X SICEL 2021

Transición energética en la 4ta revolución industrial

Universidad Tecnológica de Pereira

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Proposal for the optimal management of a DC microgrid

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I. Introduction

Motivation

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- Colombia is a privileged country in terms of wide access to natural resources.
- High levels of solar radiation are complemented with richness of hydraulic resources spread all over the country.
- Particular features of local geography make difficult to provide electricity to communities at certain rural zones.
- In isolated (i.e. non interconnected) areas, DC microgrids can be used to attend electric power demand.

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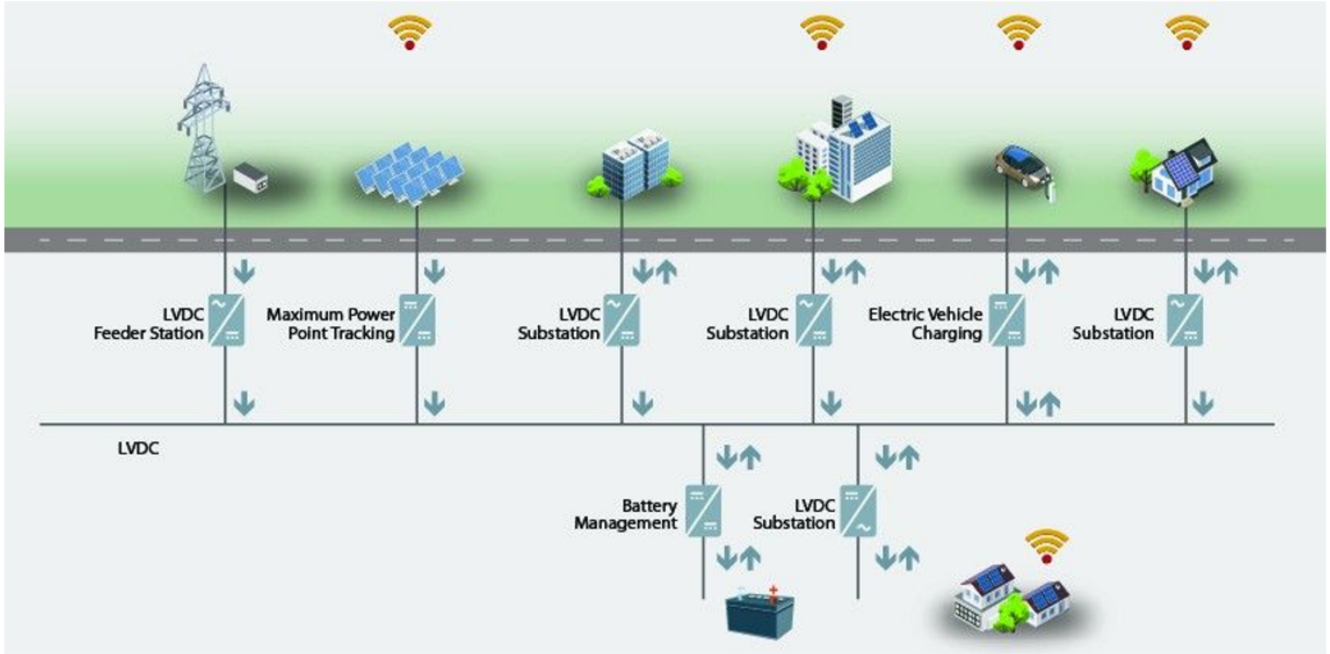

https://www.danfoss.com/en/about-danfoss/articles/dds/new-power-network/

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- DC generators are simple to control as they avoid parameters like frequency and phase.
- The reduced complexity of DC microgrids is reflected in a further reduction of costs.
- The development of low-cost, microgeneration systems including renewable sources, becomes an interesting topic for R&D projects supporting economical and social development at isolated zones.

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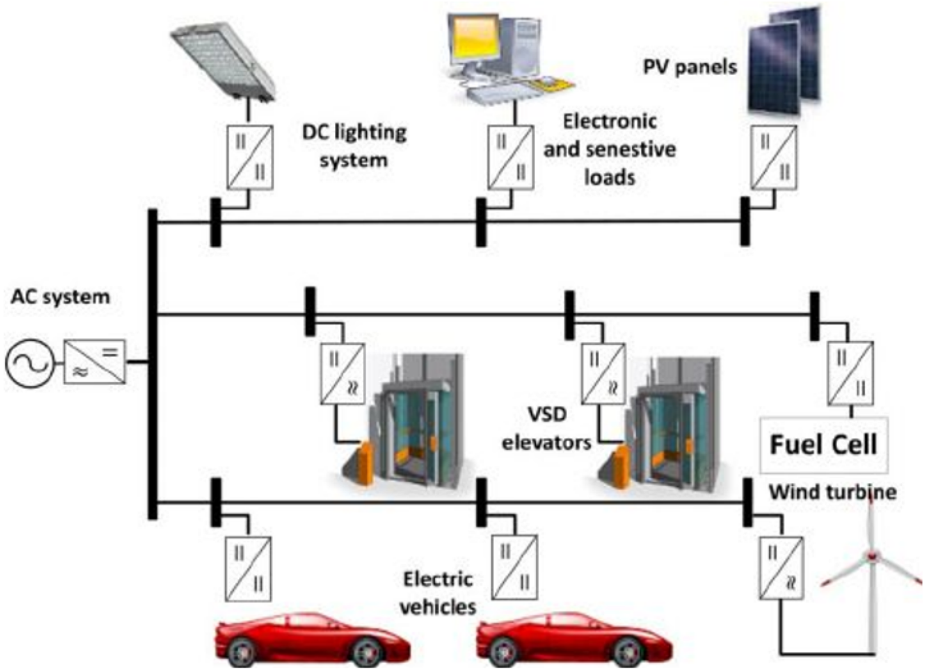

Hamad, Amr & Farag, Hany & El-Saadany, Ehab. (2015). A Novel Multiagent Control Scheme for Voltage Regulation in DC Distribution Systems. IEEE Transactions on Sustainable Energy. 6. 1-12. 10.1109/TSTE.2015.2391114.

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- The situation becomes more critical when the microgrid is isolated.
- Conventional economic dispatch policies are based on fuel prices and consider renewable energies as free resources.

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How to manage the power resources of an isolated DC microgrid?

II. Hierarchical control

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- In the case of DC microgrids the *droop parameter* is a resistance relating variations in voltage and power.
- For illustration of the technique, let us consider an isolated microgrid composed of a PV array in parallel with a battery bank, feeding a pure resistive load.

DC microgrid

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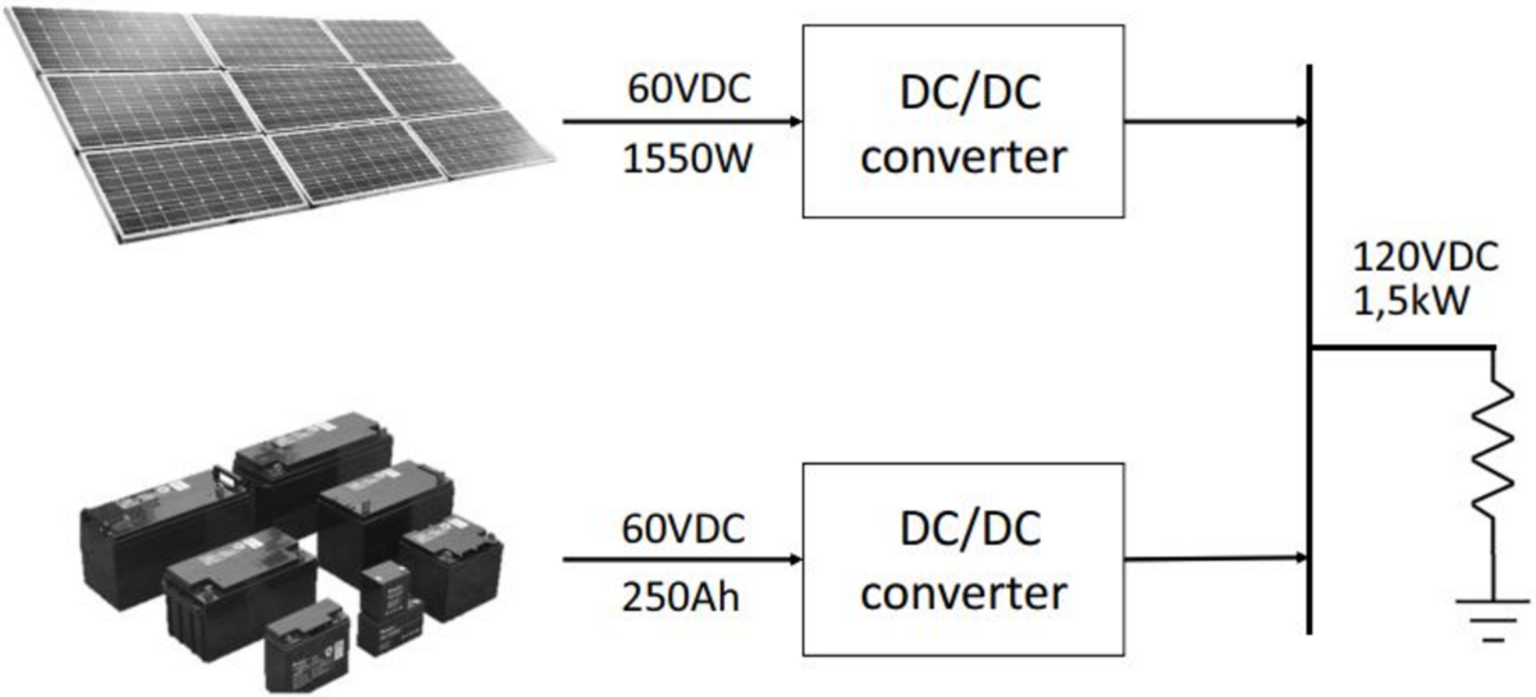

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- Equivalent circuits for generators and disturbances were implemented in PSIM.
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- Impedance of transmission lines representing physical connections between output ports of each generator and the load bus, were modelled as resistors.

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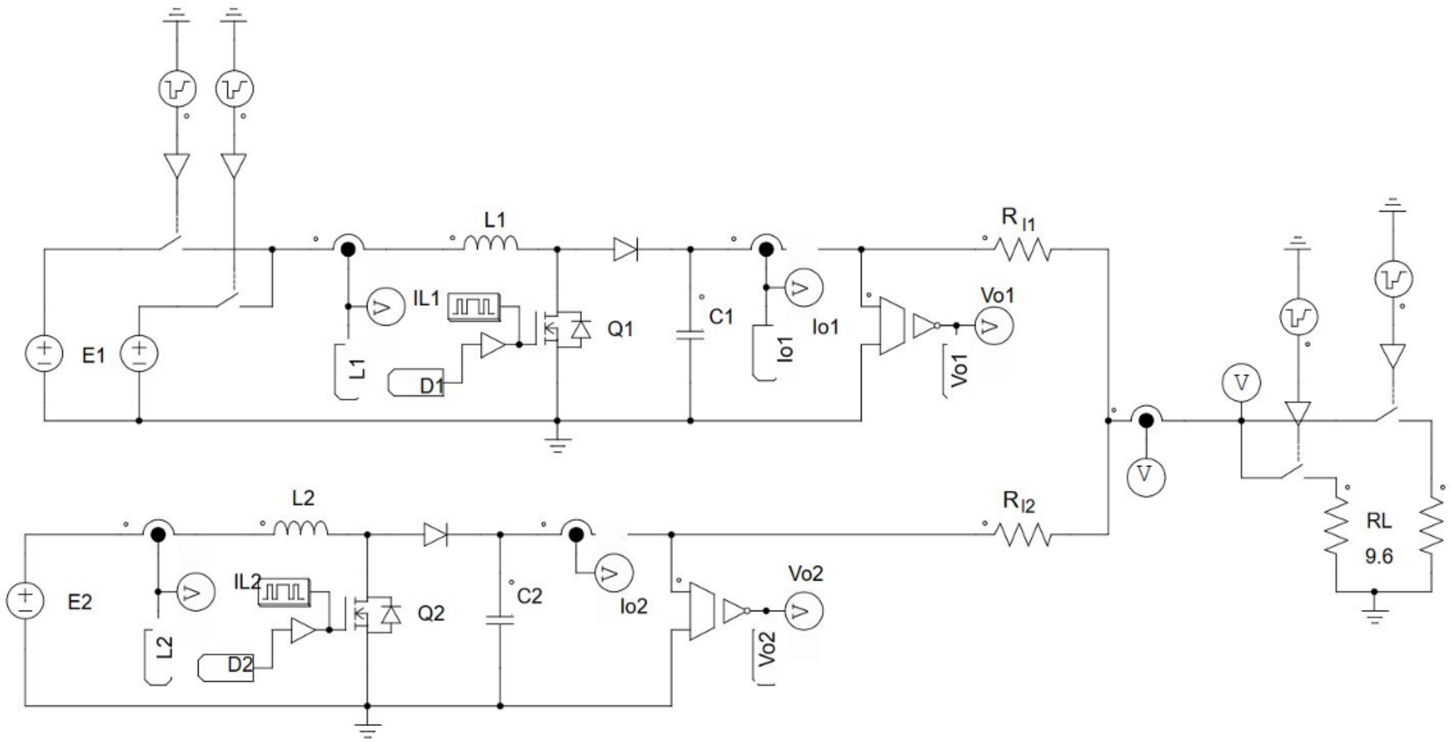

DC microgrid

DC microgrid

Parameter	Description	Value
E_1	Supply voltage at PV source	60 VDC
E_2	Supply voltage at batteries	60 VDC
$L_1 = L_2$	Inductance of boost converter	5.6 mH
$C_1 = C_2$	Capacitor of boost converter	100 μF
$Q_1 = Q_2$	IGBT of boost converter	ideal
$D_1 = D_2$	Nominal duty cycle of converter	0.5
R_{l1}	Coupling resistance converter 1	0.032 Ω
R_{l2}	Coupling resistance converter 2	0.016 Ω
f	Nominal PWM frequency	20 kHz
V	Nominal voltage at DC bus	120 VDC
R_L	Nominal system load	9.6 Ω

Converter regulation

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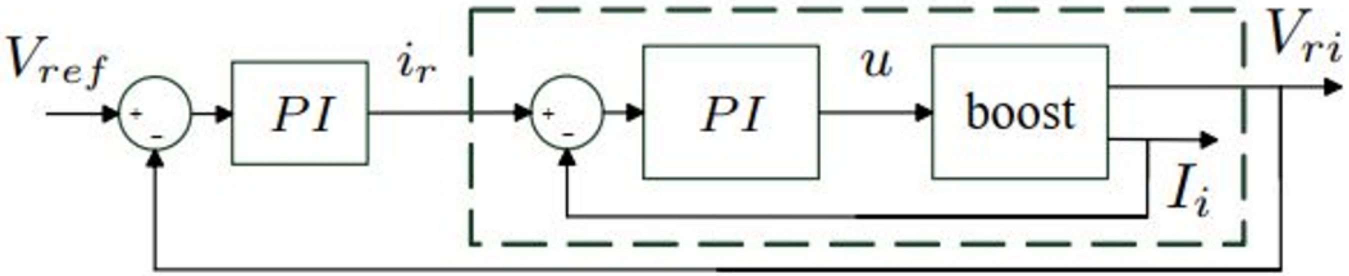

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$$R_{di} \leq \frac{\Delta V \times V_\sigma}{P_{\sigma_i}},$$

being ΔV the maximum deviation allowed for the DC bus voltage, $P_{\sigma_i} = I_{\sigma_i} \times V_\sigma$ the maximum power delivered to the load by the i-*th* generator and V_σ its minimum voltage.

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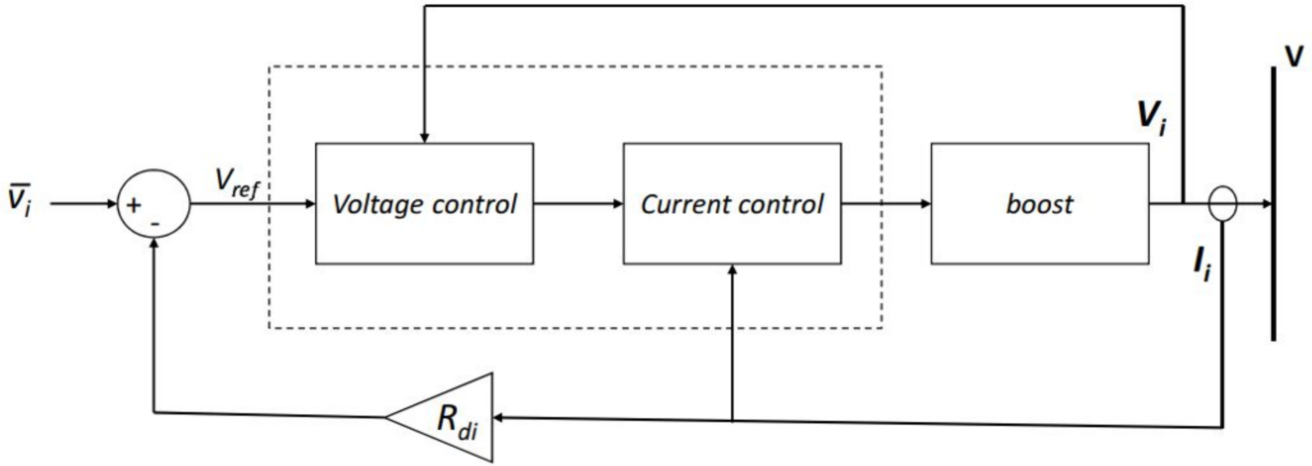

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- The combination of both generators under *droop control*, allows to construct a hierarchical structure with three levels of regulation.
- A *primary level* devoted to regulate electrical variables at the power converter circuit.
- The *secondary level* defines, by mean of *droop resistances,* the proportion of power shared among generators.
- The third level or *tertiary control* will be able to modify the amount of power provided by any generation unit attending dispatch policies.

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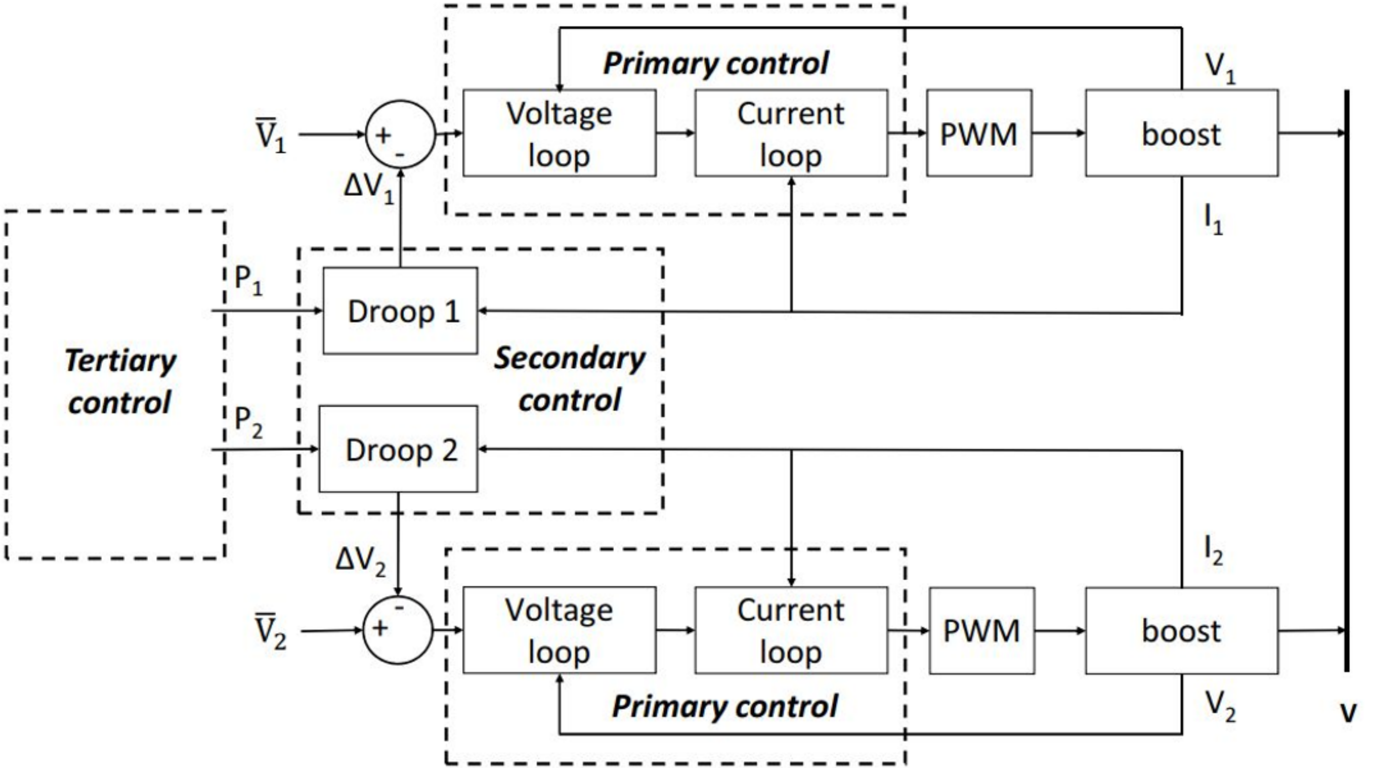

III. Optimization strategy

Dynamic droop

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- The only way to change that proportion will be modifying the parameter accordingly.
- If environmental conditions alter the availability of any of the power resources, the proportions of generation should adapt to those circumstances.
- To define the change of proportions, economic dispatch principles can be adapted to the case of renewable resources.

Renewable generation cost

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- In this work the cost models for renewable sources are taken from: M. M. Hoogwijk, "*On the global and regional potential of renewable energy sources*", Ph.D. Thesis at Faculteit Scheikunde, Universiteit Utrecht, 2004.

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$$C(P) = (\alpha \times \mathcal{I} \times P) + (\mathcal{M} \times P)\,,$$

being α the annuity factor, $\mathcal{I}$ the investment cost per unit power P installed and $\mathcal{M}$ the maintenance cost per unit power P installed. In particular, employing the information provided

Renewable generation cost

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Parameter	Description	Value
α	Annuity factor per hour	0.04
$\mathcal{I}_1$	Investment cost per kW/hour of PV power installed	\$781.85
$\mathcal{I}_2$	Investment cost per kW/hour of battery power installed	\$390.92
$\mathcal{M}_1$	Maintenance cost per kW/hour of PV power installed	\$7.04
$\mathcal{M}_2$	Maintenance cost per kW/hour of battery power installed	\$3.9

Values adapted to Colombian pesos, from https://www.irena.org

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$$\begin{aligned} \text{minimize} \quad & C(P_1, P_2) \\ \text{subjected to} \quad & P_1 + P_2 = 1500\,W. \end{aligned}$$

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$$\begin{aligned}\Gamma(P_1, P_2) &= (38.314 \times P_1)^2 + (19.5368 \times P_2)^2 \\ &= \left(1467.96 \times P_1^2\right) + \left(381.69 \times P_2^2\right),\end{aligned}$$

and then minimizing $\Gamma(P_1, P_2)$ corresponds to minimize $C(P_1, P_2)$, as it can be easily shown that $\Gamma \geq C$.

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- That proportion of power is used to update the values of the *droop parameter* at each generator.
- The implementation of the *Newton-Raphson* algorithm in PSIM was accomplished by coding in a *C-block* a recursive equation obtained analytically by the method of *Lagrange multipliers*.

IV. Results

Simulation scenario

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- for t = 0.11 the load value return to the nominal condition.
- for t > 0.14 the input voltage at the photovoltaic unit is modified by a decaying lobe emulating the reduction in solar radiation after the noon.

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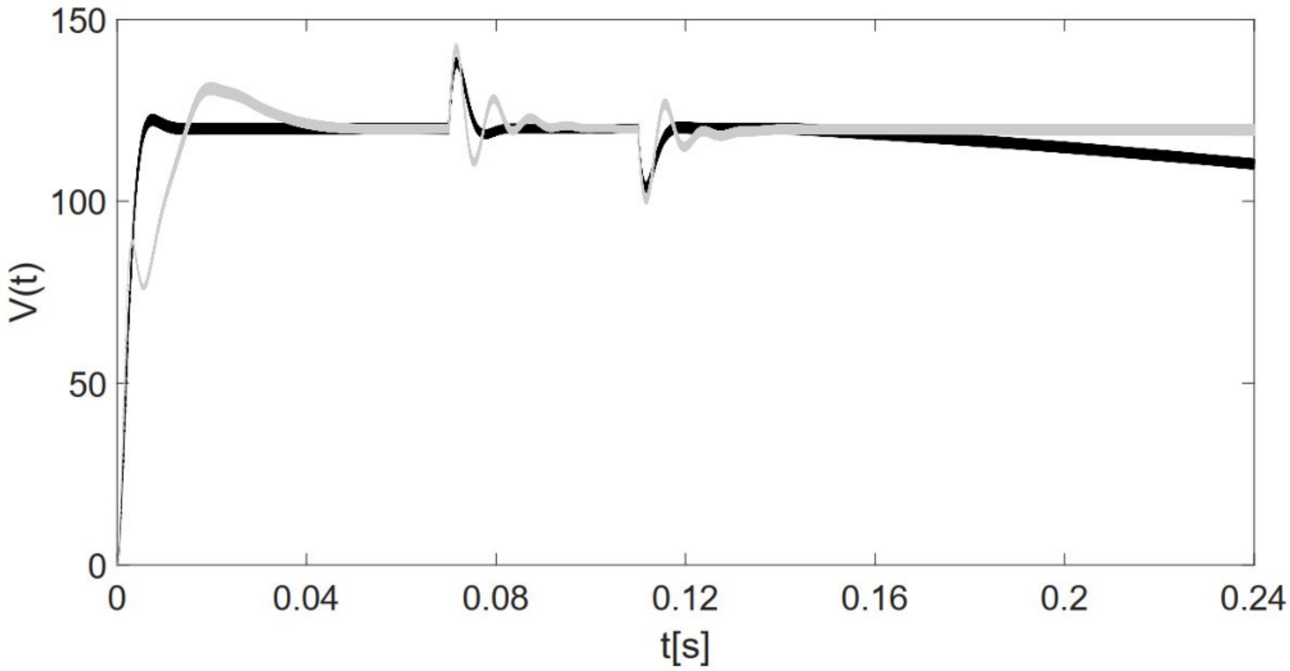

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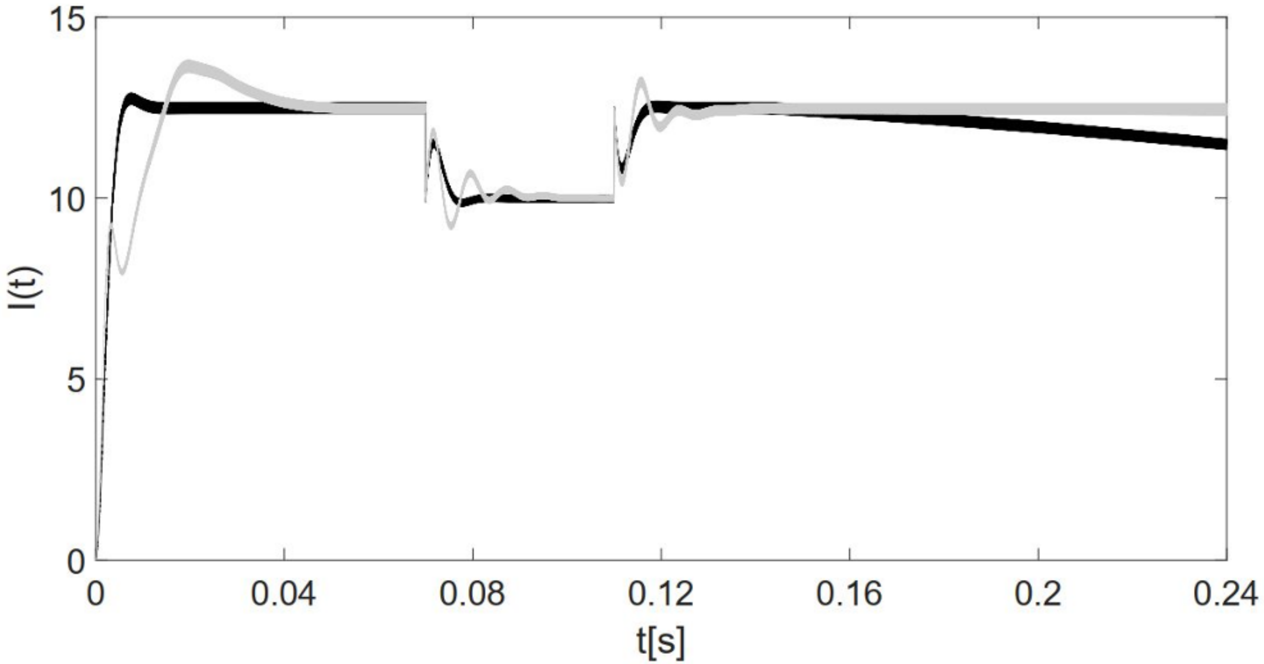

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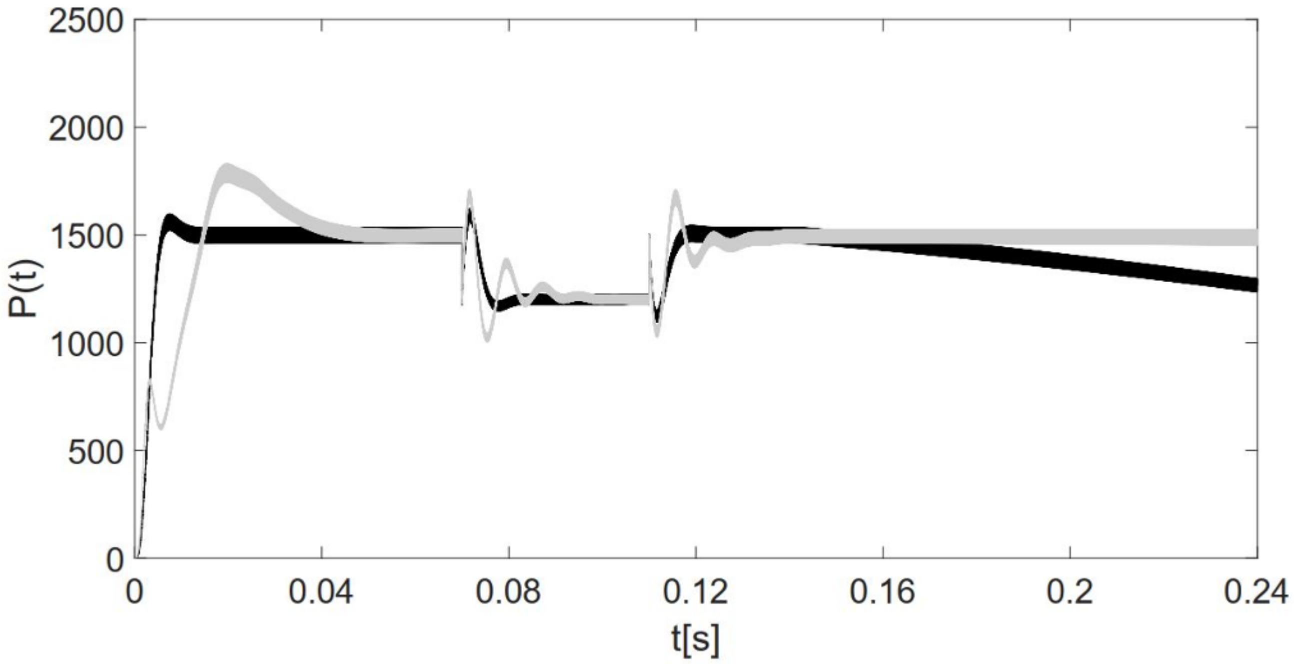

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- By contrast, a fixed power sharing of 60% - 40% is overimposed.

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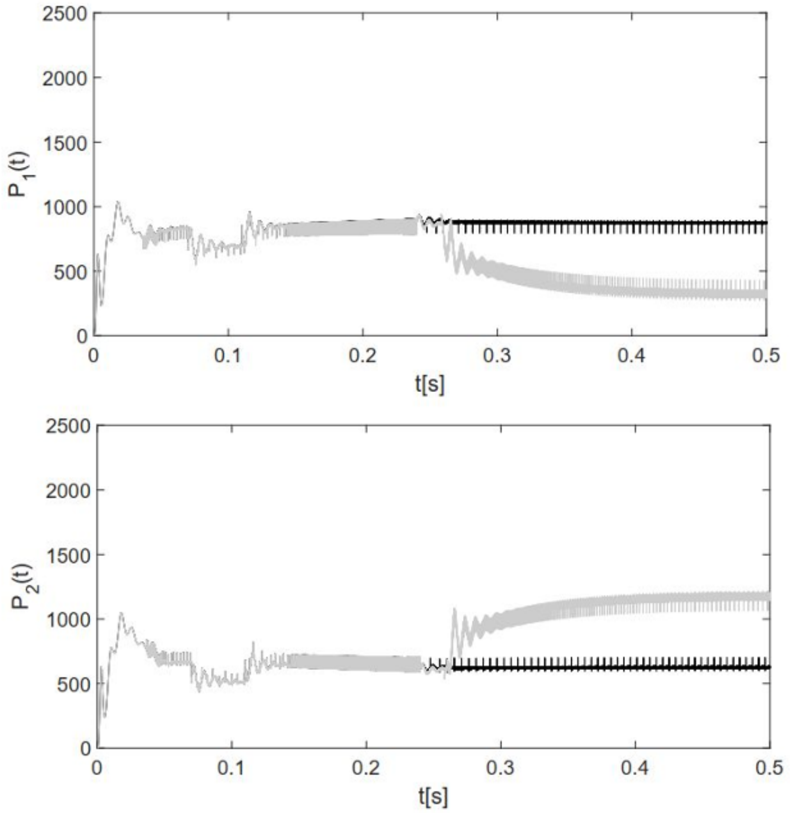

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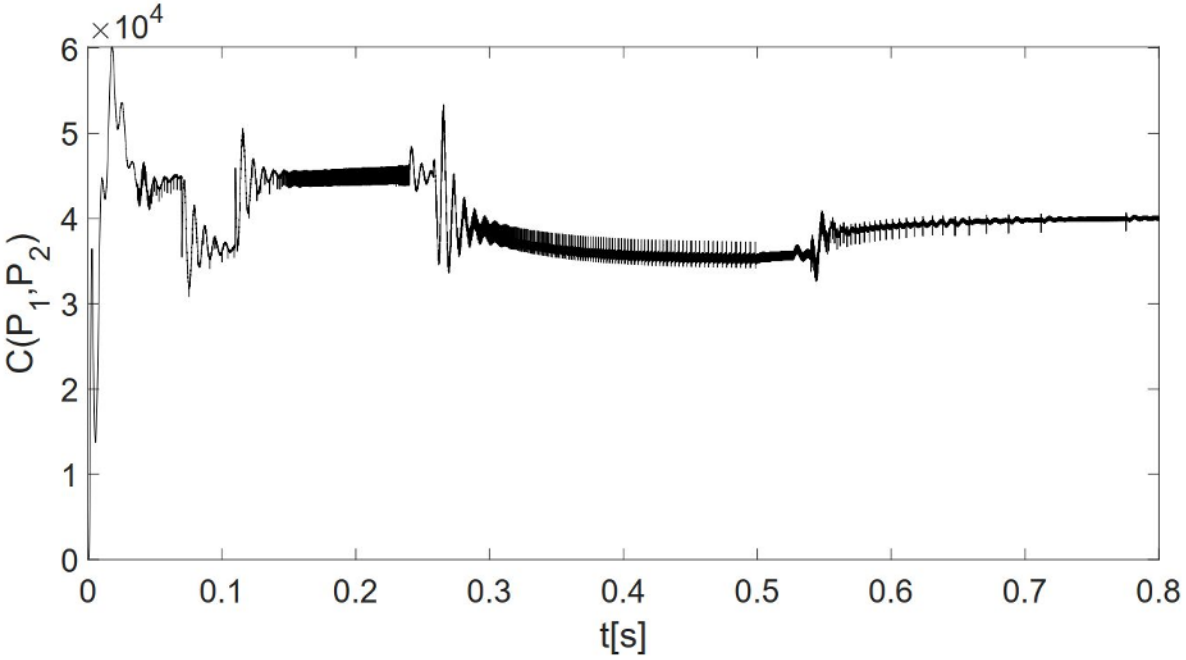
- The analysis for the cost function over the whole time interval suggest that it is minimal just after the optimization algorithm starts performing calculations.
- Also, it is important to notice that despite the increase of costs after altering the function of the battery bank, it is not higher than the initial (unoptimized) value.

Minimum cost

Minimum cost



V. Conclusions

Concluding remarks

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- Simulation results performed in PSIM allowed to verify the dynamic calculations for droop parameters and the corresponding adaptation of power proportions to environmental changes in the system.
- Ongoing work is currently devoted to experimental verification of the proposed management strategy on a laboratory prototype built at the Universidad Industrial de Santander.

Acknowledgements

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Authors wanted to acknowledge the financial support of the Universidad Industrial de Santander under the grant code VIE-UIS 2479, funding the project entitled: “Control centralizado para un sistema de generación de energía con potencial aplicación en zonas rurales del departamento de Santander”.

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Questions?

Thank you for your attention !!!

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