Optimising Load Flexibility for the Day Ahead in Distribution Networks with Photovoltaics

J-A. Velasco and H. Amarís
Universidad Carlos III de Madrid
(Spain)

V. Rigoni, A. Soroudi and A. Keane
University College Dublin
(Ireland)

Tuesday, 25th June 2019
Milano (Italy)

Table of contents

Introduction

- In recent years a massive integration of renewable-based DERs (Distributed Energy Resources) has been taken place in Low Voltage (LV) distribution systems
- This is positive since DERs can contribute to the reduction of Greenhouse emissions and the increase of renewable energy consumption
- However, DER can lead to contingencies (such as over-voltages, overloadings, etc.) if the hosting capacity of the circuits they are connected to is exceeded
- In this context, Demand Flexibility, becomes a well suited solution to efficiently integrate those DERs avoiding those technical problems.

Introduction

- In recent years a massive integration of renewable-based DERs (Distributed Energy Resources) has been taken place in Low Voltage (LV) distribution systems
- This is positive since DERs can contribute to the reduction of Greenhouse emissions and the increase of renewable energy consumption
- However, DER can lead to contingencies (such as over-voltages, overloadings, etc.) if the hosting capacity of the circuits they are connected to is exceeded
- In this context, Demand Flexibility, becomes a well suited solution to efficiently integrate those DERs avoiding those technical problems.

Introduction

- In recent years a massive integration of renewable-based DERs (Distributed Energy Resources) has been taken place in Low Voltage (LV) distribution systems
- This is positive since DERs can contribute to the reduction of Greenhouse emissions and the increase of renewable energy consumption
- However, DER can lead to contingencies (such as over-voltages, overloadings, etc.) if the hosting capacity of the circuits they are connected to is exceeded
- In this context, Demand Flexibility, becomes a well suited solution to efficiently integrate those DERs avoiding those technical problems.

Introduction

- In recent years a massive integration of renewable-based DERs (Distributed Energy Resources) has been taken place in Low Voltage (LV) distribution systems
- This is positive since DERs can contribute to the reduction of Greenhouse emissions and the increase of renewable energy consumption
- However, DER can lead to contingencies (such as over-voltages, overloadings, etc.) if the hosting capacity of the circuits they are connected to is exceeded
- In this context, Demand Flexibility, becomes a well suited solution to efficiently integrate those DERs avoiding those technical problems.

Introduction

Therefore we present...

- A methodology to calculate load flexibility schedule for the next 24 hours
- Objective: minimise the flexibility quantity used to alleviate the contingencies

Considering...

- Unbalance operation of LV distribution system
- Presence of Photovoltaics (PV) panels as DER technology
- Customers participating in a Demand Response (DR) program
- Forecast of the demand, PV generation and weather conditions.

Introduction

Therefore we present...

- A methodology to calculate load flexibility schedule for the next 24 hours
- Objective: minimise the flexibility quantity used to alleviate the contingencies

Considering...

- Unbalance operation of LV distribution system
- Presence of Photovoltaics (PV) panels as DER technology
- Customers participating in a Demand Response (DR) program
- Forecast of the demand, PV generation and weather conditions.

Introduction

Therefore we present...

- A methodology to calculate load flexibility schedule for the next 24 hours
- Objective: minimise the flexibility quantity used to alleviate the contingencies

Considering...

- Unbalance operation of LV distribution system
- Presence of Photovoltaics (PV) panels as DER technology
- Customers participating in a Demand Response (DR) program
- Forecast of the demand, PV generation and weather conditions.

Introduction

Therefore we present...

- A methodology to calculate load flexibility schedule for the next 24 hours
- Objective: minimise the flexibility quantity used to alleviate the contingencies

Considering...

- Unbalance operation of LV distribution system
- Presence of Photovoltaics (PV) panels as DER technology
- Customers participating in a Demand Response (DR) program
- Forecast of the demand, PV generation and weather conditions.

Introduction

Therefore we present...

- A methodology to calculate load flexibility schedule for the next 24 hours
- Objective: minimise the flexibility quantity used to alleviate the contingencies

Considering...

- Unbalance operation of LV distribution system
- Presence of Photovoltaics (PV) panels as DER technology
- Customers participating in a Demand Response (DR) program
- Forecast of the demand, PV generation and weather conditions.

Introduction

Therefore we present...

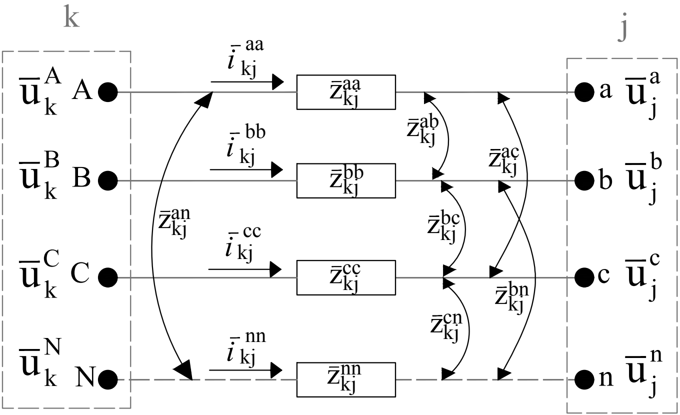
- A methodology to calculate load flexibility schedule for the next 24 hours
- Objective: minimise the flexibility quantity used to alleviate the contingencies

Considering...

- Unbalance operation of LV distribution system
- Presence of Photovoltaics (PV) panels as DER technology
- Customers participating in a Demand Response (DR) program
- Forecast of the demand, PV generation and weather conditions.

System Modelling

- Unbalance operation of the LV systems ⇒ three phase modelling



Power flow modelling

- Minimise mismatch between power injections specified and calculated for each node and phase.

$$F(\mathcal{X}) = 0 = \begin{bmatrix} F_p(\mathcal{X}) \\ F_q(\mathcal{X}) \end{bmatrix} = \begin{bmatrix} p_{i,k}^{p,sp} + p_{i,k}^{p,cal} \\ q_{i,k}^{p,sp} + q_{i,k}^{q,cal} \end{bmatrix}$$

- Decomposition in real and imaginary part of the electrical magnitudes

$$\mathcal{X} = \begin{bmatrix} \begin{bmatrix} u_1^{a,re} \, u_1^{b,re} \, u_1^{c,re} \ldots u_N^{a,re} \, u_N^{b,re} \, u_N^{c,re} \end{bmatrix}^T \\ \begin{bmatrix} u_1^{a,im} \, u_1^{b,re} \, u_1^{c,im} \ldots u_N^{a,im} \, u_N^{b,im} \, u_N^{c,im} \end{bmatrix}^T \end{bmatrix}$$

Power flow modelling

- Minimise mismatch between power injections specified and calculated for each node and phase.

$$F(\mathcal{X}) = 0 = \begin{bmatrix} F_p(\mathcal{X}) \\ F_q(\mathcal{X}) \end{bmatrix} = \begin{bmatrix} p_{i,k}^{p,sp} + p_{i,k}^{p,cal} \\ q_{i,k}^{p,sp} + q_{i,k}^{q,cal} \end{bmatrix}$$

- Decomposition in real and imaginary part of the electrical magnitudes

$$\mathcal{X} = \begin{bmatrix} \begin{bmatrix} u_1^{a,re} \, u_1^{b,re} \, u_1^{c,re} \ldots u_N^{a,re} \, u_N^{b,re} \, u_N^{c,re} \end{bmatrix}^T \\ \begin{bmatrix} u_1^{a,im} \, u_1^{b,re} \, u_1^{c,im} \ldots u_N^{a,im} \, u_N^{b,im} \, u_N^{c,im} \end{bmatrix}^T \end{bmatrix}$$

PV Modelling

- PV panels model which depends on the temperature $T_{cell,t}$ and the solar irradiation $\hat{G}_t$.

$$p_{g,k,t}^{p,sp} = \frac{P_{PV_k}}{S_B}\left(\frac{\hat{G}_t}{1000}\left[1+\gamma\left(T_{cell,t}+25\right)\right]\right)$$

- Forecast of the weather conditions $\Rightarrow$ ARIMA model

$$\hat{y}_{t+\tau} = \delta + \sum_{i=1}^{p_a+d_a} \phi_i y_{t+\tau-i} + \varepsilon_{t+\tau} - \sum_{j=1}^{q_a} \theta_j \varepsilon_{t+\tau-j}$$

PV Modelling

- PV panels model which depends on the temperature $T_{cell,t}$ and the solar irradiation $\hat{G}_t$.

$$p^{p,sp}_{g,k,t} = \frac{P_{PV_k}}{S_B}\left(\frac{\hat{G}_t}{1000}\left[1+\gamma\left(T_{cell,t}+25\right)\right]\right)$$

- Forecast of the weather conditions $\Rightarrow$ ARIMA model

$$\hat{y}_{t+\tau} = \delta + \sum_{i=1}^{p_a+d_a} \phi_i y_{t+\tau-i} + \varepsilon_{t+\tau} - \sum_{j=1}^{q_a} \theta_j \varepsilon_{t+\tau-j}$$

Load Modelling

- To account for the voltage dependency of the demand, is considered a load ZIP model, tuning with smart meters data.

$$p^{p,sp}_{d,k,t} = \hat{p}^{p}_{d,k,t}\left[c^{p,1}_{p,k}\left(u^{p}_{k,t}\right)^2 + c^{p,2}_{p,k}\left(u^{p}_{k,t}\right) + c^{p,3}_{p,k}\right]$$

$$q^{p,sp}_{d,k,t} = \hat{q}^{p}_{d,k,t}\left[c^{p,1}_{q,k}\left(u^{p}_{k,t}\right)^2 + c^{p,2}_{q,k}\left(u^{p}_{k,t}\right) + c^{p,3}_{q,k}\right]$$

Load Flexibility

- Load shifting mechanism is considered for managing the flexibility of the load demand of the customers participating in the DR program.

$$p^{p,sp}_{i,k,t} = p^{p,sp}_{g,k,t} - \left(p^{p}_{d,k,t} + \Delta p^{p}_{d,k,t}\right), \forall k \in \tilde{\Omega}_c$$

$$p^{p}_{d,k,t} + \Delta p^{p}_{d,k,t} \geqslant \beta_k \cdot p_{ctd,k}$$

$$\sum_{t \in \{t_0,\ldots,t_n\}} \Delta p^{p}_{d,k,t} = 0$$

$$-\alpha_k \cdot p_{ctd,k} \leqslant \Delta p^{p}_{d,k,t} \leqslant \alpha_k \cdot p_{ctd,k}$$

Load Flexibility

- Load shifting mechanism is considered for managing the flexibility of the load demand of the customers participating in the DR program.

$$p^{p,sp}_{i,k,t} = p^{p,sp}_{g,k,t} - \left(p^{p}_{d,k,t} + \Delta p^{p}_{d,k,t}\right), \forall k \in \tilde{\Omega}_c$$

$$p^{p}_{d,k,t} + \Delta p^{p}_{d,k,t} \geqslant \beta_k \cdot p_{ctd,k}$$

$$\sum_{t \in \{t_0, \dots, t_n\}} \Delta p^{p}_{d,k,t} = 0$$

$$-\alpha_k \cdot p_{ctd,k} \leqslant \Delta p^{p}_{d,k,t} \leqslant \alpha_k \cdot p_{ctd,k}$$

Optimisation problem

Load demand flexibility methodology is formulated as an unbalance optimal power flow (OPF) which results in a non-linear programming problem (NLP)

- Minimise:

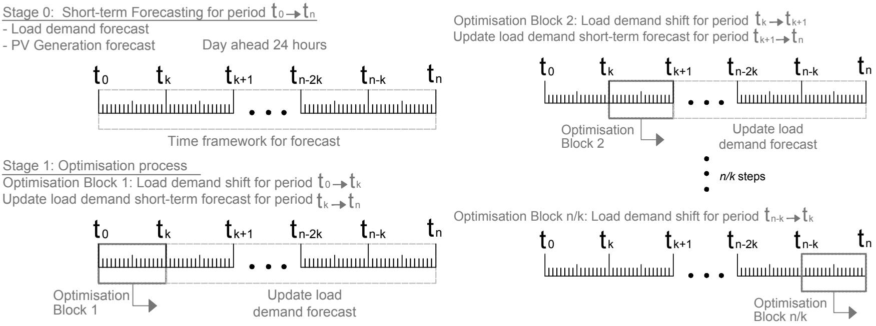
$$OF = \sum_{t \in T} \sum_{p \in \{a,b,c\}} \sum_{k \in \tilde{\Omega}_c} \left(\Delta p^{p}_{d,k,t} \right)^2$$

- Subject to:

$$(i^{p,re}_{kj,t})^2 + (i^{p,im}_{kj,t})^2 \leqslant (i^{max,p}_{kj})^2$$

$$(u^{min})^2 \leqslant (u^{p,re}_{k,t})^2 + (u^{p,im}_{k,t})^2 \leqslant (u^{max})^2$$

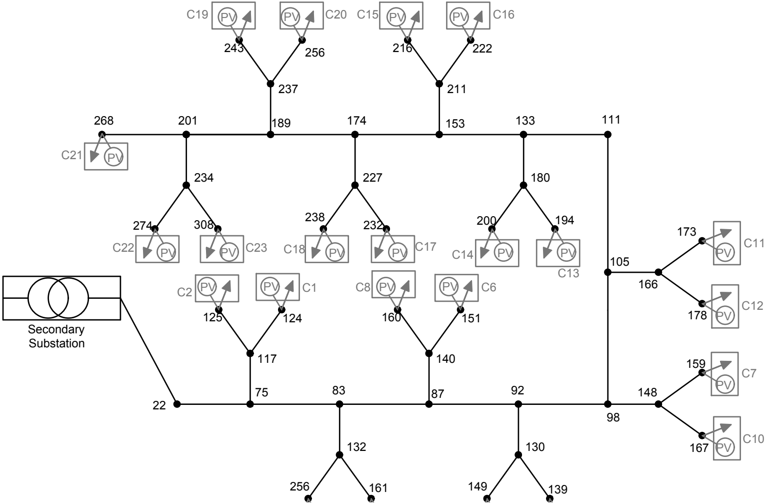
Rolling optimisation



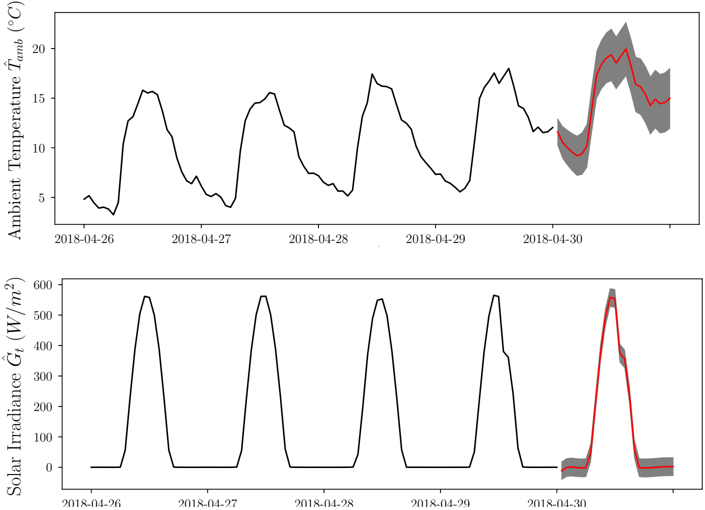
Case Study

- Real medium-size LV distribution system (LVNS project)
- 23 single-phase residential customers
  - $P_{ctd} = \{3, 15\}\ kW$
- 23 PV facilities
  - $P_{PV} = 4\ kW$
- Load flexibility control parameters:
  - $\beta_k \in (0.05, 0.1)$
  - $\alpha_k \in (0.1, 0.5)$

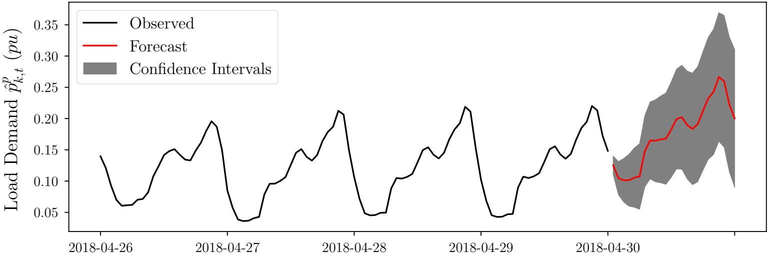
Case Study


C19
C20
C15
C16
243
256
216
222
237
211
268
201
189
174
153
133
111
C21
234
227
180
274
308
238
232
200
194
173
C11
C22
C23
C18
C17
C14
C13
105
166
C12
C2
C1
C8
C6
178
Secondary Substation
125
124
160
151
117
140
159
C7
75
83
87
92
148
22
98
167
C10
132
130
256
161
149
139
PV

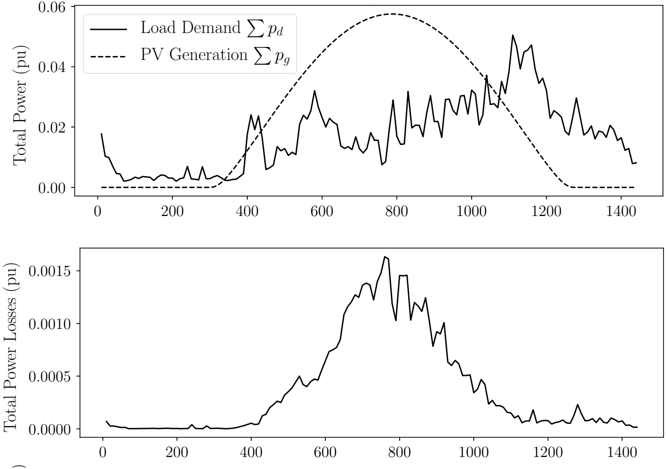
Case study: forecast weather conditions



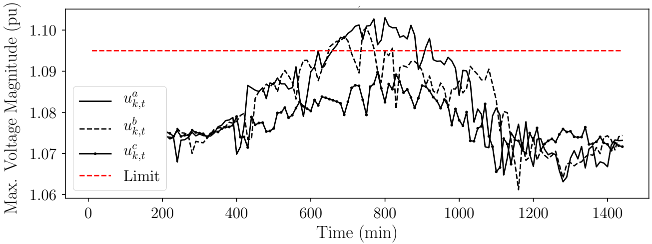
Case study: forecast demand

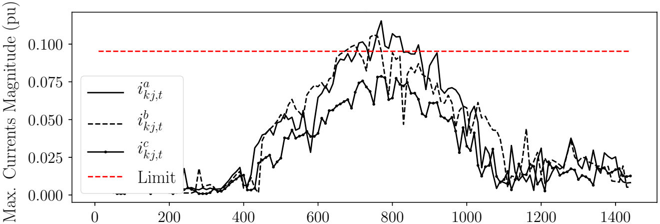


Case study: Demand, PV generation and losses

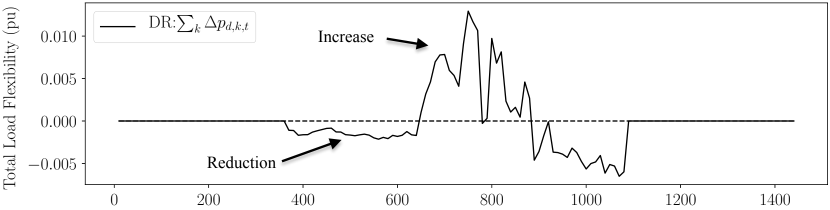


Case study: Over-voltages, Over-currents

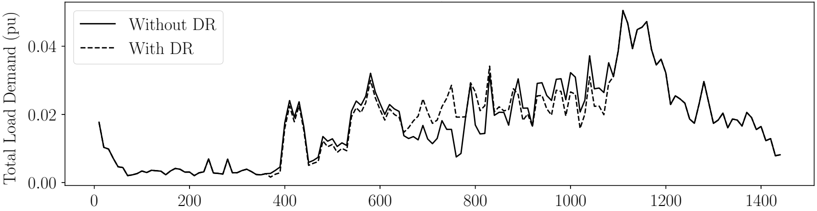




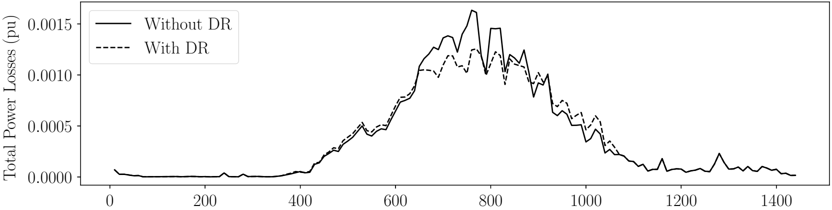
Flexibility Results: Load flexibility



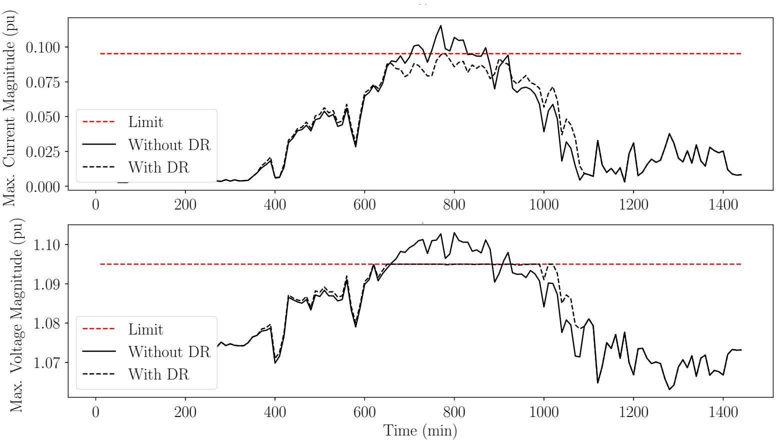
Flexibility Results: Change in demand



Flexibility Results: Losses



Flexibility Results: Maximum voltage and current



Conclusions

- A simple and efficient optimisation methodology was presented to obtain the load flexibility schedule in LV systems with high PV penetration
- The problem is solved in a rolling optimisation fashion, updating the forecast after completing each optimisation block
- load shift is used as flexibility enabler
- Simulation results show the capability of the load shift mechanism to reduce the over-voltages and over-loading's of the system and even a reduction of the power losses has been achieved
- Future work :
  - Include other DERs: Electric Vehicles, Energy Storage, etc.
  - Include temperature dependant component of demand

Conclusions

- A simple and efficient optimisation methodology was presented to obtain the load flexibility schedule in LV systems with high PV penetration
- The problem is solved in a rolling optimisation fashion, updating the forecast after completing each optimisation block
- load shift is used as flexibility enabler
- Simulation results show the capability of the load shift mechanism to reduce the over-voltages and over-loading's of the system and even a reduction of the power losses has been achieved
- Future work :
  - Include other DERs: Electric Vehicles, Energy Storage, etc.
  - Include temperature dependant component of demand

Conclusions

- A simple and efficient optimisation methodology was presented to obtain the load flexibility schedule in LV systems with high PV penetration
- The problem is solved in a rolling optimisation fashion, updating the forecast after completing each optimisation block
- load shift is used as flexibility enabler
- Simulation results show the capability of the load shift mechanism to reduce the over-voltages and over-loading's of the system and even a reduction of the power losses has been achieved
- Future work :
  - Include other DERs: Electric Vehicles, Energy Storage, etc.
  - Include temperature dependant component of demand

Conclusions

- A simple and efficient optimisation methodology was presented to obtain the load flexibility schedule in LV systems with high PV penetration
- The problem is solved in a rolling optimisation fashion, updating the forecast after completing each optimisation block
- load shift is used as flexibility enabler
- Simulation results show the capability of the load shift mechanism to reduce the over-voltages and over-loading's of the system and even a reduction of the power losses has been achieved
- Future work :
  - Include other DERs: Electric Vehicles, Energy Storage, etc.
  - Include temperature dependant component of demand

Conclusions

- A simple and efficient optimisation methodology was presented to obtain the load flexibility schedule in LV systems with high PV penetration
- The problem is solved in a rolling optimisation fashion, updating the forecast after completing each optimisation block
- load shift is used as flexibility enabler
- Simulation results show the capability of the load shift mechanism to reduce the over-voltages and over-loading's of the system and even a reduction of the power losses has been achieved
- Future work :
  - Include other DERs: Electric Vehicles, Energy Storage, etc.
  - Include temperature dependant component of demand

Conclusions

- A simple and efficient optimisation methodology was presented to obtain the load flexibility schedule in LV systems with high PV penetration
- The problem is solved in a rolling optimisation fashion, updating the forecast after completing each optimisation block
- load shift is used as flexibility enabler
- Simulation results show the capability of the load shift mechanism to reduce the over-voltages and over-loading's of the system and even a reduction of the power losses has been achieved
- Future work :
  - Include other DERs: Electric Vehicles, Energy Storage, etc.
  - Include temperature dependant component of demand

Conclusions

- A simple and efficient optimisation methodology was presented to obtain the load flexibility schedule in LV systems with high PV penetration
- The problem is solved in a rolling optimisation fashion, updating the forecast after completing each optimisation block
- load shift is used as flexibility enabler
- Simulation results show the capability of the load shift mechanism to reduce the over-voltages and over-loading's of the system and even a reduction of the power losses has been achieved
- Future work :
  - Include other DERs: Electric Vehicles, Energy Storage, etc.
  - Include temperature dependant component of demand

Thank you very much for your attention

Q?

Jose Angel Velasco
Universidad Carlos III de Madrid
joseangel.velasco@uc3m.es