X SICEL 2021

Transición energética en la 4ta revolución industrial

Universidad Tecnológica de Pereira

UNIVERSIDAD NACIONAL DE COLOMBIA

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Integration of DER in the Planning of Low Voltage Electric Distribution Networks

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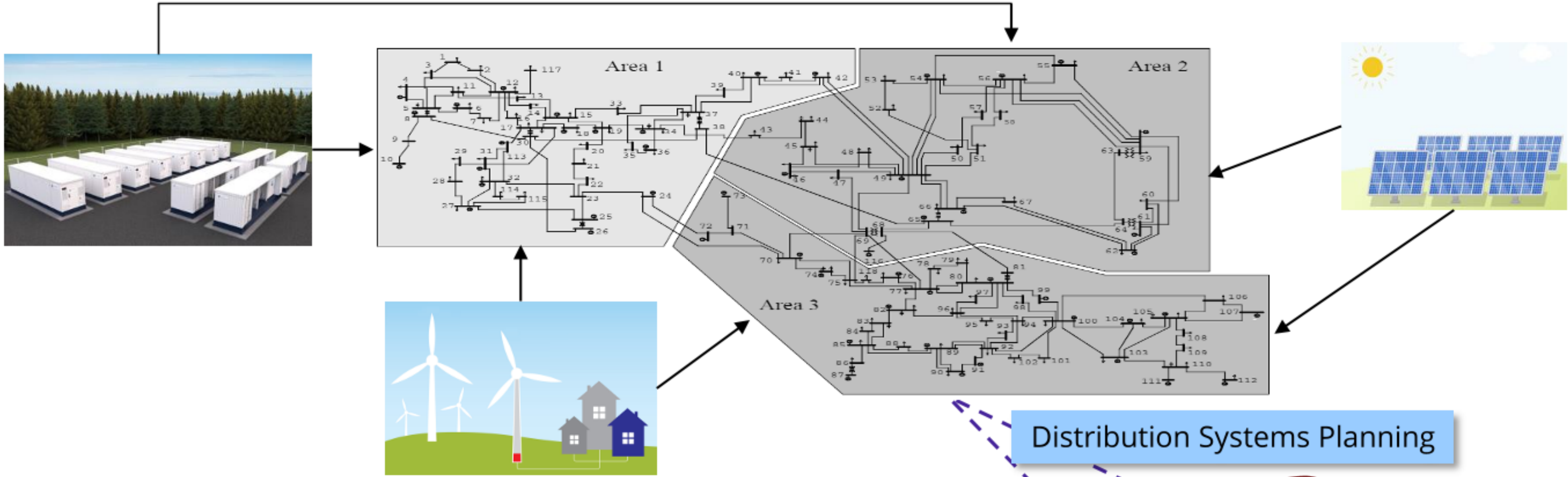
I. Introduction



How to plan the expansion of electric distribution systems considering the integration of DERs?

II. Mathematical model

$$\min \quad \{T_1 + T_2 + T_3 + T_4 - T_5\} \tag{1}$$

$$\text{subject to} \quad (8) - (31) \tag{2}$$

Objective function

$$T_1 = \sum_{i \in \Omega_{NDT}} \sum_{d \in \Omega_{DT}} C_d^{DT} \sigma_{i,d}^{DT} \tag{3}$$

$$T_2 = \sum_{ij \in \Omega_{NB}} \sum_{s \in \Omega_S} C_s^{NB} \sigma_{ij,s}^{NB} l_{ij} + \sum_{ij \in \Omega_{EB}} \sum_{s \in \Omega_S} C_s^{EB} \sigma_{ij,s}^{EB} l_{ij} \tag{4}$$

$$T_3 = \sum_{i \in \Omega_{NPV}} \sum_{g \in \Omega_{PV}} C_g^{PV} \sigma_{i,g}^{PV} + \sum_{i \in \Omega_{NWT}} \sum_{w \in \Omega_{WT}} C_w^{WT} \sigma_{i,w}^{WT} \tag{5}$$

$$T_4 = \sum_{i \in \Omega_{NES}} \sum_{b \in \Omega_{ES}} \left(C_b^{ES} + F(i, \lambda)\, O_{\&} M_b^{fx} \right) \sigma_{i,b}^{ES} \tag{6}$$

$$T_5 = F(i, \lambda) \sum_{h=1}^{T} \left[C^S \sum_{i \in \Omega_N} P_{i,h}^{D} ZIP_{i,h} - C_h^P \sum_{i \in \Omega_{NDT}} P_{i,h}^{DT} \right] D^y \Delta_h^T \tag{7}$$

II. Mathematical model

Power flow equations

$$P_{i,h}^{DT} + P_{i,h}^{PV} + P_{i,h}^{WT} + P_{i,h}^{ES} = P_{i,h}^{D} ZIP_{i,h} + \mathbb{R}\mathrm{e}\left[V_{i,h} \sum_{j \in \Omega_N} I_{ij,h}^{*} \right] \quad \forall i \in \Omega_N; \forall h \in \Omega_T \tag{8}$$

$$Q_{i,h}^{DT} = Q_{i,h}^{D} ZIP_{i,h} + \mathbb{I}\mathrm{m}\left[V_{i,h} \sum_{j \in \Omega_N} I_{ij,h}^{*} \right] \quad \forall i \in \Omega_N; \forall h \in \Omega_T \tag{9}$$

$$I_{ij,h} = \sum_{s \in \Omega_S} \left(\sigma_{ij,s}^{NB} + \sigma_{ij,s}^{EB} \right) \frac{V_{i,h} - V_{j,h}}{\left(R_s + jX_s \right) l_{ij}} \quad \forall ij \in \Omega_B; \forall h \in \Omega_T \tag{10}$$

$$ZIP_{i,h} = c_0 + c_1 \left| V_{i,h} \right| + c_2 \left| V_{i,h} \right|^2 \quad \forall i \in \Omega_N; \forall h \in \Omega_T \tag{11}$$

II. Mathematical model

Operative limits of the low voltage networks

$$|I_{ij,h}| \leq \sum_{s \in \Omega_S} \left(\sigma_{ij,s}^{NB} + \sigma_{ij,s}^{EB}\right) I_s^{max} \qquad \forall ij \in \Omega_B; \forall h \in \Omega_T \tag{12}$$

$$\left(P_{i,h}^{DT}\right)^2 + \left(Q_{i,h}^{DT}\right)^2 \leq \sum_{d \in \Omega_{DT}} \sigma_{i,d}^{DT} S_d^{max} \qquad \forall i \in \Omega_{NDT}; \forall h \in \Omega_T \tag{13}$$

$$V_i^{\min} \leq |V_{i,h}| \leq V_i^{\max} \qquad \forall i \in \Omega_N; \forall h \in \Omega_T \tag{14}$$

Renewable energy sources modeling

$$P_{i,h}^{PV} = \sum_{g \in \Omega_{PV}} \sigma_{i,g}^{PV} \overline{P}_g^{PV} T_h^{PV} \qquad \forall i \in \Omega_{NPV}; \forall h \in \Omega_T \tag{15}$$

$$P_{i,h}^{WT} = \sum_{w \in \Omega_{WT}} \sigma_{i,w}^{WT} \overline{P}_w^{WT} T_h^{WT} \qquad \forall i \in \Omega_{NWT}; \forall h \in \Omega_T \tag{16}$$

II. Mathematical model

Energy storage systems modeling

$$P_{i,h}^{ES} = P_{i,h}^{ESD} - P_{i,h}^{ESC} \quad \forall i \in \Omega_{NES}; \forall h \in \Omega_T \quad (17)$$

$$\sum_{b \in \Omega_{ES}} \sigma_{i,b}^{ES} \delta_{i,h}^{ES} \underline{P}_b^C \leq P_{i,h}^{ESC} \leq \sum_{b \in \Omega_{ES}} \sigma_{i,b}^{ES} \delta_{i,h}^{ES} \overline{P}_b^C \quad \forall i \in \Omega_{NES}; \forall h \in \Omega_T \quad (18)$$

$$\sum_{b \in \Omega_{TES}} \sigma_{i,b}^{ES} \underline{P}_b^D \left(1 - \delta_{i,h}^{ES}\right) \leq P_{i,h}^{ESD} \leq \sum_{b \in \Omega_{ES}} \sigma_{i,b}^{ES} \overline{P}_b^D \left(1 - \delta_{i,h}^{ES}\right) \quad \forall i \in \Omega_{NES}; \forall h \in \Omega_T \quad (19)$$

$$SoC_{i,h} = SoC_{i,h-1} - \sum_{b \in \Omega_{ES}} \left(\frac{1}{\eta_b^+} P_{i,h}^{ESD} - \eta_b^- P_{i,h}^{ESC} \right) \Delta_h^T \; \phi_b \; \sigma_{i,b}^{ES} \quad \forall i \in \Omega_{NES}; \forall h \in \Omega_T \quad (20)$$

$$SoC_{i,h} = SoC_i^0 \quad h = 0; \forall i \in \Omega_{NES} \quad (21)$$

$$SoC_{i,h} = SoC_i^F \quad h = T; \forall i \in \Omega_{NES} \quad (22)$$

$$SoC_i^{min} \leq SoC_{i,h} \leq SoC_i^{max} \quad \forall i \in \Omega_{NES}; \forall h \in \Omega_T \quad (23)$$

II. Mathematical model

Logical constraints

$$\sum_{s\in\Omega_S} \left(\sigma_{ij,s}^{NB} + \sigma_{ij,s}^{EB}\right) \leq 1 \qquad \forall ij \in \Omega_B \tag{24}$$

$$\sum_{d\in\Omega_{DT}} \sigma_{i,d}^{DT} \leq 1 \qquad \forall i \in \Omega_{NDT} \tag{25}$$

$$\sum_{g\in\Omega_{PV}} \sigma_{i,g}^{PV} \leq 1 \qquad \forall i \in \Omega_{NPV} \tag{26}$$

$$\sum_{w\in\Omega_{WT}} \sigma_{i,w}^{WT} \leq 1 \qquad \forall i \in \Omega_{NWT} \tag{27}$$

$$\sum_{b\in\Omega_{ES}} \sigma_{i,b}^{ES} \leq 1 \qquad \forall i \in \Omega_{NES} \tag{28}$$

II. Mathematical model

Investment limit for DERs

$$\sum_{i \in \Omega_{NPV}} \sum_{g \in \Omega_{PV}} \sigma_{i,g}^{PV} \leq N^{PV} \tag{29}$$

$$\sum_{i \in \Omega_{NWT}} \sum_{w \in \Omega_{WT}} \sigma_{i,w}^{WT} \leq N^{WT} \tag{30}$$

$$\sum_{i \in \Omega_{NES}} \sum_{b \in \Omega_{ES}} \sigma_{i,b}^{ES} \leq N^{ES} \tag{31}$$

The presented model is a mixed-integer nonlinear programming (MINLP) problem

III. Literature overview

The presented problem can be solved with classic optimization and metaheuristic algorithms.

- Classic optimization guarantees an optimal global solution but requires excessive computational efforts for medium and large real systems.

- Metaheuristics are powerful tools for solving complex optimization problems and are widely used in large real distribution planning problems.

Moreover, only one paper considered the integration of solar DGs and ESSs in the planning of low voltage networks.

The optimal operation of ESSs is a difficult problem to address in the planning of distribution systems.

IV. Proposed methodology

Distribution system encoding

The planning decision variables (i.e., location and type of transformers, DERs, and cables) of the low voltage distribution networks are encoded using a vector of integer numbers. The information of the vector represents the size and location of the new and existing elements.

Initial solution

The initial solution is obtained by using a heuristic algorithm. The algorithm aims to connect the distribution transformers to load buses while preserving radiality of the low voltage networks.

IV. Proposed methodology

Solution evaluation

The solutions are evaluated by using a two-stage decomposition method. The first stage solves a linear programming (LP) model that temporarily removes electrical variables from the system and obtains the optimal ESSs operation.

Then, in the second stage, the ESSs charge and discharge powers obtained from the first stage are treated as injections and consumptions of power (PQ nodes) in any power flow algorithm to obtain the real operating state of the system.

IV. Proposed methodology

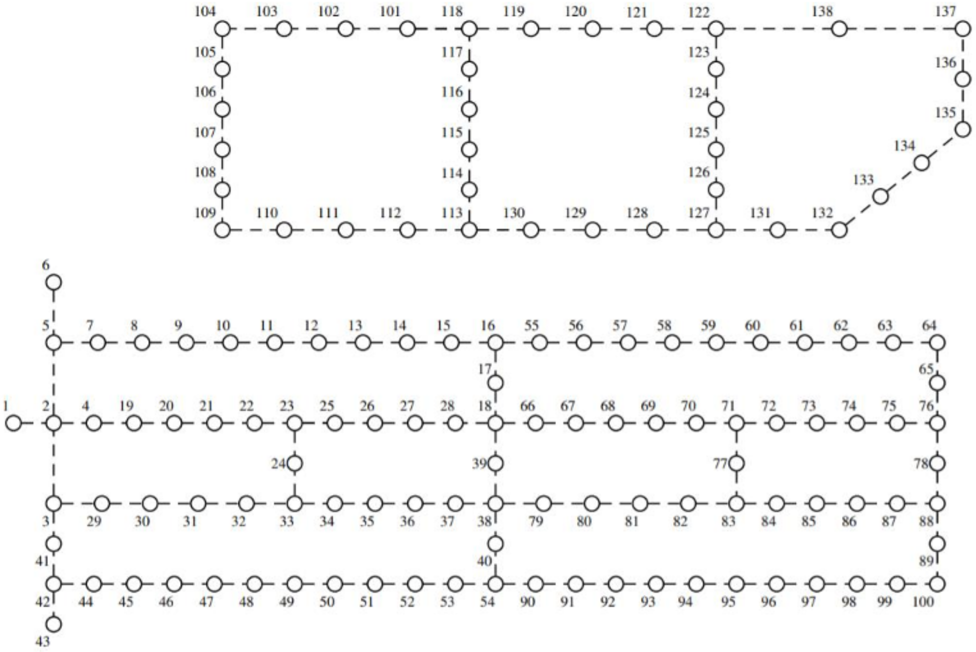
Iterated local Search (ILS) algorithm

Algorithm 1 Pseudocode of ILS algorithm

Generate the initial configuration
Evaluate initial solution
Initialize: Incumbent, stopping criteria, I_{local}^{max}
while stopping criteria are not reached **do**
  for $i = 1$ to I_{local}^{max} **do**
    Obtain a solution from the neighborhood scheme
    Evaluate new solution
    if $OF^{new} < OF^{current}$ **then**
      Update the current solution
    end if
    if $OF^{current} < OF^{incumbent}$ **then**
      Update the incumbent solution
    end if
  end for
  The incumbent solution is perturbed to obtain a new initial solution for the next local search
end while
Print results

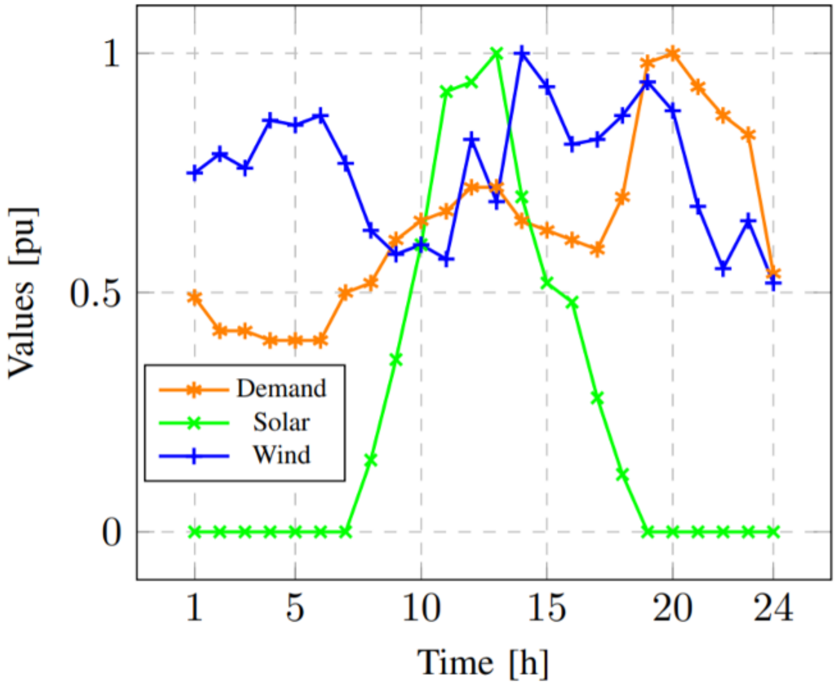
V. Results

Test distribution system of 138 nodes



V. Results

Demand and renewable sources behavior



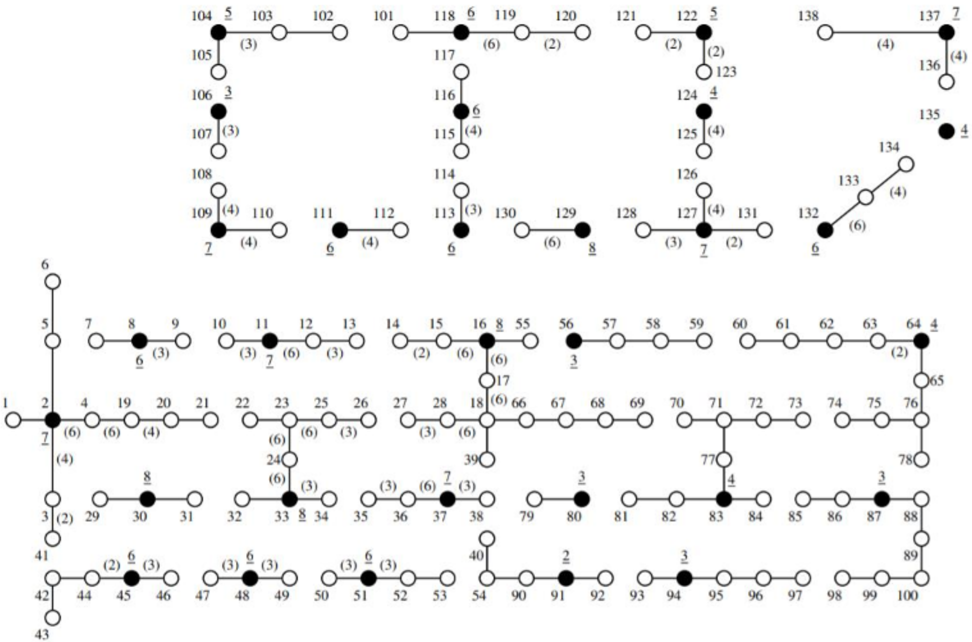
V. Results

Obtained results for Cases 1 and 2 [USD x10^6]

Cost	Description	Case 1	Case 2
Variable	Energy purchased	26.709	12.827
	Energy sold	30.682	30.996
	Profit	3.973	18.169
Fixed	Secondary circuits	0.391	0.403
	DTs	0.370	0.335
	Solar DGs	—	1.838
	Wind DGs	—	4.200
	ESSs	—	0.768
	O&M of ESSs	—	0.545
Operational	TEL cost in secondary circuits	0.376	0.423
	TEL cost in DTs	0.165	0.172
	TEL cost in ESSs	—	0.395
Total profit (OF)		**3.212**	**10.081**

V. Results

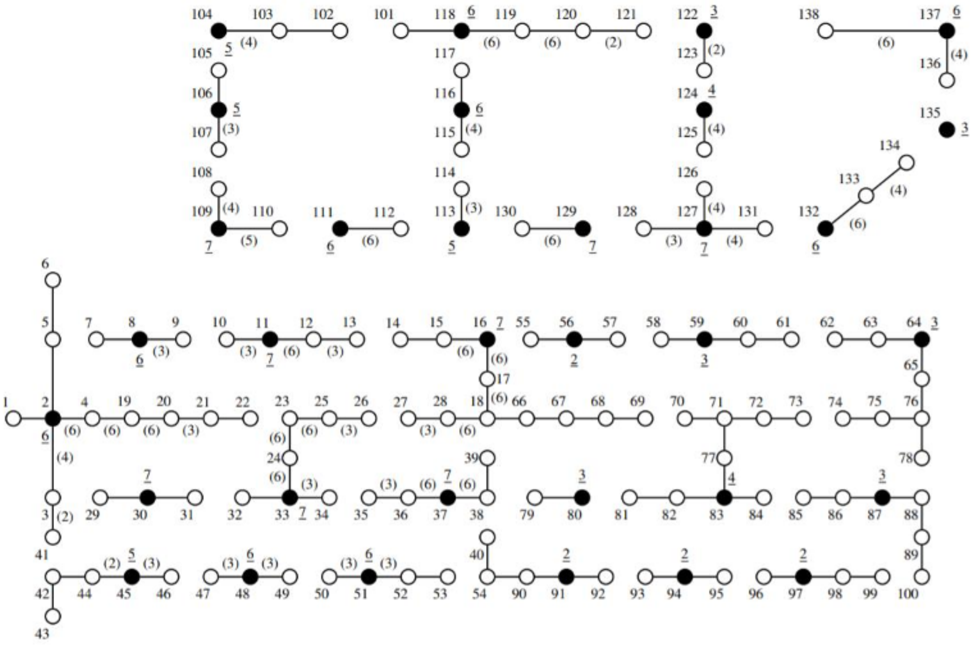
Solution obtained for Case 1



V. Results

Solution obtained for Case 2

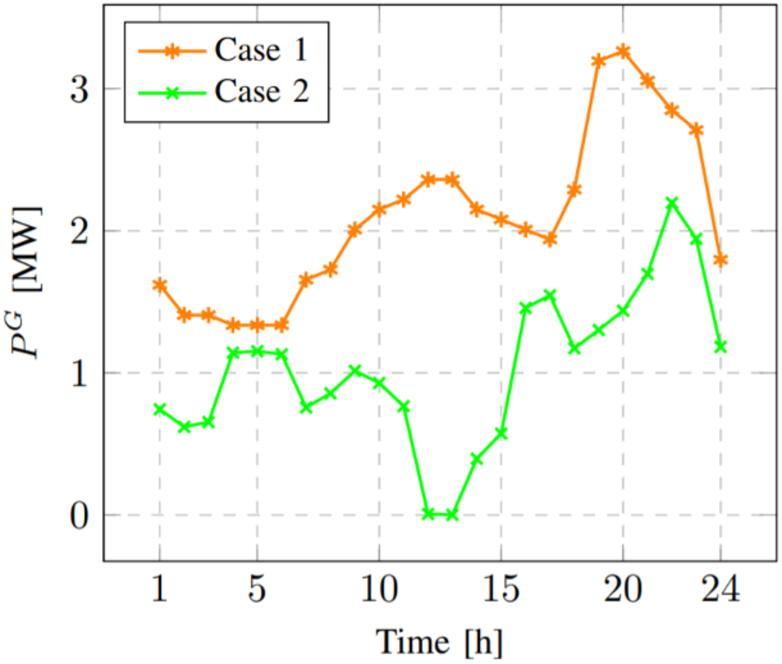
6 ESSs (type 4) are installed in nodes 8, 11, 48, 109, 127, and 132; and 7 solar DGs (type 4) are installed in nodes 23, 38, 103, 110, 130, 131, and 136.



4 wind DGs (type 4) are installed in nodes 19, 112, 119, and 130; and 1 wind DG (type 3) is installed in node 138.

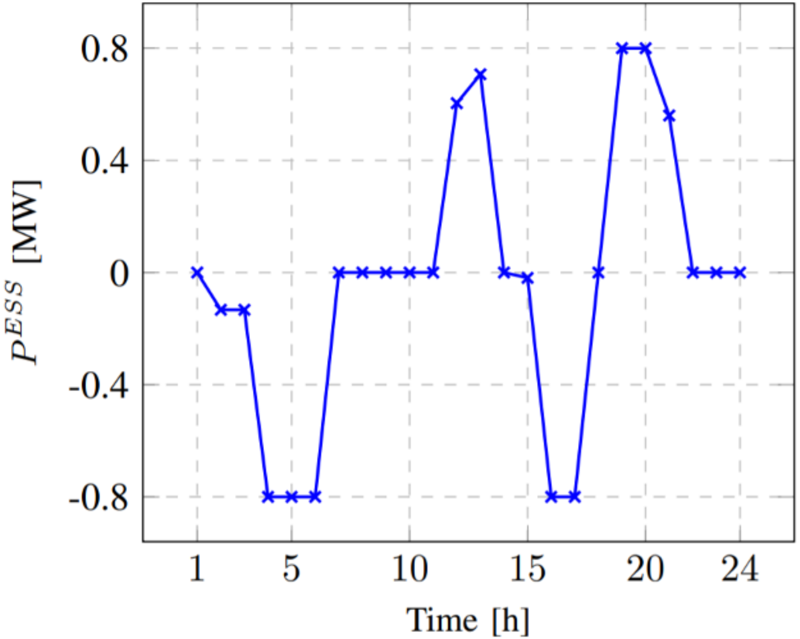
V. Results

Total active power injected by the primary feeder in [MW]



V. Results

Total active power extracted and injected by the ESSs in [MW]



VI. Conclusions

This paper proposes a new methodology to solve the problem related to the installation of DERs (i.e., renewable DGs and ESSs) in the distribution system planning problem of low voltage networks. The proposed methodology minimizes the fixed and operational costs of the networks and the total purchase cost of energy from the primary feeder. Hence, the total profit increased by minimizing the energy purchase cost of the system by installing new renewable DGs and ESSs. Moreover, the purchase cost is also minimized by way of an optimal operation of ESSs based on the behavior of energy prices and the electrical demand. The obtained results show that the integration of DERs in the distribution systems planning problem increases the profits of distribution companies from energy purchase and sale as well as reduces the fixed costs.

VI. Conclusions

The total technical energy losses cost can increase with the integration of DERs because the profit obtained from the reduction of the purchase cost of demanded energy is more significant than the profit obtained from the minimization of the purchase cost of technical energy losses. Consequently, distribution companies can use the proposed methodology to measure the economical and operative advantages or disadvantages of the integration of DERs in the distribution systems planning problem of LV networks. The increase in technical energy losses can be controlled in the proposed methodology by adding a new constraint that limits the energy losses to a predefined value established by the distribution company.

VII. Questions

Thank you!

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