Effective Microgrid Optimal Dispatch Settings

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Agenda

- **Background**
- **Optimal Dispatch Problem**
- **Proposed Effective Settings for Optimal Dispatch**
- **Results and Discussions**

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Background: Microgrid and Controller

- A microgrid is defined as a collection of controllable distributed energy resources (DERs) and loads.

- A microgrid can operate in both grid-connected and islanded modes.

- Combination of renewable sources and energy storage in microgrids bring up many challenges.

- The microgrid controller is responsible for coordinating among the microgrid assets.

- The microgrid controller tasks
  - Continuously monitor the microgrid DERs and loads
  - Calculate optimal setpoints based on real-time measurements
  - Send the new commands to DERs and loads

- The microgrid Controller contain several functions such as *active power control*, planned islanding, unplanned islanding, reactive power control, black start, and reconnect

Background: Active Power Control

- The active power control function is mainly responsible for dispatching DERs.
- In the grid-connected mode, the impot and export power to the grid are controlled.
- In the islanded mode, the reserve margin in grid-forming DER(s) and stored energy are maintained.
- The active power control function can be implemented based on solving an optimization problem
- Optimal dispatch determines the optimal set-points of DERs.

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Optimal Dispatch Objective

- **Objective**: The main objective of the optimal dispatch problem is to schedule the microgrid assets in order to achieve the minimum cost.

$$Costs = \sum_{t=1}^{\mathcal{N}_T} C^{Ex}[t] + C^{G}[t] + C^{S}[t]$$

- $C^{Ex}[t]$ is the cost associated with exchanged power with the grid
- $C^{S}[t]$ represents the operation cost of the energy storages
- $C^{G}[t]$ is the generation cost of generators, includes fuel cost, shutdown/startup cost, etc.

Constraints

- **Constraints**: operational considerations in microgrid operation which are necessary to guarantee the proper operation of microgrid upon scheduling the DERs.

  - *Power Balance***:** the balance between generation and load should be maintained in microgrid.

  - *Storage Energy Balance*: this constraint dictates how storage SOC should be evolved over time, depending upon the storage charging/discharging powers, efficiencies, and standby loss.

  - *Storage Simultaneous Charge/Discharge*: this constraint ensures that the storage is either in charge or discharge mode.

  - *Storage Sustainability*: this constraint ensures that storage is operated with a constant cycle over the prediction horizon.

Hard Constraints vs. Soft Constraints

- **Hard Constraint:** the constraints related to operation of a microgrid or individual assets that is firm and cannot be violated

$$P_i^{min} \leq P_i \leq P_i^{max}$$

- **Soft Constraint:** the constraints that are not firm and can be violated depending on the microgrid conditions and configurations.

$$-\varepsilon_i + P_i^{min} \leq P_i \leq P_i^{max} + \varepsilon_i$$

- **Modified Objective**: the auxulary variables are minimize in objective function.

$$Objective = Costs + \sum_{i}^{n} PF_i \times \varepsilon_i$$

- $\boldsymbol{PF_i}$: Penalty factor is supposed to determine the importance and priority of violation in optimization problem and should be coordinated with costs.

Soft Constraints in Optimal Dispatch

- **DER Power Limits**: the power of a DER should be kept within an operational range defined by maximum and minimum acceptable power. For $i \in \mathcal{N}_{DER}$,

$$P_i^{DER}[t] \leq P_i^{DER-Max} \quad \Rightarrow \quad P_i^{DER}[t] \leq P_i^{DER-Max} + P_i^{Violate+}[t]$$

$$P_i^{DER}[t] \geq P_i^{DER-Min} \quad \Rightarrow \quad P_i^{DER}[t] \geq P_i^{DER-Min} - P_i^{Violate-}[t]$$

- **Load Power**: the value of loads power over the optimization horizon are provided through forecasting. For $i \in \mathcal{N}_L$,

$$P_i^{L}[t] = P_i^{LF}[t] \quad \Rightarrow \quad P_i^{L}[t] = P_i^{LF}[t] - P_i^{Shed}[t]$$

- **Renewable Power**: similar to loads, the value of renewable resources power over the optimization horizon are provided through the forecasting. For $i \in \mathcal{N}_R$,

$$P_i^{R}[t] = P_i^{RF}[t] \quad \Rightarrow \quad P_i^{R}[t] = P_i^{RF}[t] - P_i^{Curtail}[t]$$

Soft Constraints in Optimal Dispatch

- **Storage State-of-Charge**: state-of-charge (SOC) of storage should be kept within an operational range defined by maximum and minimum acceptable SOC, $i \in \mathcal{N}_S$

$$SOC_i[t] \geq SOC_i^{Min} \quad\Rightarrow\quad SOC_i[t] \geq SOC_i^{Min} - SOC_i^{Violate-}[t]$$

$$SOC_i[t] \leq SOC_i^{Max} \quad\Rightarrow\quad SOC_i[t] \leq SOC_i^{Max} + SOC_i^{Violate+}[t]$$

- **Smooth Operation of Storage**: smooth operation of storages are introduced as follows:

$$-P_i^{Smooth}[t] \leq P_i^S[t] - P_i^S[t-1] \leq P_i^{Smooth}[t]$$

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Method I: Reducing the Number of PF

- Soft constraints **load power**, **renewable power,** and **power limits** are mainly used to ensure power balance in microgrid is met.
- The aggregated value of these variables is presented by power balance slack variable

$$P^{Slack}[t] = \underbrace{\sum_{i=1}^{N_L} P_i^{Shed}[t]}_{Load\ power} - \underbrace{\sum_{i=1}^{N_R} P_i^{Curtail}[t]}_{Renewable\ power} + \underbrace{\sum_{i=1}^{N_{DER}} P_i^{Violate+}[t] - P_i^{Violate-}[t]}_{Power\ limits}$$

$$Penalty^{Slack}[t] = PF^{Slack}|P^{Slack}[t]|$$

- The $P^{Slack}[t]$ determines the extent to which there is excessive generation or excessive load in the microgrid.
- $P^{Slack}[t]$ will be used then in a post-optimization process for curtailment and load shedding.
- Introduce PF^{Slack} instead of
  - $PF_i^{Violate-}$ and $PF_i^{Violate+}$ for all DER
  - $PF_i^{Curtail}$ for all the renewable resources
  - PF_i^{Shed} for all the loads
- The user needs to define the priority for renewable resource curtailment, load shedding, power limit violation.

Method II: Per-Unitized Penalty Factors

- As mentioned, the penalty factors are integrated into the objective function

$$Objective = \ Costs + \sum_{i}^{n} PF_i \times \varepsilon_i$$

- The value of penalty factors should be selected according to the costs.
- Time-of-use (TOU) electricity price, fuel cost of diesel and gas generators, operation cost of storages, etc.
- **Difficulty**: Update penalty factors once the prices are changed.
- **Solution:** Propose an adjustable basis for the penalty factors and per-unitize all the penalty factors according to this basis.

Electricity TOU

$$Price_{TOU}^{Max} = \max_{t \in \mathcal{N}_T} \{Price_{TOU}[t]\}$$

Electricity TOU

$$Price_{GS}^{Max} = \max_{g \in \mathcal{N}_G} \{Price_{g}^{Max}\}$$

$$Price_{base} = max\{Price_{TOF}^{Max}, \quad Price_{GS}^{Max}\}$$

Price Base

$$PF(p.u.) = \frac{PF}{Price_{base}}$$

Per-Unitized PF

Method III: Define Range of Penalty Factors

- $\boldsymbol{PF^{Slack}(p.u.)}$: Power balance penalty factor
  - Avoid undesired to do the load shedding or renewable resources curtailment
  - PF^{Slack} should be always greater than the maximum operation price
    - $PF^{Slack}(p.u.) > 1$
- $\boldsymbol{PF_i^{SOC}(p.u.)}$: SOC violation penalty factors
  - Storage SOC limit violation would happen in rare condition to make real-time operation of microgrid feasible.
  - This violation should not interfere with normal operation of the microgrid.
  - SOC violation does not affect the power balance requirement in the microgrid.

$$PF_i^{SOC}(p.u.) > PF^{Slack}(p.u.)$$

- $\boldsymbol{PF_i^{Smooth}(p.u.)}$: Smooth operation penalty factors
  - This constraint avoids immediate changes in storage power
  - It does not affect the feasibility of the optimization problem solution.
  - smoothing of storage operation should not be at the cost of causing load shedding or renewable resources curtailment

$$PF_i^{Smooth}(p.u.) < PF^{Slack}(p.u.)$$

$$PF_i^{Smooth}(p.u.) < PF^{Slack}(p.u.) < PF_i^{SOC}(p.u.)$$

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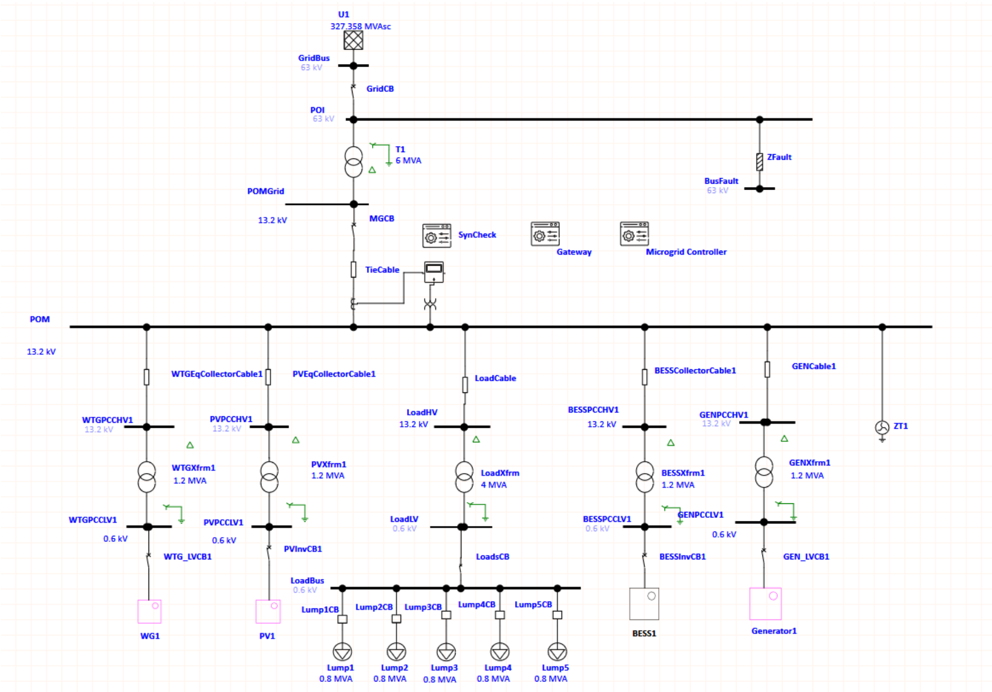
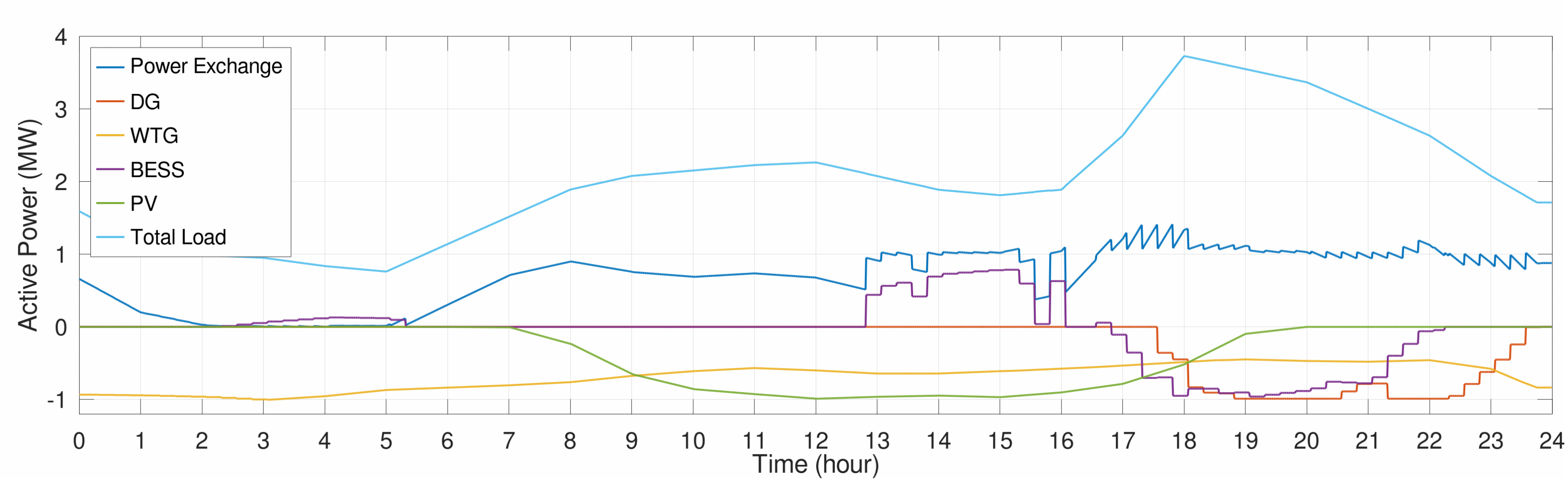


Parameter	Value
Maximum Export	0.0 MW
Maximum Import	1 MW
Maximum SOC	90%
Minimum SOC	10%
Initial SOC	50 %
Smooth Operation Penalty Factor	0.5 p.u.
Power Balance Penalty Factor	3 p.u.
SOC Violation Penalty Factor	5 p.u.

Results



Optimal dispatch results for one day.

- BESS is scheduled to charge between 1:00 to 4:00
- BESS also discharges between 17:00 to 22:00
- The generator becomes available after 17:30
- The small violation of imported power between 16:00 to 18:00 is due to the fast load changing

Conclusion

- Penalty factors significantly impact on effective and optimal utilization of energy resources within a microgrid.
- The process of tuning penalty factors needs a knowledgeable user both in optimization and power system.
- This paper proposed three strategies to minimize the efforts of tuning penalty factors.
- First, it is proposed to combine power balance variables used in optimal dispatch problem and come up with one slack variable for power balance which needs one penalty factor.
- Second, a base price is proposed to per-unitize the penalty factors, which facilitates the auto tuning the penalty factors upon changing the prices in the microgrid.
- Finally, a tailored range is defined for penalty factors, which guarantees the proper solution of optimal dispatch and avoids any mis-operation in the microgrid.

Thank You!