X SICEL 2021

Transición energética en la 4ta revolución industrial

Universidad Tecnológica de Pereira

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Power Factor Correction in Converters for PV Systems using Convex Optimization

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Contents

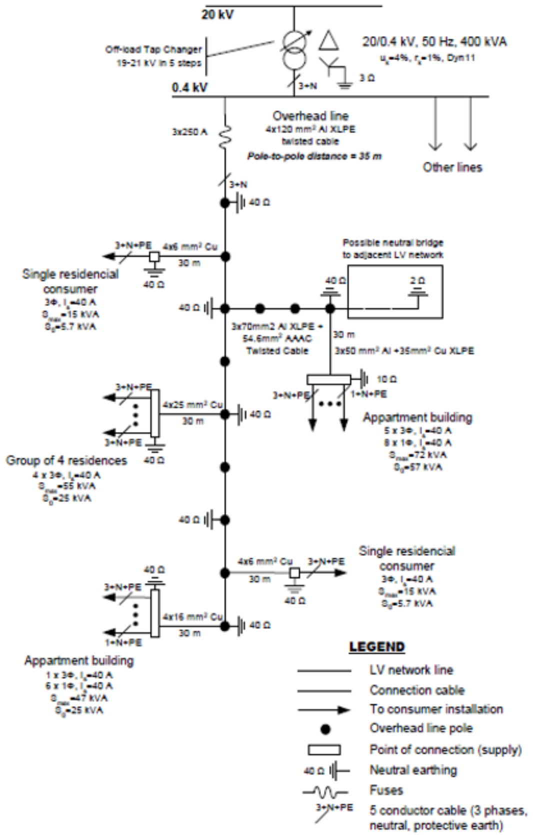
I. Introduction

It is presented a method for the optimal power factor calculation on power electronic converters for photovoltaic (PV) systems. Also, both three-phase and single-phase converters are considered through an unbalanced model of the grid.

II. Investigation Question

How to control the reactive power on microgrids with high inclusion of renewable energy, in order to optimize the operation and taking into account the stochasticity of the system?

III. Power Flow Model – CIGRE Microgrid



III. Power Flow Model

The optimization model consists of minimizing the expected value of total losses p_L subject to technical constrains.

Complete model for the optimal set point of the reactive power in a three-phase grid:

$$\text{mín } \mathbb{E}(p_L, \xi_t)$$

$$(\mathrm{p}_{kG} - p_{kD}) - j(q_{kG} - q_{kD}) = \sum_m v_k^* y_{km} v_m$$

$$\mathrm{v}_{min} \leq \|v_k\| \leq v_{max}$$

$$\sqrt{p_{kG}^2 + q_{kG}^2} \leq s_{k(max)}$$

$$\mathrm{p}_{kG} \leq p_{kG(max)}(\xi_t)$$

IV. Problem Linearization

Wirtinger's linearization is used for the power flow equations in order to obtain an affine set of constraint and make the problem convex.

$$S^* = H \cdot V_N^* + M \cdot V_N + T$$

where H, M, T are constant matrices defined by:

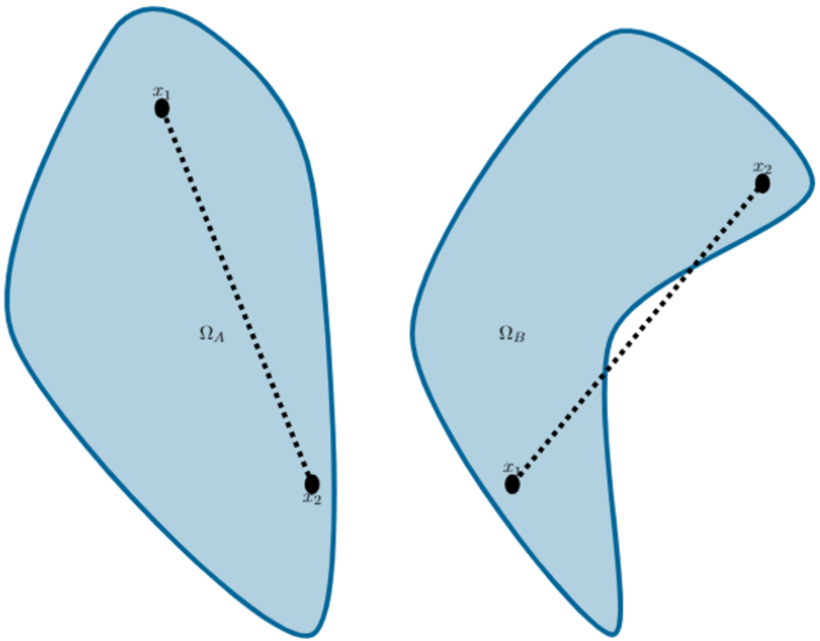
$$\begin{aligned} H &= diag(Y_{Sk} \cdot V_S) + diag(Y_N \cdot V_{N0}) \\ M &= diag(V_{N0}^*) \cdot Y_N \\ T &= -diag(V_{N0}) \cdot (Y_N \cdot V_{N0}^*) \end{aligned}$$

IV. Problem Linearization

$$(p_{kG} - p_{kD}) + j(q_{kG} - q_{kD}) = T_k + \sum_{m=1}^{N} H_{km} v_m^* + M_{km} v_m$$

Notice that this equation define an affine space even when it is separated into real and imaginary parts, since neither H, M or T depends of the power.

V. Methodology Development – Convex Optimization



Global optimum

Guarantee convergence

Uniqueness

Real time operation

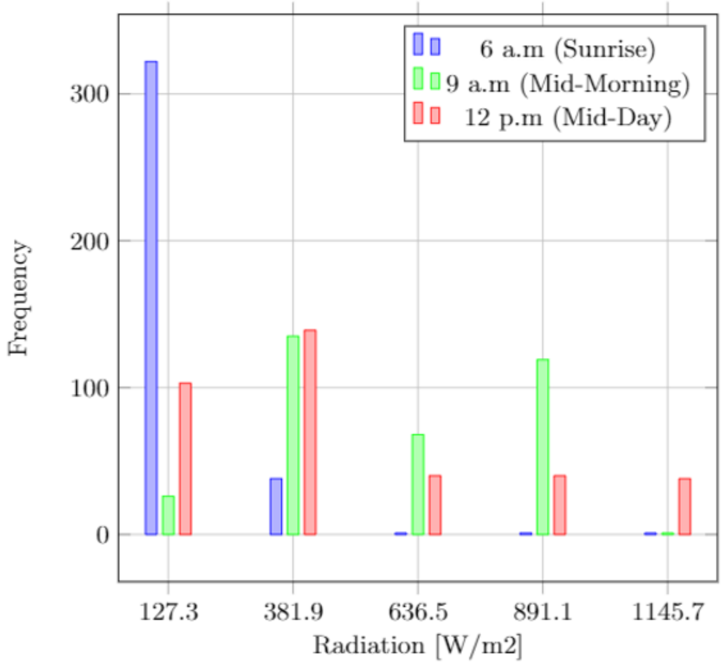
Dual variables

V. Methodology Development – Solar Distribution

- The stochastic phenomenon was modeled as a set of scenarios using a database of irradiance with 8605 values taken in September of 2012 at Universidad Tecnológica de Pereira.

- Five cases with different scenarios of solar radiation were generated, one at sunrise (6:00 a.m), the second one at mid-morning (9:00 a.m) and the last one at maximum solar radiation point (12:00 p.m).

V. Methodology Development – Solar Distribution



V. Methodology Development – Restriction for PF

$$\varphi_k = p_k / s_k$$

$$q_k = p_k \sqrt{(1/\varphi_k^2) - 1}$$

$$\rho_k = \sqrt{(1/\varphi_k^2) - 1}$$

$$q_k = p_k * \rho_k$$

V. Methodology Development – Stochastic Power Flow Model

$$\text{mín } \sum_t \xi_t^{n_t} p_{Lt}$$

$$(\mathrm{p}_{kG} - p_{kD}) + j(q_{kG} - q_{kD}) = T_k + \sum_{m=1}^{N} H_{km} v_m^* + M_{km} v_m$$

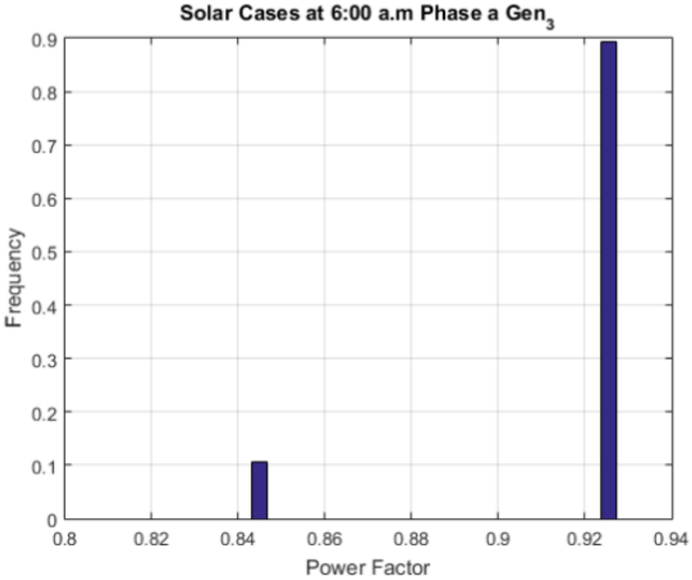
$$\mathrm{v}_{min} \leq \|v_k\| \leq v_{max}$$

$$\sqrt{p_{kG}^2 + q_{kG}^2} \leq s_{k(max)}$$

$$\mathrm{p}_{kG} \leq p_{kG(max)}(\xi_t)$$

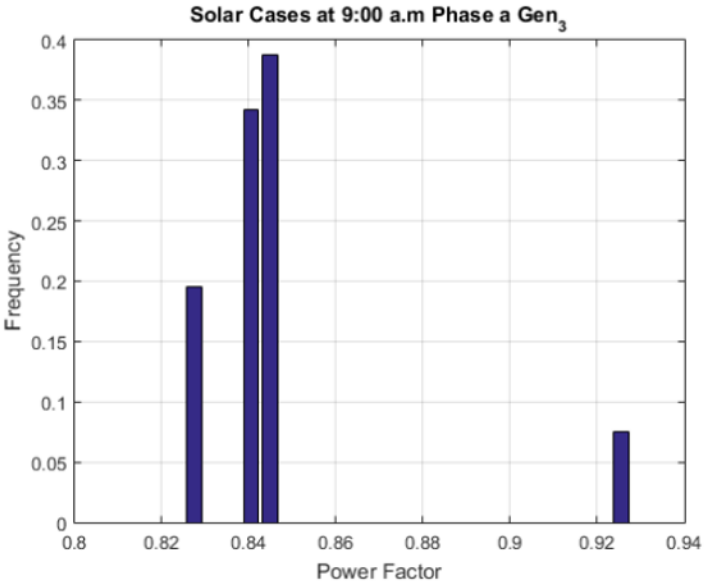
$$\rho_k = \sqrt{(1/\varphi_k^2) - 1}$$

VI. Results – 6 a.m



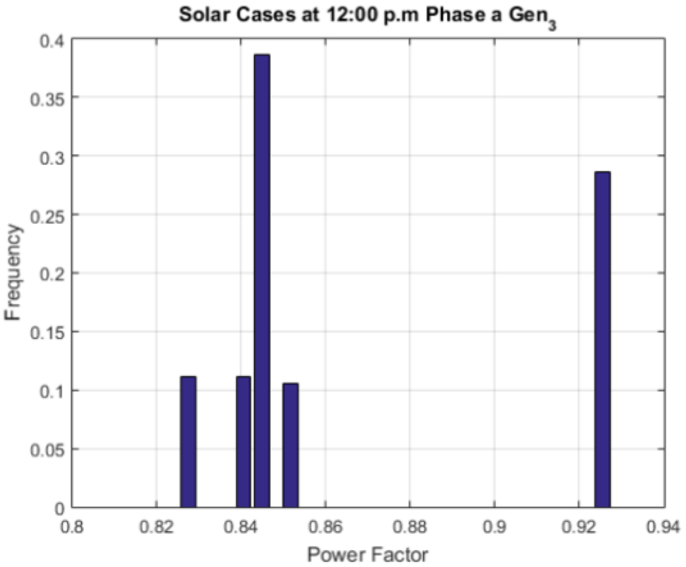
Generator	Node	Phase	E_φ
$1_{1\phi}$	2	A	1.0000
$2_{1\phi}$	2	B	1.0000
$3_{1\phi}$	2	C	1.0000
$1_{3\phi}$	7	ABC	1.0000
$1_{3\phi}$	7	ABC	1.0000
$1_{3\phi}$	7	ABC	1.0000
$2_{3\phi}$	13	ABC	0.9169
$2_{3\phi}$	13	ABC	0.9169
$2_{3\phi}$	13	ABC	0.9169
$3_{3\phi}$	18	ABC	1.0000
$3_{3\phi}$	18	ABC	1.0000
$3_{3\phi}$	18	ABC	1.0000

VI. Results – 9 a.m



Generator	Node	Phase	E_φ
$1_{1\phi}$	2	A	1.0000
$2_{1\phi}$	2	B	1.0000
$3_{1\phi}$	2	C	1.0000
$1_{3\phi}$	7	ABC	0.9960
$1_{3\phi}$	7	ABC	0.9960
$1_{3\phi}$	7	ABC	0.9960
$2_{3\phi}$	13	ABC	0.8460
$2_{3\phi}$	13	ABC	0.8460
$2_{3\phi}$	13	ABC	0.8460
$3_{3\phi}$	18	ABC	1.0000
$3_{3\phi}$	18	ABC	1.0000
$3_{3\phi}$	18	ABC	1.0000

VI. Results – 12 p.m



Generator	Node	Phase	E_φ
$1_{1\phi}$	2	A	1.0000
$2_{1\phi}$	2	B	1.0000
$3_{1\phi}$	2	C	1.0000
$1_{3\phi}$	7	ABC	0.9951
$1_{3\phi}$	7	ABC	0.9951
$1_{3\phi}$	7	ABC	0.9951
$2_{3\phi}$	13	ABC	0.8662
$2_{3\phi}$	13	ABC	0.8662
$2_{3\phi}$	13	ABC	0.8662
$3_{3\phi}$	18	ABC	1.0000
$3_{3\phi}$	18	ABC	1.0000
$3_{3\phi}$	18	ABC	1.0000

VII. Conclusions

- This methodology, allows through the use linearized models, stochastic process and convex optimization, the use of the capability that converters have to be programmed with multiple power factor behaviors, so they can consume or inject reactive power to the grid.

- The main idea on power systems is to have a unitary power factor, it was found that on microgirds with high inclusion of photovoltaic sources, as the radiation level rises through the time, the generators tend to decrease their power factor injecting reactive power,both to reduce losses and improve the voltage profiles, allowing us to set effectively the behavior of the sources without the need of a master controller that could increase the cost of the microgrid, making viable the use of these technologies on a small scale.

VIII. Questions

Thanks for your Attention.

Questions?