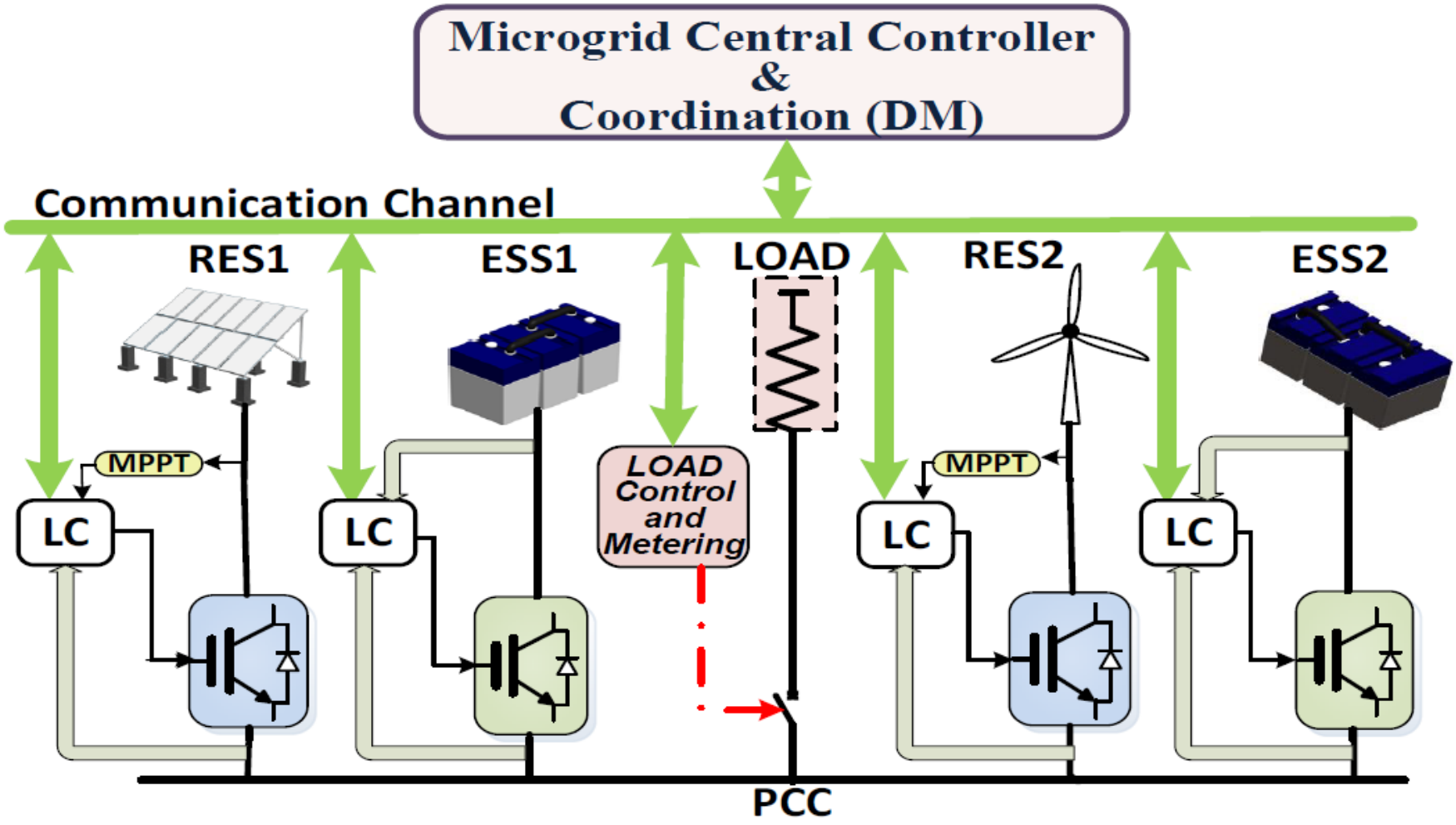


Wit Fuzzy function



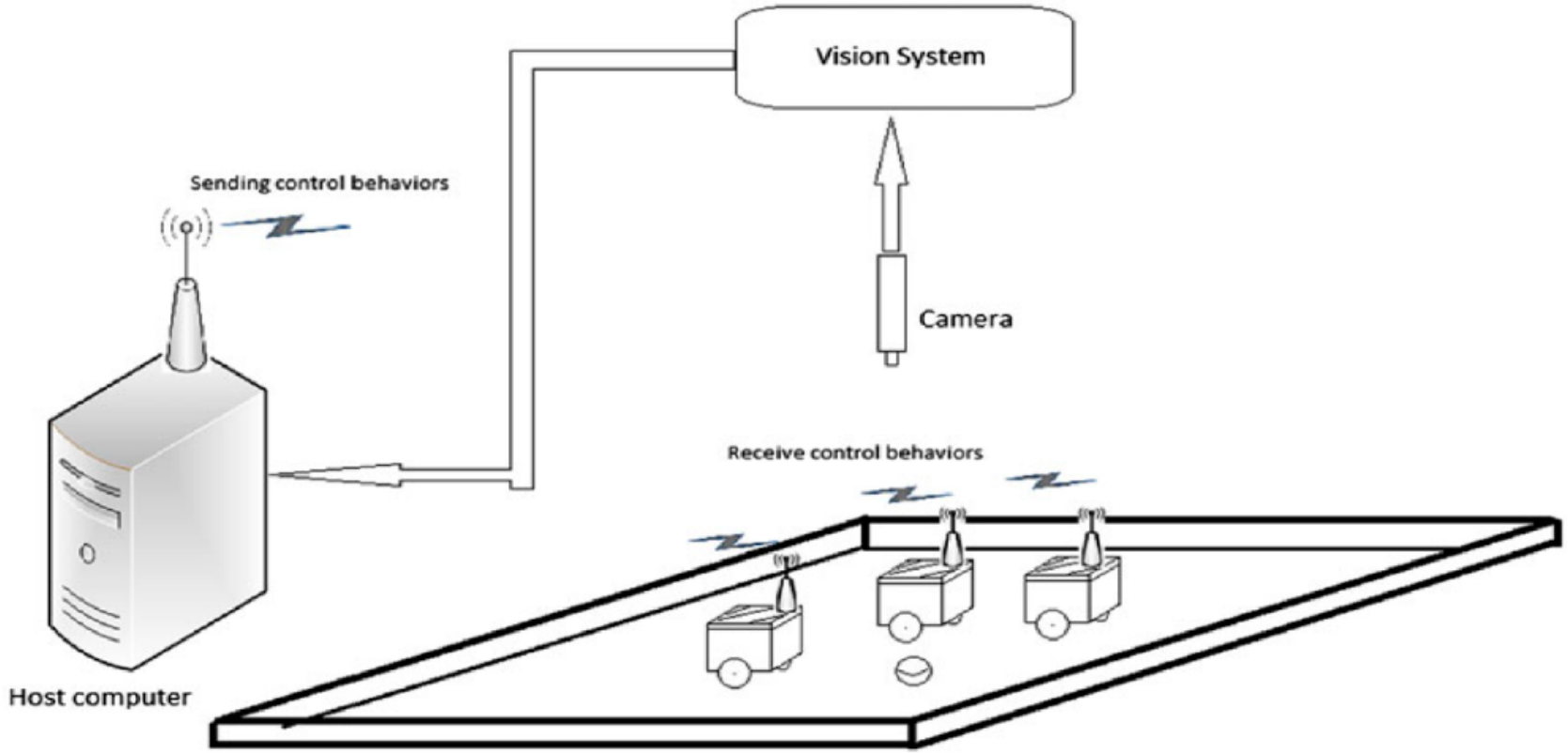
2. Coordination- Centralized Approach

Case Study MG



2. Coordination- Centralized Approach

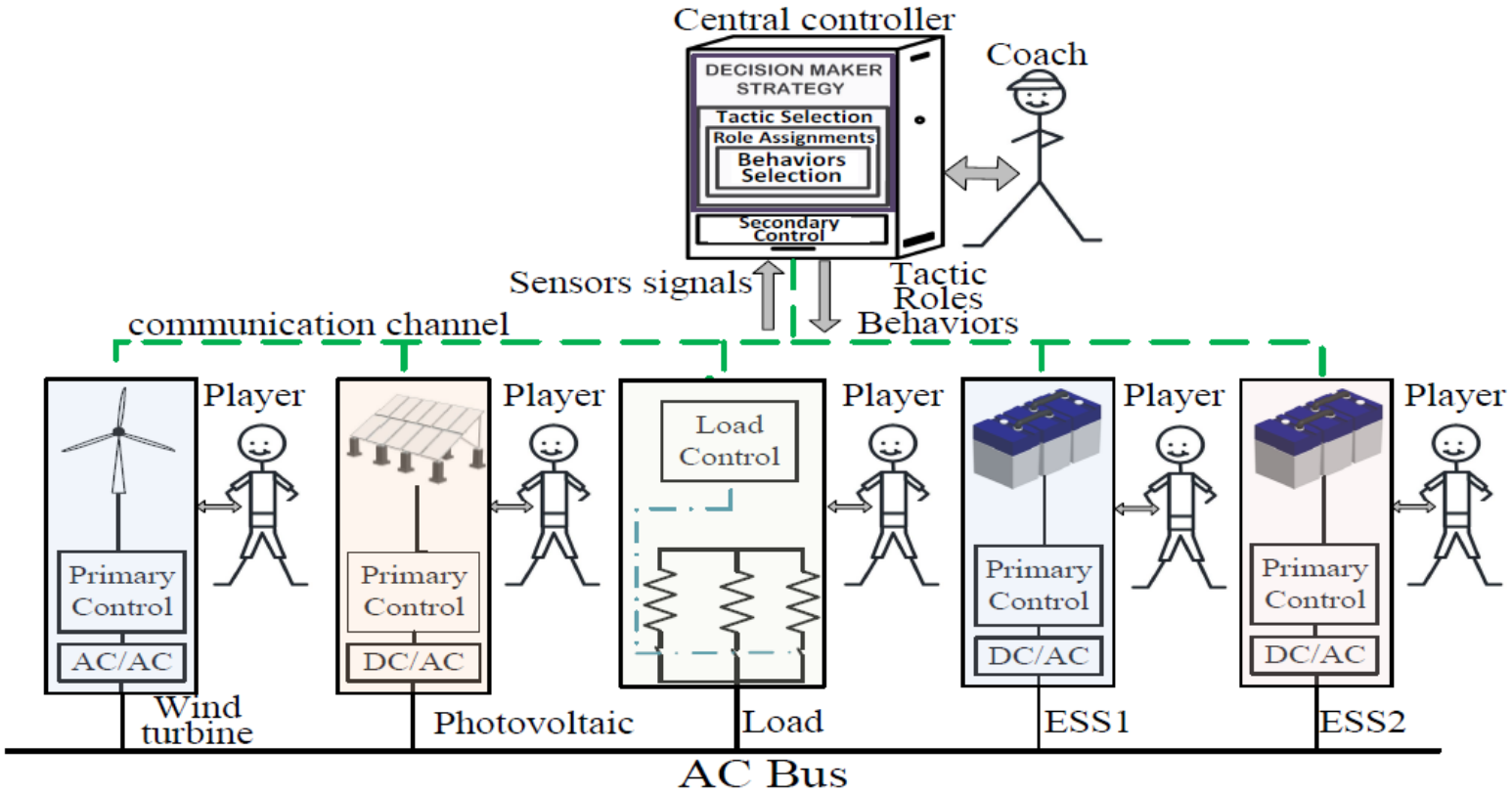
Inspired by Robot-Soccer Coordination



J. G. Guarnizo, M. Mellado, C. Y. Low, and F. Blanes, "Architecting centralized coordination of soccer robots based on principle solution," Advanced Robotics, 2015.

2. Coordination- Centralized Approach

Inspired by Robot-Soccer Coordination



[5]Díaz, N. L., et al, (2016). A Robot-Soccer-Coordination Inspired Control Architecture Applied to Islanded Microgrids. IEEE Transactions on Power Electronics.

2. Coordination- Centralized Approach

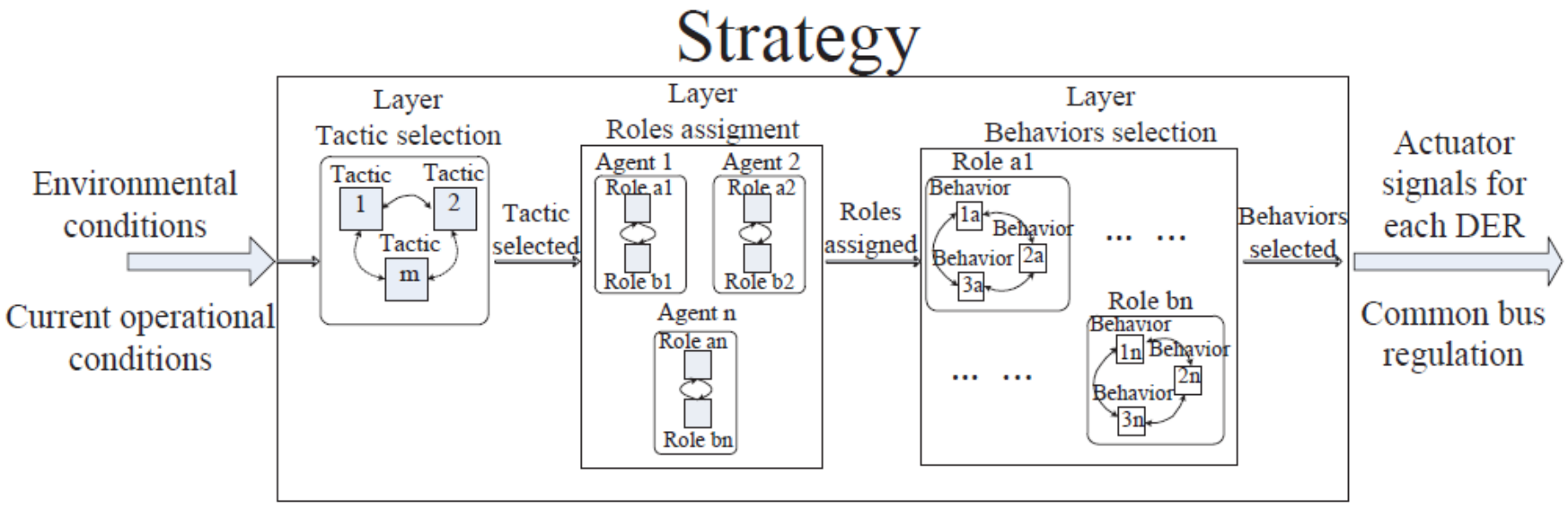
As in a robot soccer the operation of a microgrid can be defined in term of:

- **Team Strategy:** Reliability of the islanded power system.
- **Tactics:**
  - **Power Balance:** ESSs are the Grid-Forming
  - **Power curtailment:** RESs are the Grid-Forming
  - **Load shedding:** When ESSs are reaching their minimum levels.
- **Roles:** Grid-Forming or Grid-Following.
- **Behaviour:** Interactive or Non-interactive operation.

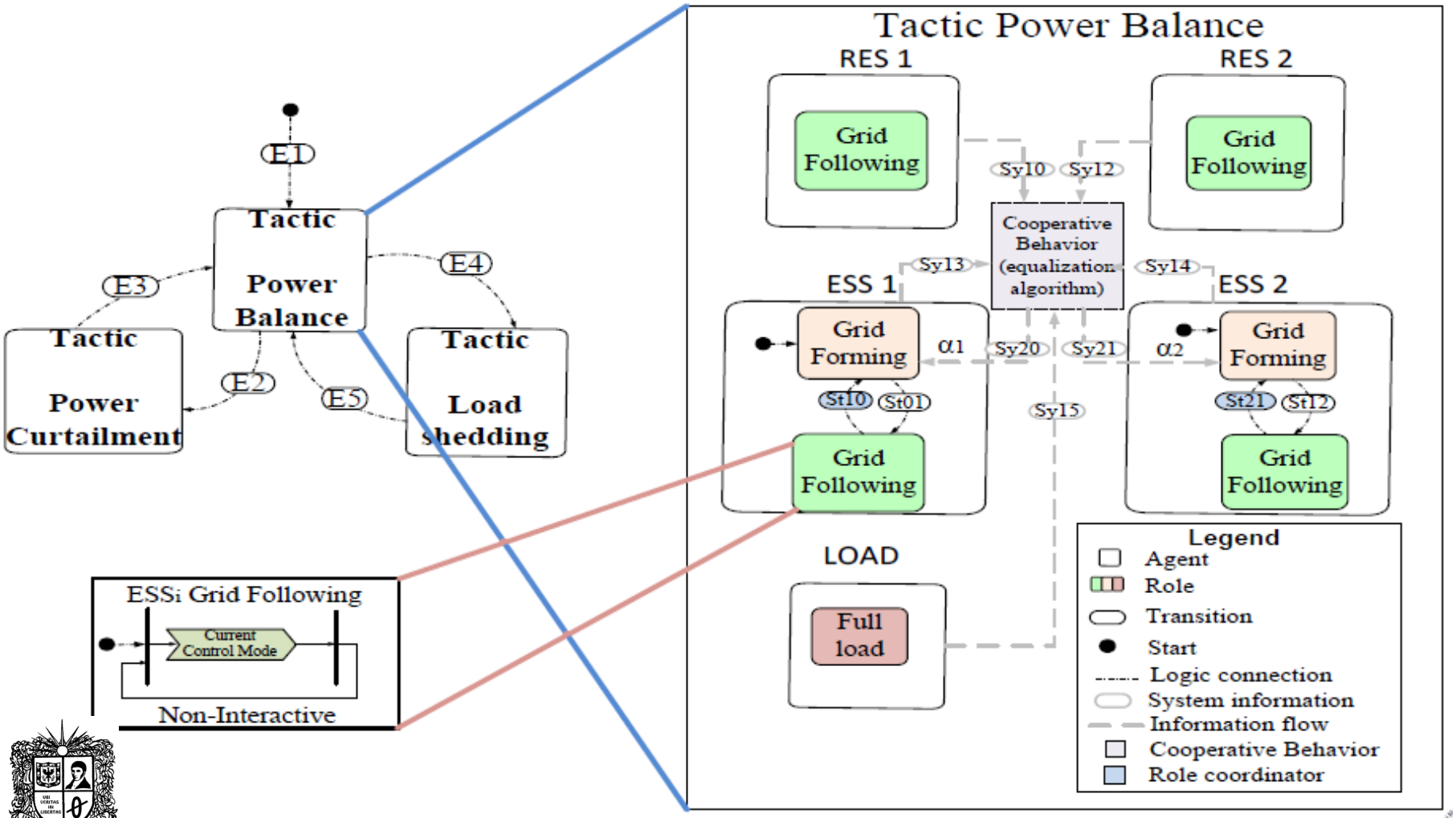
Interactive	Non-Interactive
Droop Control	MPPT
Power Dispatch	Constant-Voltage Charge

2. Coordination- Centralized Approach

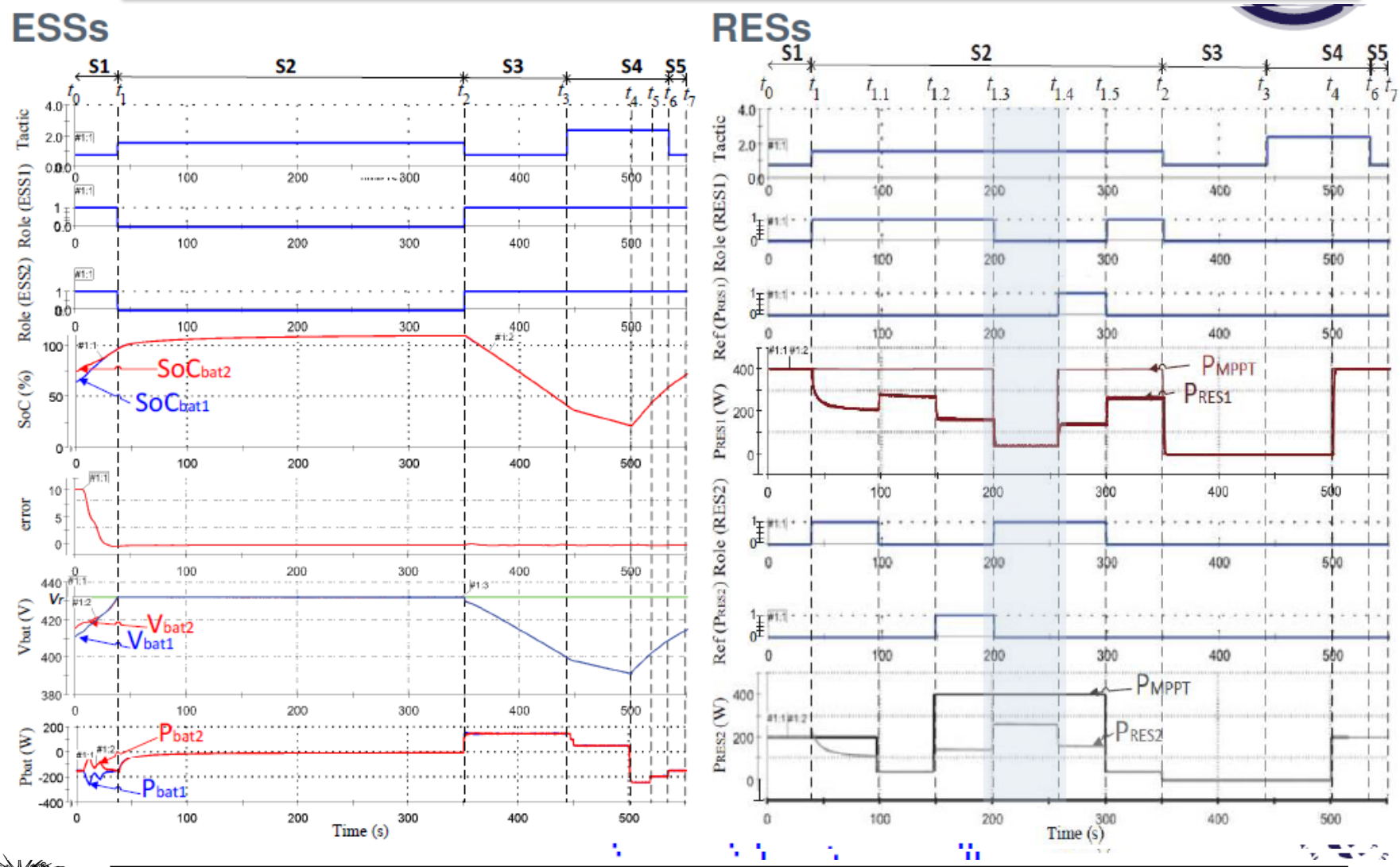
The proposed strategy is implemented using a hierarchical finite state machine



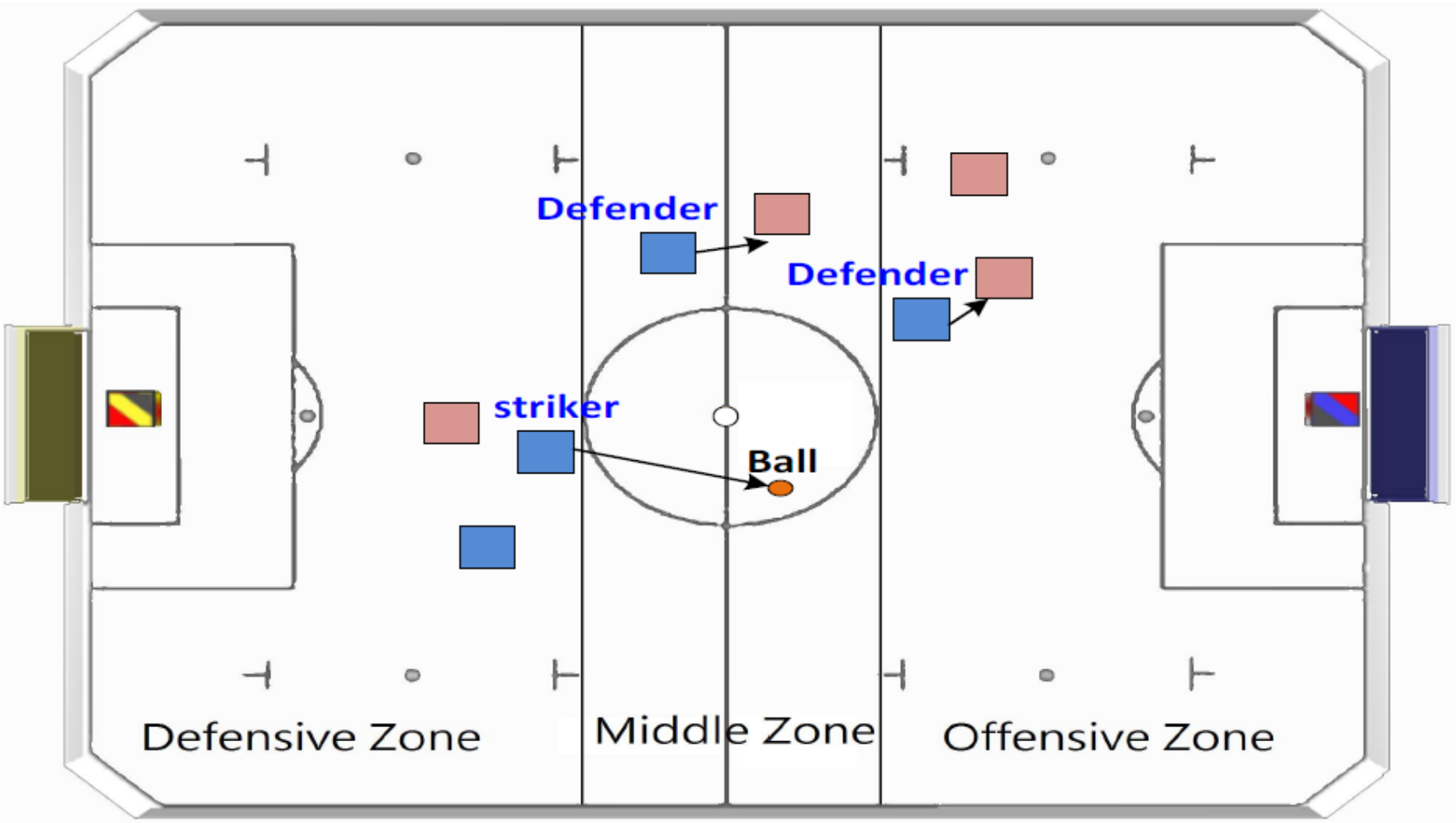
2. Coordination- Centralized Approach



2. Coordination- Centralized Approach



2. Coordination- Centralized Approach



2. Coordination- Centralized Approach