PSR

Impact Analysis of the Inclusion of *FACTs* and *Smart Wires* in Transmission Expansion Planning

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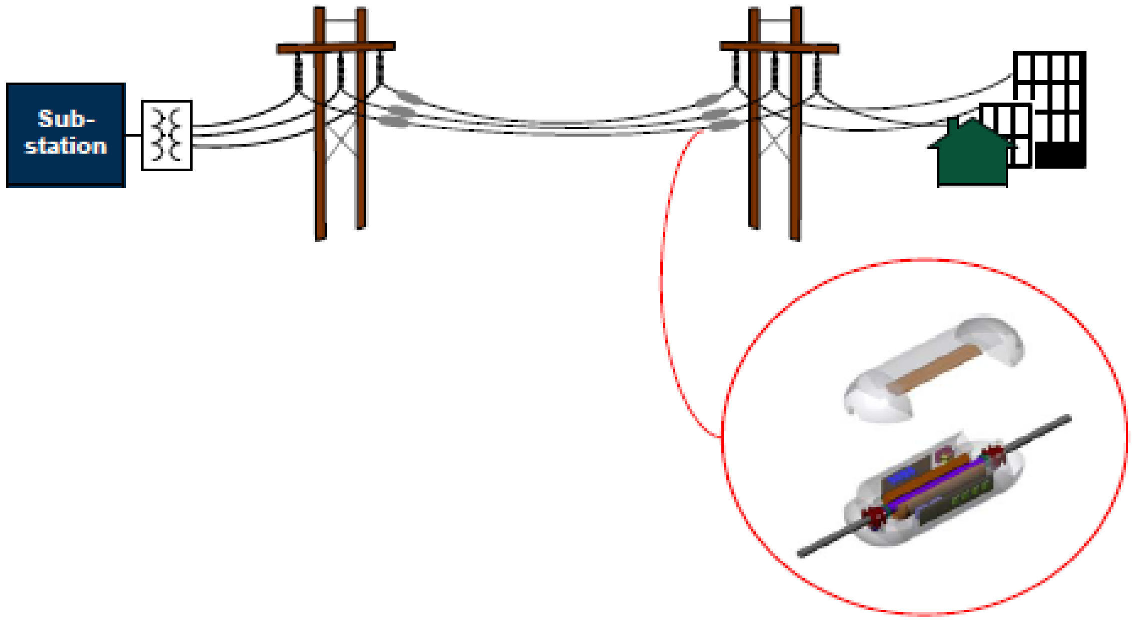
Introduction

- There are several reasons to explain why transmission system loading is less than 100%:
  - Reliability
  - Uncertainties associated with the demand growth forecast
  - Different dispatch scenarios (hydrothermal systems)

- The conjunction of these facts leads to high investments to meet different dispatch scenarios and low loading throughout the year

DFACTs – Smart Wires

- *Distributed Series Reactance* (DSR)
- Operating possibilities: fixed value / *setpoints* received by remote communication system
- The trigger control can be made gradually, so that not all the compensation reactance is added at once



DFACTs – Smart Wires

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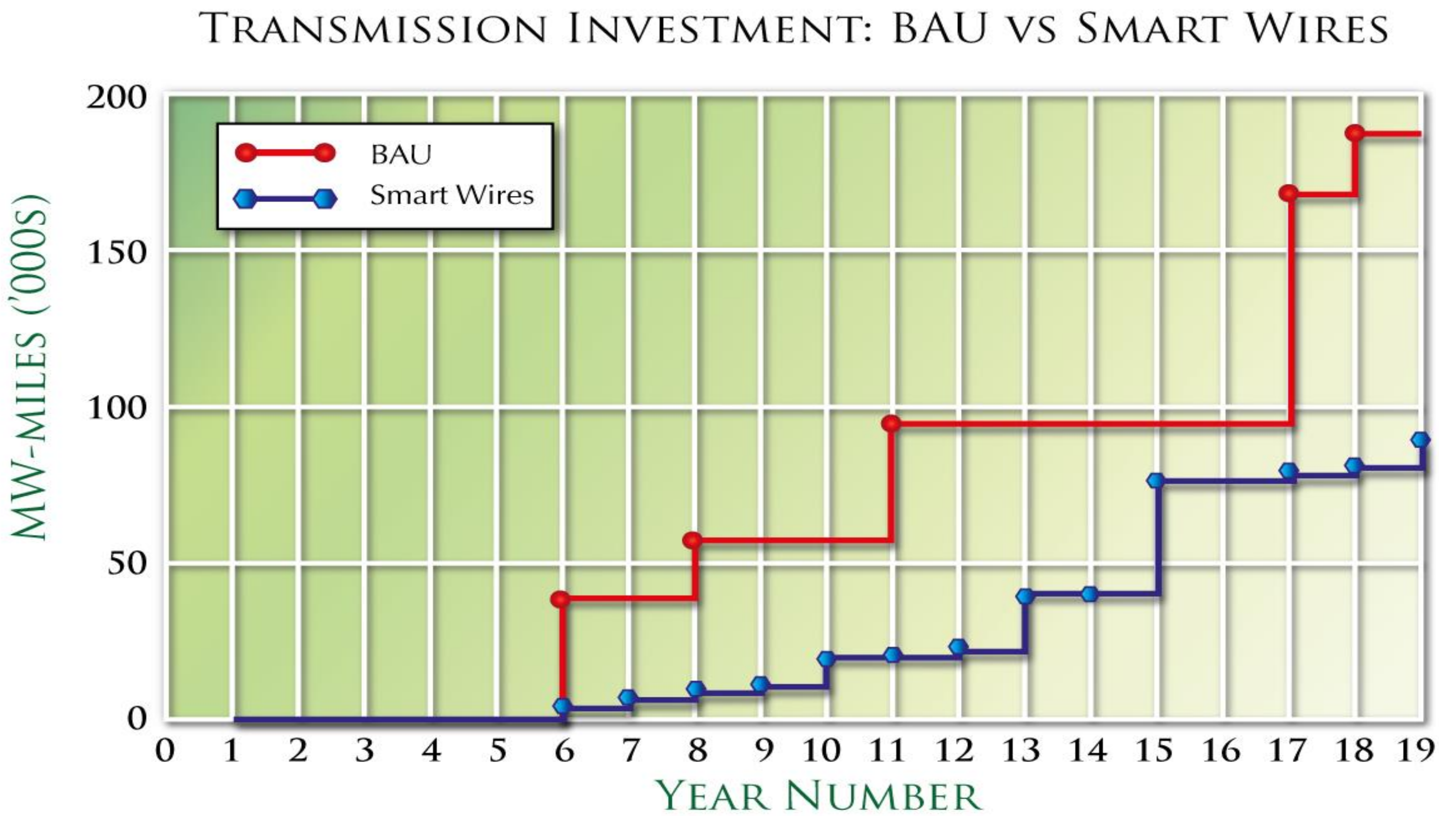
- With regard to investment costs, it is estimated that today a 10kVA module costs $ 1000
- To compensate 10% of typical 345 and 765kV lines, 5 and 25 modules per kilometer are respectively needed



DFACTs – Smart Wires

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- Technological differential ➔ modularity technology ➔ economic scale gains
- This standardization is one of the great advantages over the traditional *FACTs* devices, since they are manufactured for specific applications, resulting in higher costs and lead times
- Smart wires' technology is still being developed and consequently the associated costs are not fully known
- The objective of this work is not the inclusion of still uncertain costs in the expansion planning problem, but getting a ceiling cost reference to ensure the economic viability of its application

Linearized Power Flow Equations

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$$Min \sum_{k=1}^{K} c_k \, x_k$$

***Subject to*:**

Binary x variables "couple" the OPF equations for all dispatch scenarios

$$S\, f^n = d^n - g^n$$

$$-M(1-x) \le f^n - \gamma\, x\, S'\theta^n \le M(1-x)$$

$$-\bar{f}\, x \le f^n \le \bar{f}\, x$$

Disjunctive formulation

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- Second Kirchhoff's law for candidate circuits:

$$f_k = \gamma_k\, \boldsymbol{x_k}(\boldsymbol{\theta_i} - \boldsymbol{\theta_j})$$

- Non linearity due to product of bus angle and binary variable
- Disjunctive linear inequality replacing non linear equality:

$$-M(1 - x_k) \leq f_k - \gamma_k(\theta_i - \theta_j) \leq M(1 - x_k)$$

Extremely high values of M leads to ill conditioning of the problem.

A special algorithm is used in order to obtain optimal value of M for each circuit [2].

Hybrid Model

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- Changes in the problem formulation are needed to include the following constraint:

$$0 \leq \gamma \leq \overline{\gamma}$$

- Multiplying the terms from the constraint shown above by $\boldsymbol{\Delta\theta}$, $\boldsymbol{\gamma\Delta\theta}$ can be replaced by a variable $\boldsymbol{I}$ (which denotes an injection) and the problem is reformulated as follows:

Hybrid Model

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$$Min \sum_{k=1}^{K} c_k \, x_k$$

***Subject to*:**

$$Sf^n + I^n = d^n - g^n$$

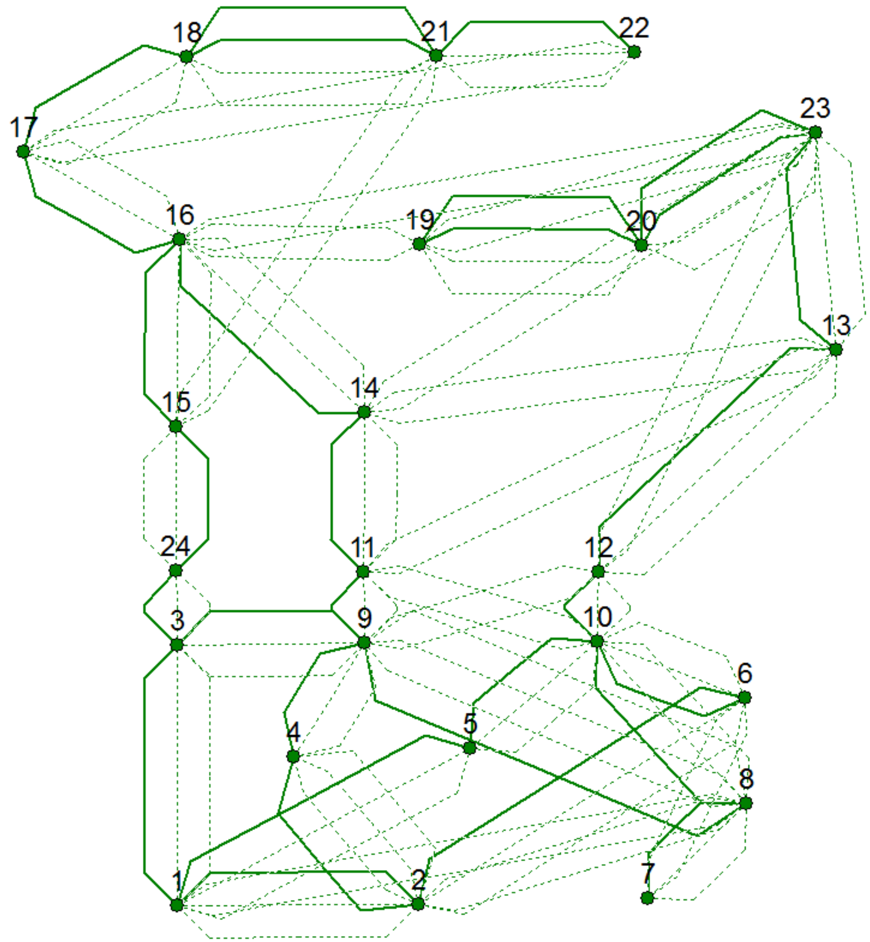
$$-\bar{\gamma}\,\Delta\theta^n \leq I^n \leq \bar{\gamma}\,\Delta\theta^n$$

$$-|\overline{f}|\,x \leq I^n \leq |\overline{f}|\,x$$

$$I_j^n - f_k^n \leq |\overline{f}|(1 - x_j)$$

$$I_j^n - f_k^n \geq |\overline{f}|(1 - x_j)$$

Case Study – IEEE24-Bus System



- The system under analysis presents 30 existing circuits and 84 candidates: 56 duplications; 28 located in 14 new corridors.

Expansion Plans: Single Dispatch Scenario

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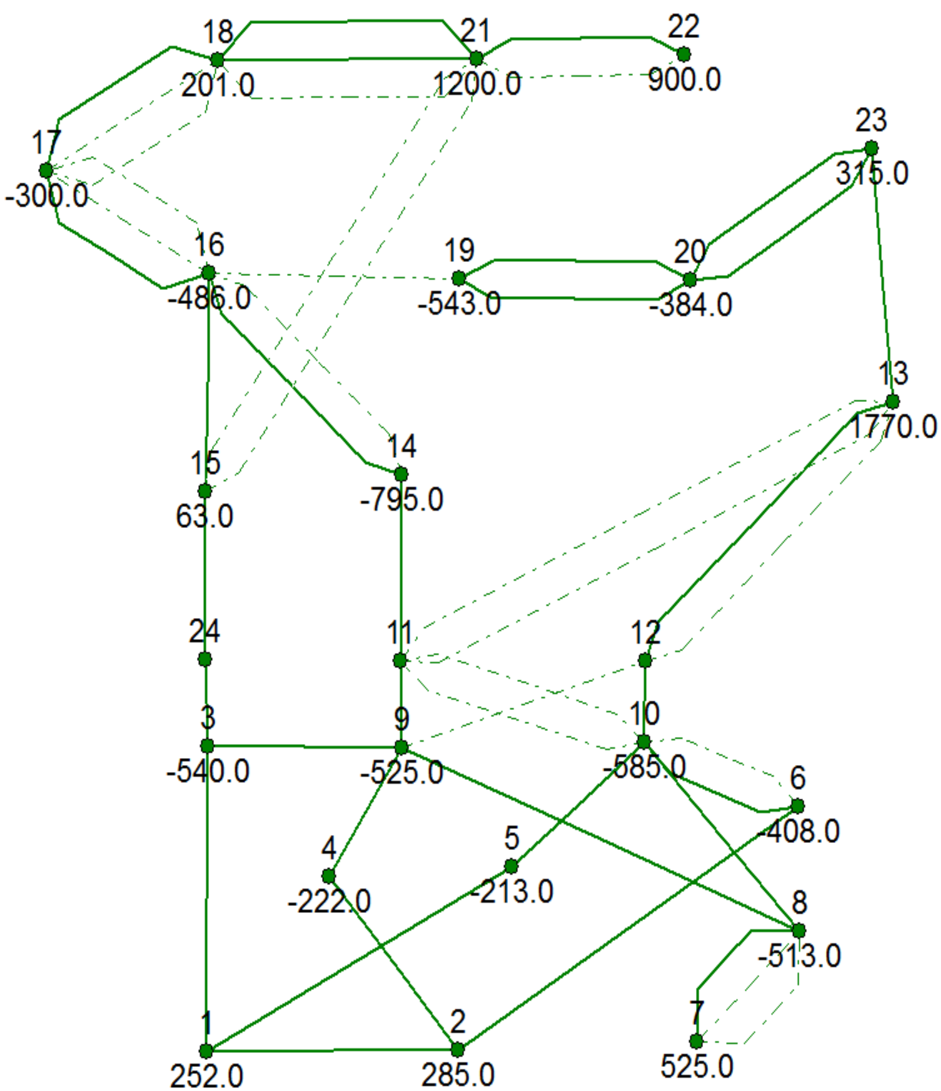
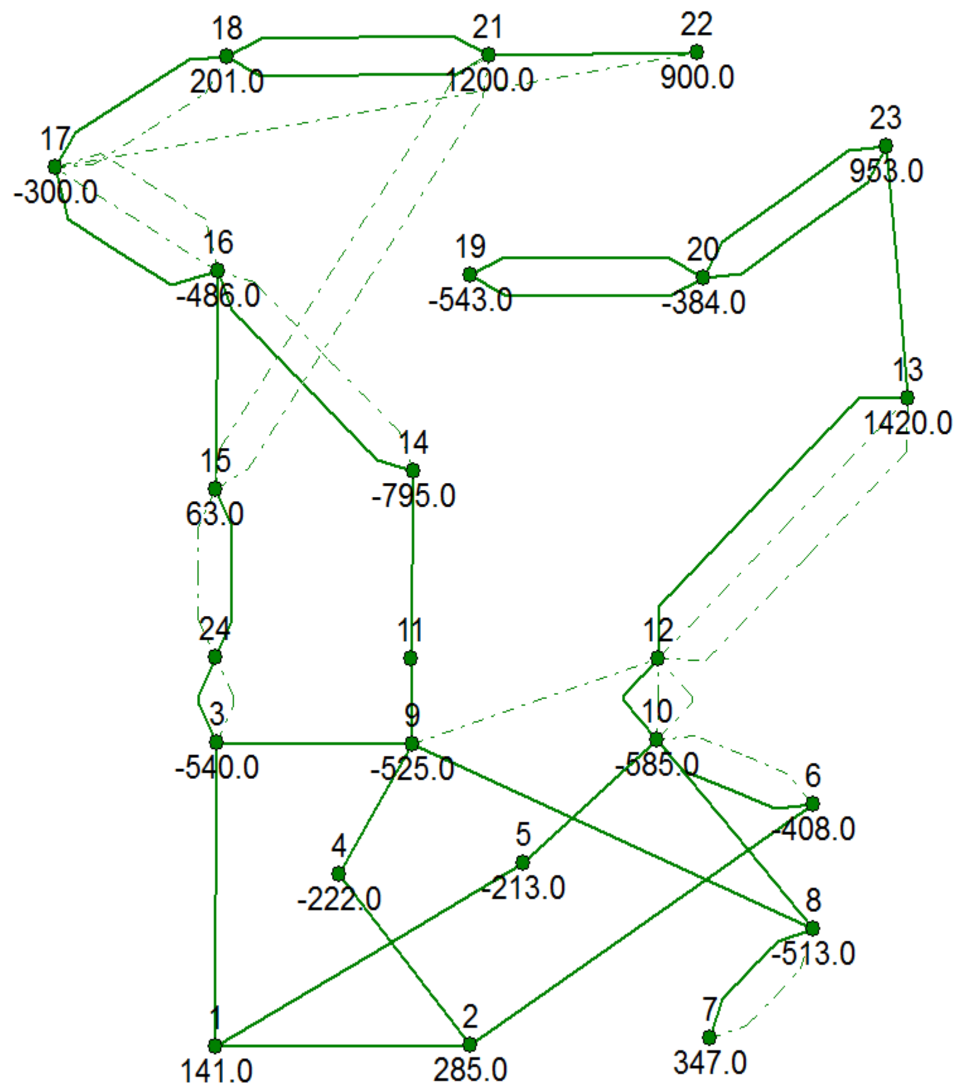
Dispatch Scenario: G1



Dispatch Scenario: G2



Expansion Plans: Single Dispatch Scenario

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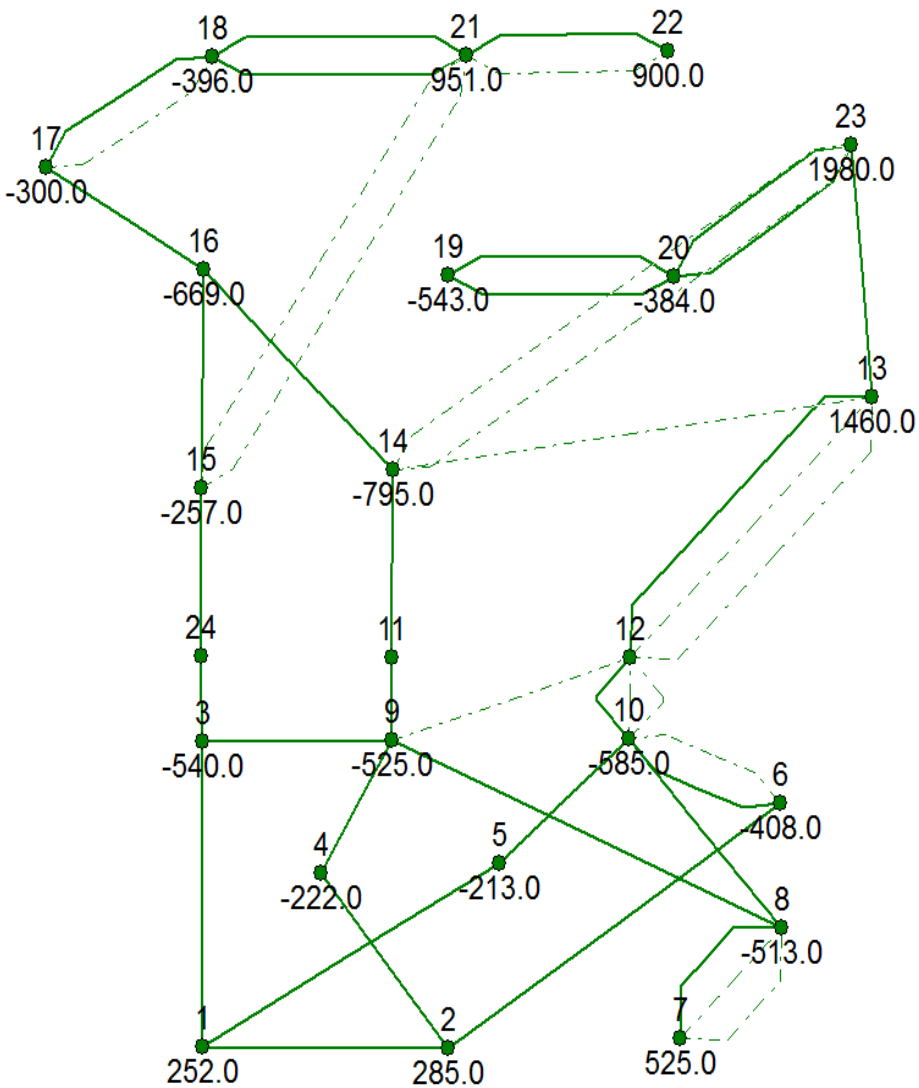
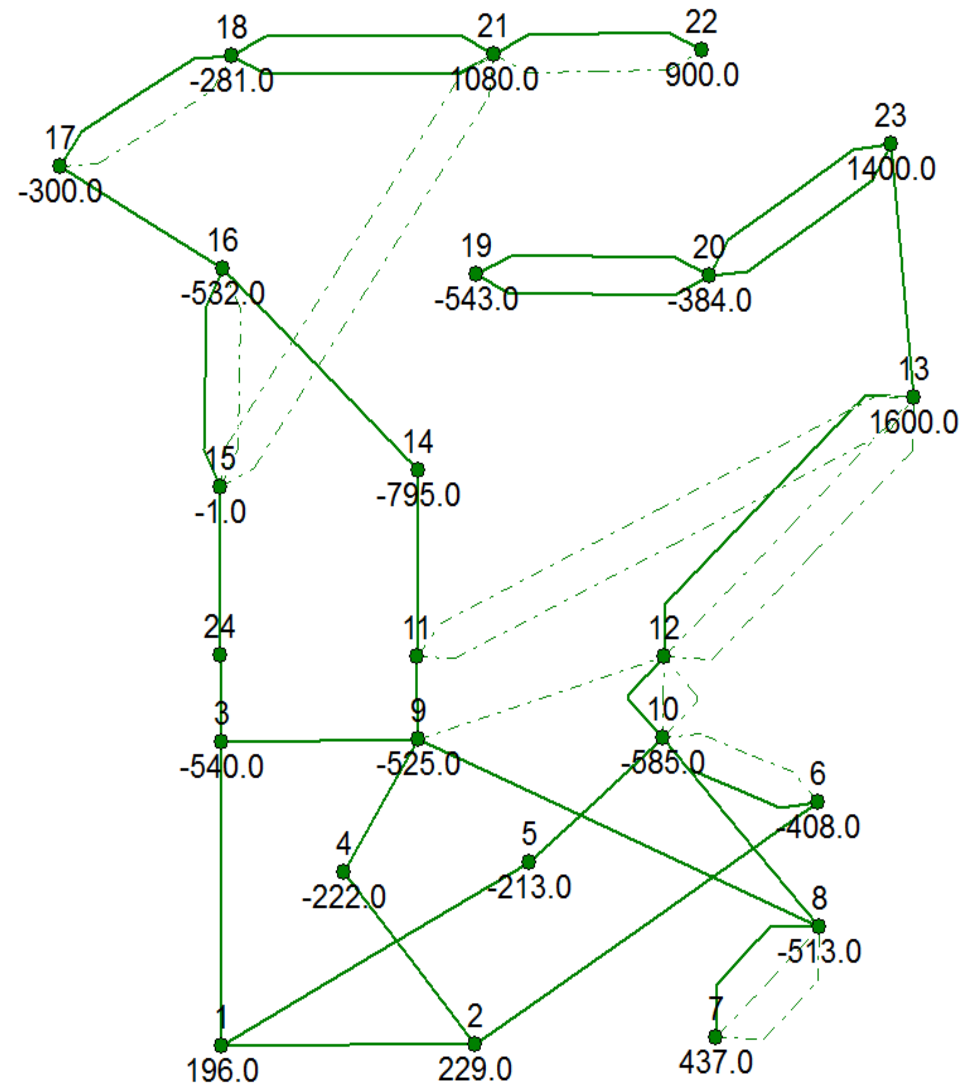
Dispatch Scenario: G3



Dispatch Scenario: G4



Expansion Plans: Single Dispatch Scenarios

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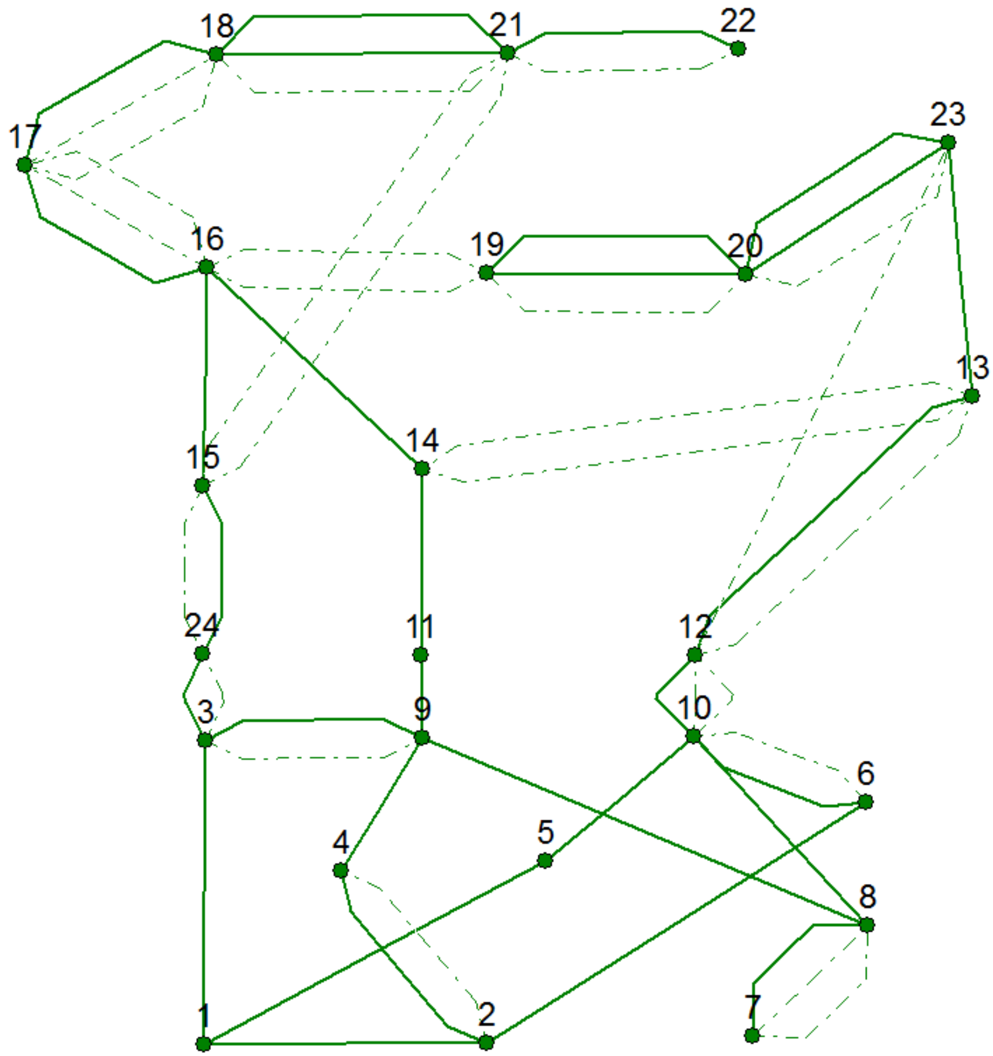
Scenario	Total Cost [10^6 U$]	Average Loading [%]
G1	860	69.37
G2	864	72.76
G3	814	70.36
G4	736	74.89

- Least cost expansion plan ➔ G4
- G1 is 16.85% more expensive than G4
- G2 is 17.39% more expensive than G4
- G3 is 10.60% more expensive than G4

Expansion Plans: All Dispatch Scenarios



Expansion Plans: All Dispatch Scenarios

- The expansion plan total cost is $ 1.2 billion dollars
- 25 added candidates (duplications: 20; new corridors: 5)
- 61% more expensive than the least cost expansion plan
- Average Loading equal to 63.23%.
- Network Usage Reduction:

Scenario in Comparison	Loading Reduction [%]
G1	9.71
G2	15.07
G3	11.27
G4	18.44

Hybrid: All Dispatch Scenarios + Same Costs

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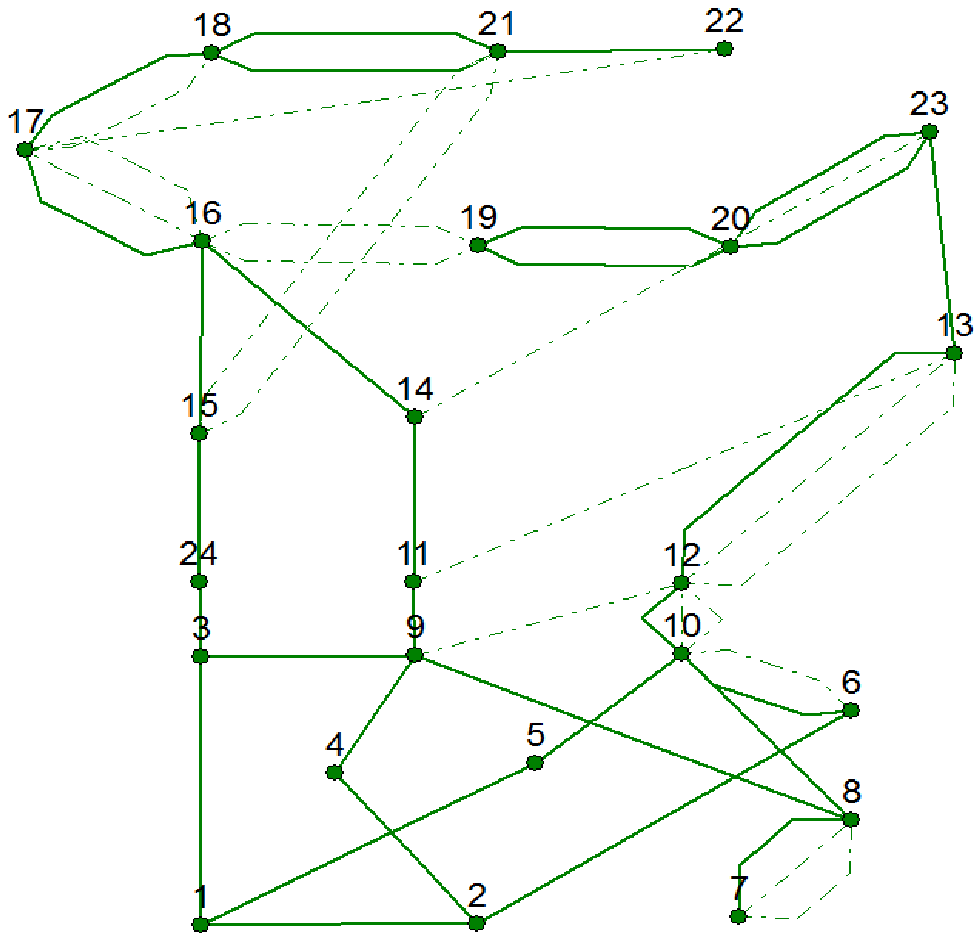

- 18 added candidates (duplications: 10; new corridors: 8)
- Hybrid expansion plan is 22.36% more economical than the conventional expansion plan

Expansion Plans – Comparison

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Candidate Cost Hybrid / Conventional [%]	Nº of Hybrid Candidates	Nº of Conventional Candidates	Expansion Plan Cost Hybrid / Conventional [%]	Loading Increase Hybrid / Conventional [%]
100	8	10	77.64	8.87
110	8	10	82.26	8.87
120	7	13	84.76	10.07
130	7	13	88.15	10.71
140	7	13	91.54	10.94
150	7	13	94.94	10.94
160	6	14	98.57	10.49
170	6	14	101.69	10.49

Expansion Plans – Comparison

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150	7	13	94.94	10.94
160	6	14	98.57	10.49
170	6	14	101.69	10.49

Break-even-point

- Hybrid candidates can be up to 60% more expensive than conventional candidates that the expansion plan is still more economical.

Conclusions

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- Two different transmission expansion planning methodologies were presented ➔ considering or not candidates with variable reactance

- Case Study ➔ Robust expansion plan attending all dispatch scenarios with conventional candidates:
  - More reinforcements are needed
  - Lower average loading
  - 61% more expensive than the least cost expansion plan for a single dispatch scenario

Conclusions

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- Smart Wires are very important for transmission expansion planning by providing an operational flexibility to different dispatch scenarios
- Case Study ➔ Hybrid candidates can be up to 60% more expensive than conventional candidates that the expansion plan is still more economical ➔ Ceiling Cost Reference
- The relevance of this theme is even greater in hydrothermal systems such as Brazil ➔ Future Work

THANKS! Questions?

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