Pseudo-geographical representations of power system buses by multidimensional scaling

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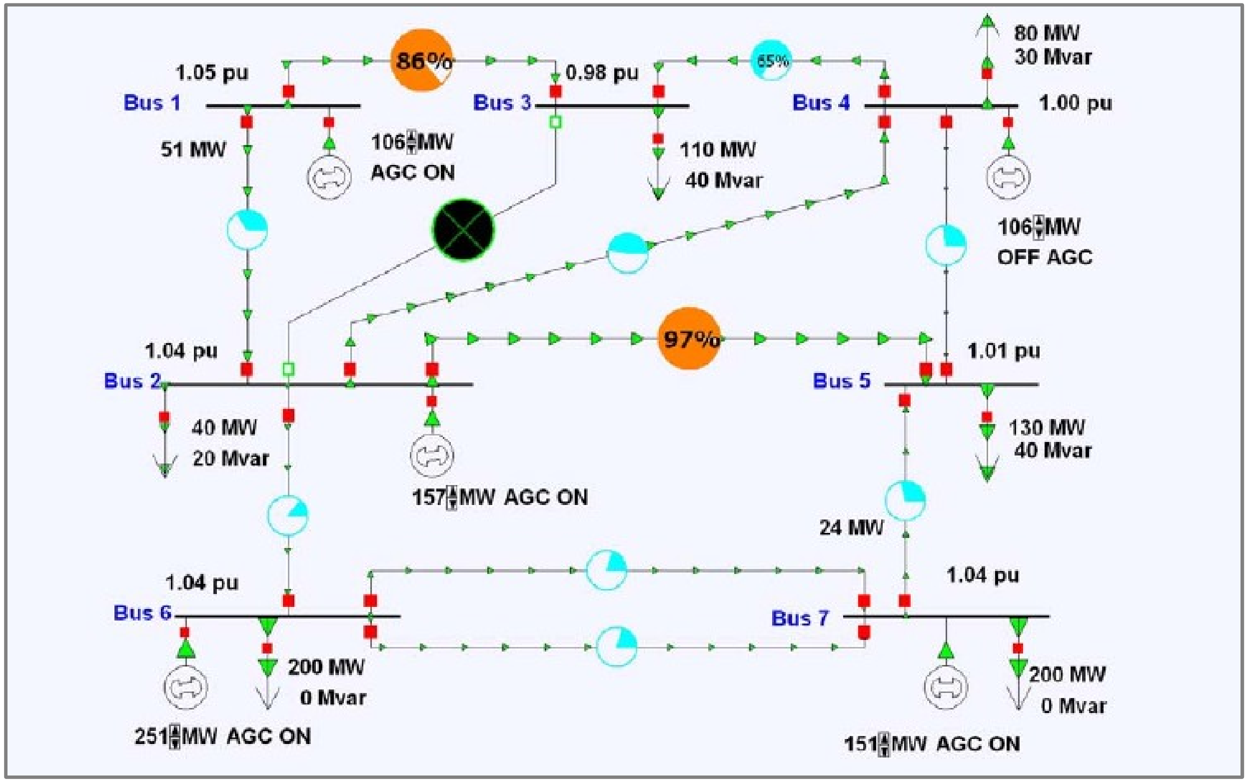
1. Motivation for creating new power system representations

Examples of existing solutions to represent physical properties of power systems

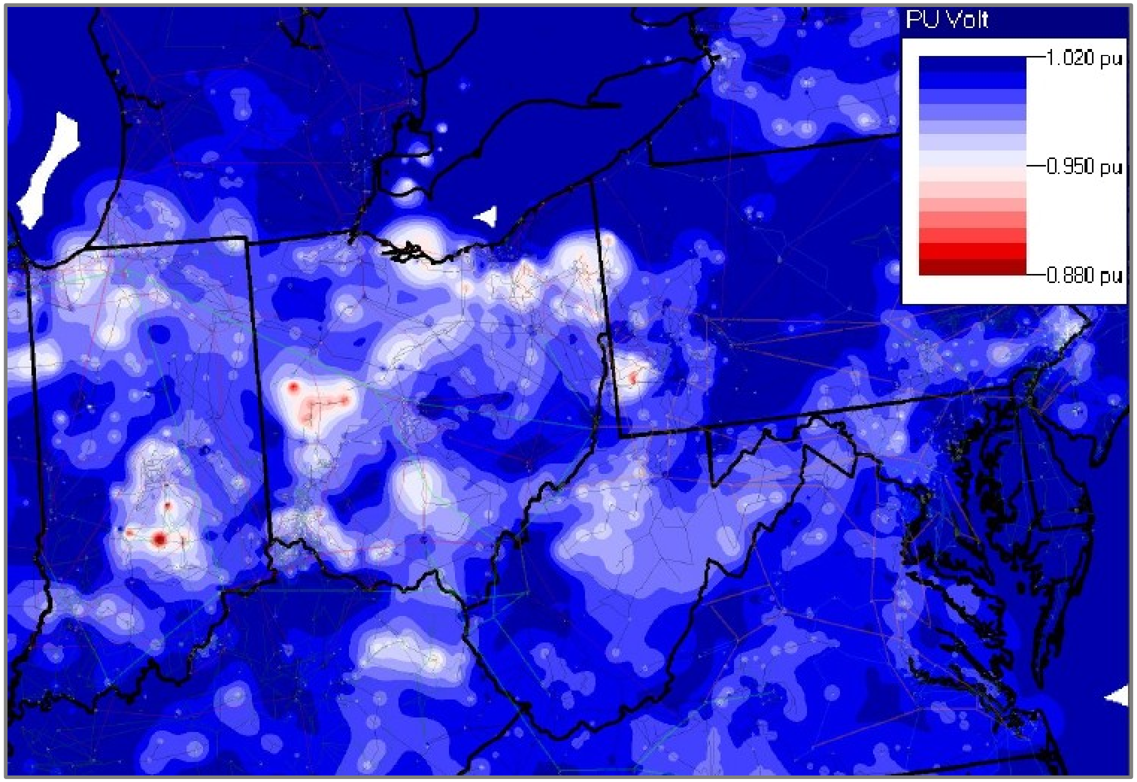
- pie charts and arrows show the flows in the transmission lines.



1. Motivation for creating new power system representations

Examples of existing solutions to represent physical properties of power systems

- color contours illustrate voltage magnitude variations.



1. Motivation for creating new power system representations

We propose a new approach to represent any kind of information about the physical properties of a power system.

- these characteristics are represented as ***distances*** between buses.

- the location of the buses reflect both their geographical coordinates and these properties.

- *examples of data represented:* line impedances, quantities related to the behavior of the buses (e.g., nodal sensitivity factors).

2. Problem formulation

- **input:** distances between each pair of buses of the system, denoted by d_{ij} and collected in a distance matrix D.

- **output:** a set of two-dimensional coordinates for the buses such that the Euclidean interbus distances approximate the distances given in matrix D.

- corresponding optimization problem:

$$\arg\min_{d_{ij}^{Eucl}} \sum_{i=1}^{n} \sum_{j=i+1}^{n} \left(d_{ij}^{Eucl} - d_{ij} \right)^2 . \qquad (1)$$

3. Computational method

First stage: resolution of the optimization problem

➢ the optimization problem underlying the computation of the suited pseudo-geographic coordinates of the buses writes:

$$\arg\min_{X} f(X) \,, \qquad (2)$$

where

$$f(X) = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \left(\sqrt{\sum_{k=1}^{2} (x_{ik} - x_{jk})^2} - d_{ij} \right)^2 .$$

➢ multidimensional scaling (MDS) techniques are used to solve this problem.

3. Computational method

Second stage: similarity transformation

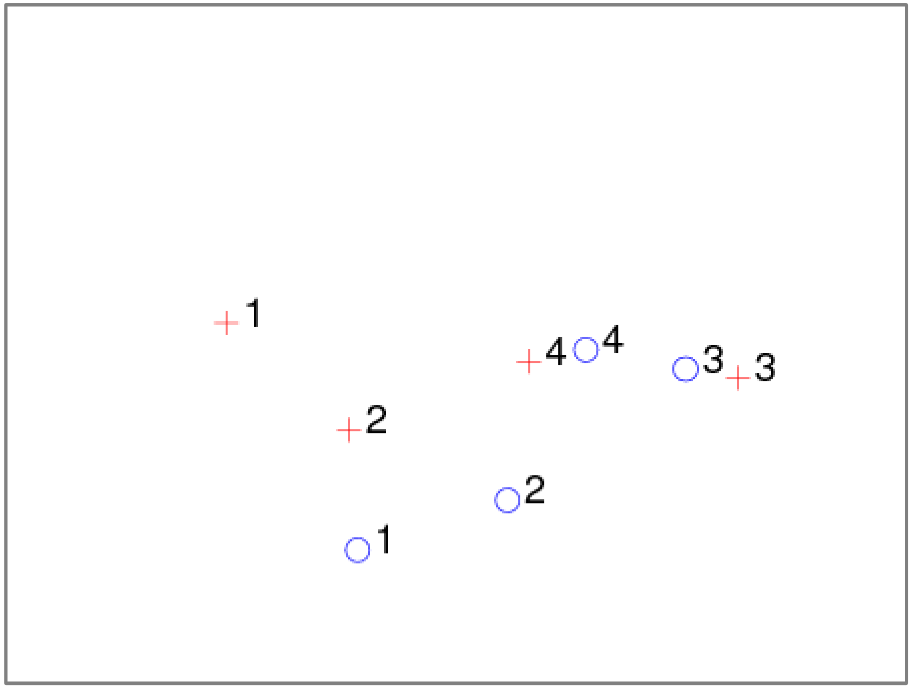
- the solution of optimization problem (2) is non-unique.

- any map obtained by translating, rotating and scaling a solution of (2) is also admitted as a solution.

- among all possibilities, we select the one in which the pseudo-geographical coordinates of two particular buses coincide with their geographical coordinates.

3. Computational method

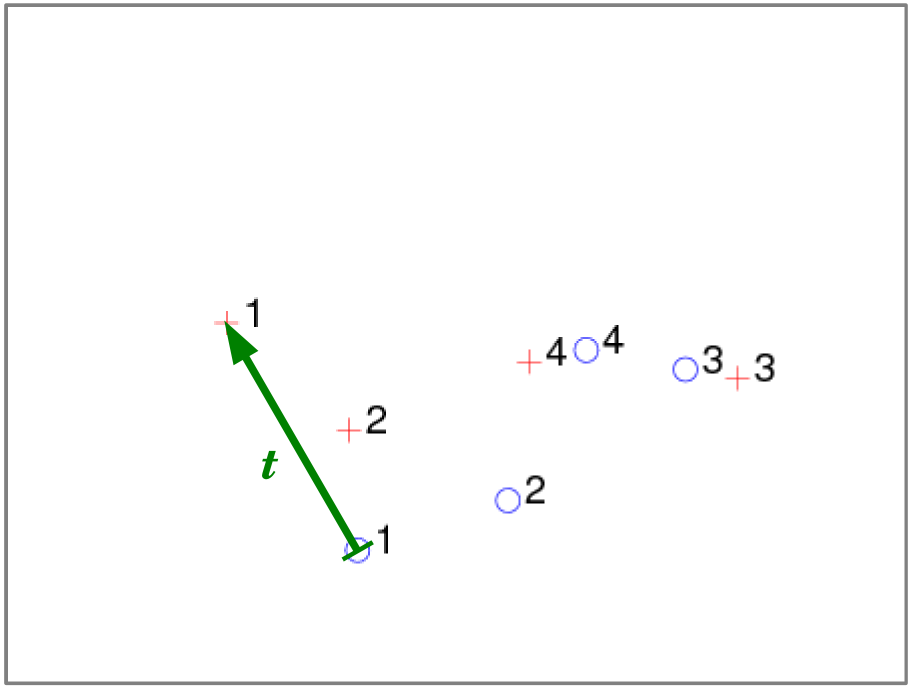
Second stage: similarity transformation, illustration



Geographical map (+) and MDS map (o)

Second stage: similarity transformation, illustration

Translation of the MDS map along vector ***t***

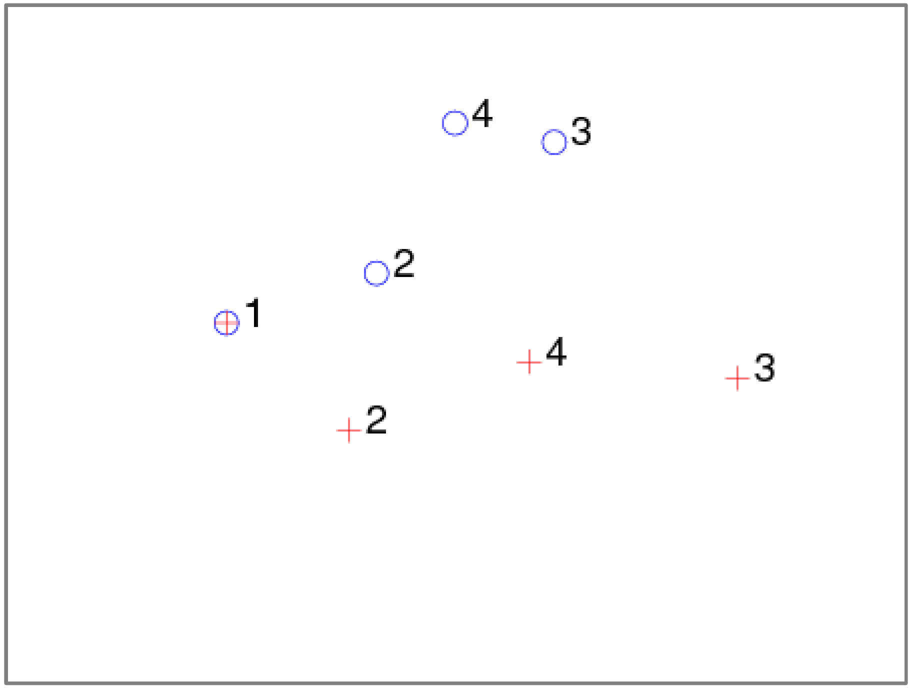


Geographical map (+) and MDS map (o)

3. Computational method

Second stage: similarity transformation, illustration

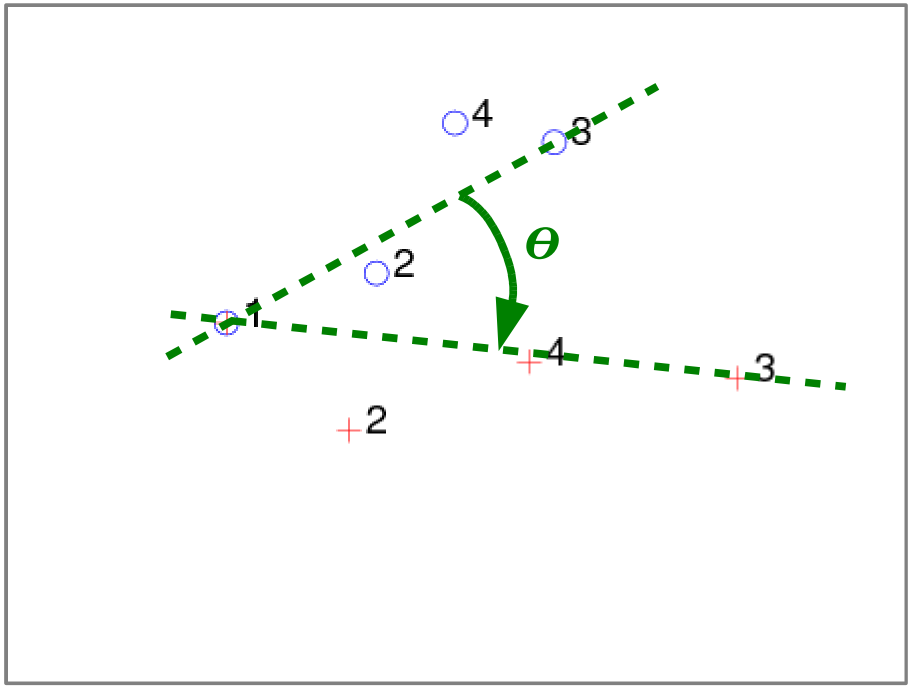
Translation of the MDS map along vector $\boldsymbol{t}$



Geographical map (+) and MDS map (o)

Second stage: similarity transformation, illustration

Rotation of the MDS map of angle θ around node 1



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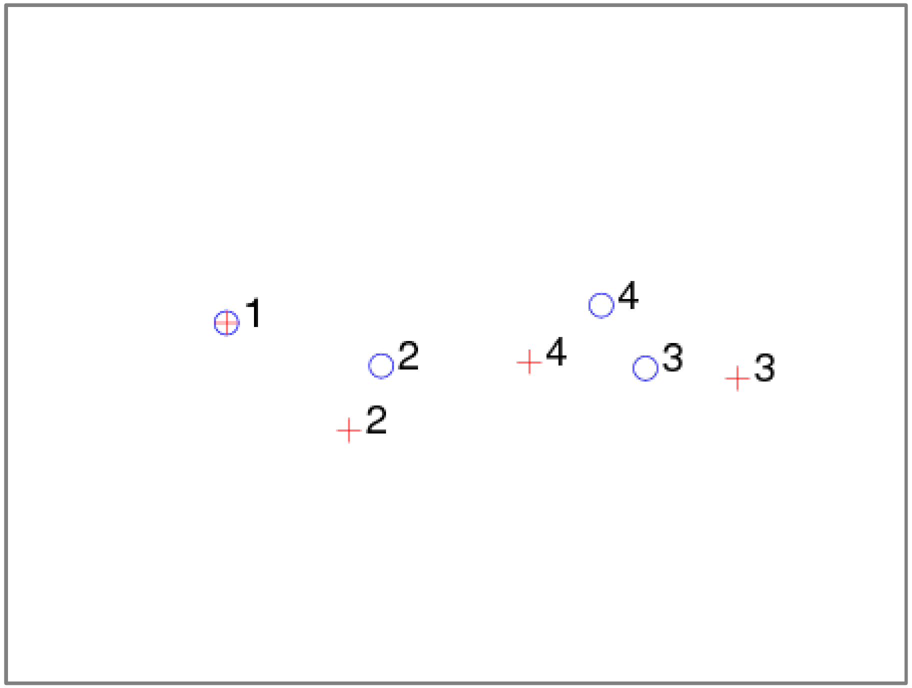
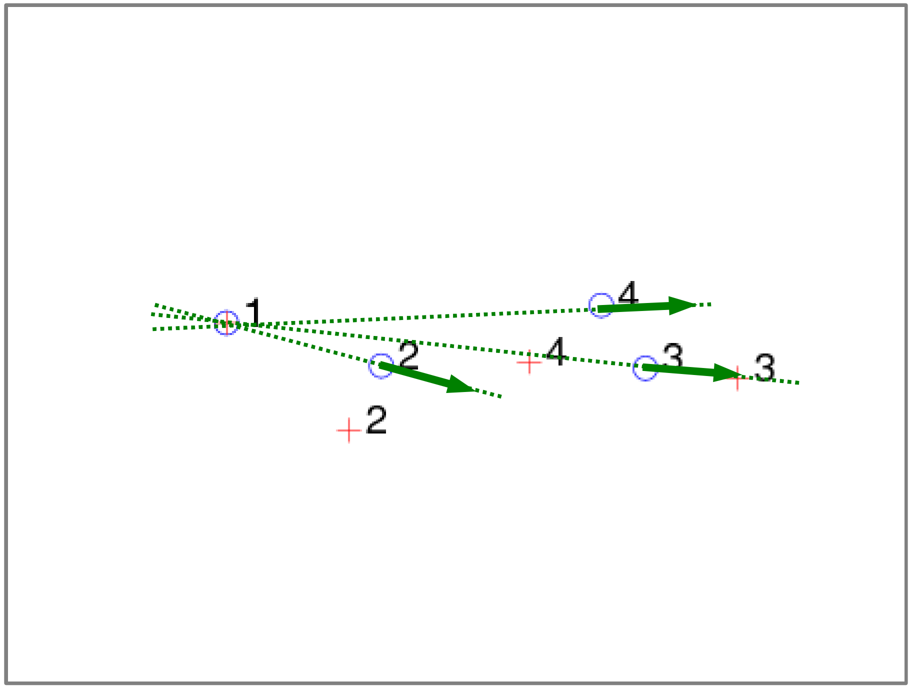


Geographical map (+) and MDS map (o)

3. Computational method

Second stage: similarity transformation, illustration

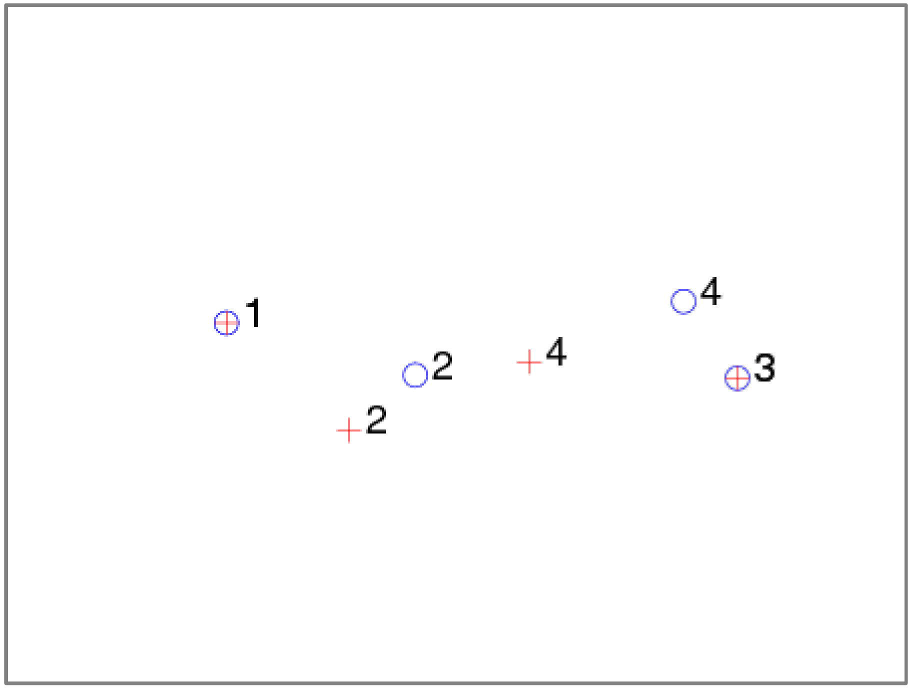
Homothety of origin node 1 to position node 3 correctly



Geographical map (+) and MDS map (o)

3. Computational method

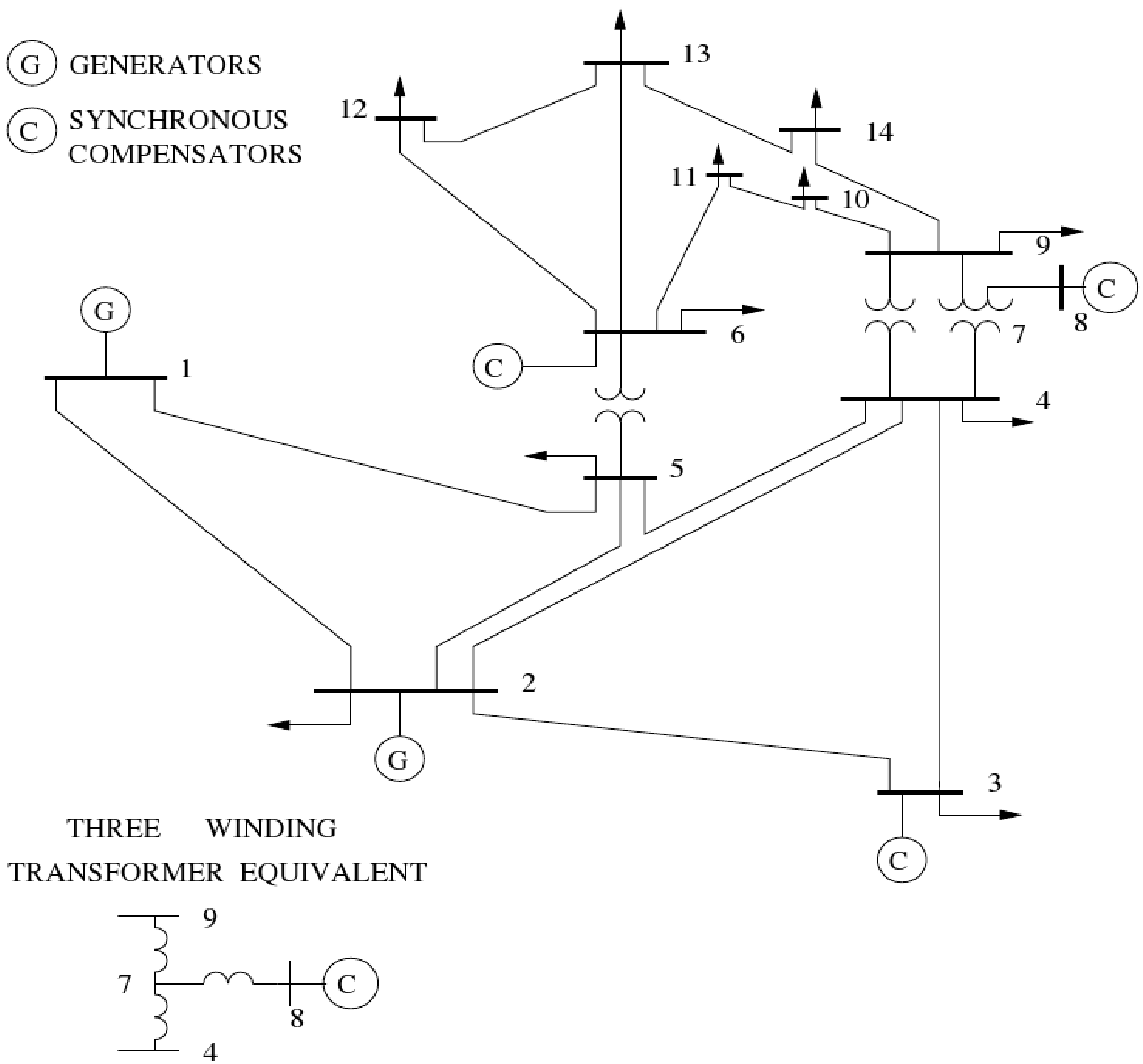
Second stage: similarity transformation, illustration



Final result: the position of nodes 1 and 3 in the MDS map (o) coincide with their geographical location (+).

4. Illustrations on the IEEE 14 bus system

Classical one-line diagram of the IEEE 14 bus system



4. Illustrations on the IEEE 14 bus system

Pseudo-geographical representation of the reduced impedances between buses

- the reduced impedance between two buses is obtained by:
  - reducing the admittance matrix of the network to these two buses,
  - computing the modulus of the inverse of this value.

- these reduced impedances can be seen as ***electrical distances***.

- they reflect for instance:
  - how close the voltage angles of two buses are likely to be,
  - how a short-circuit can affect the currents in the rest of the system.

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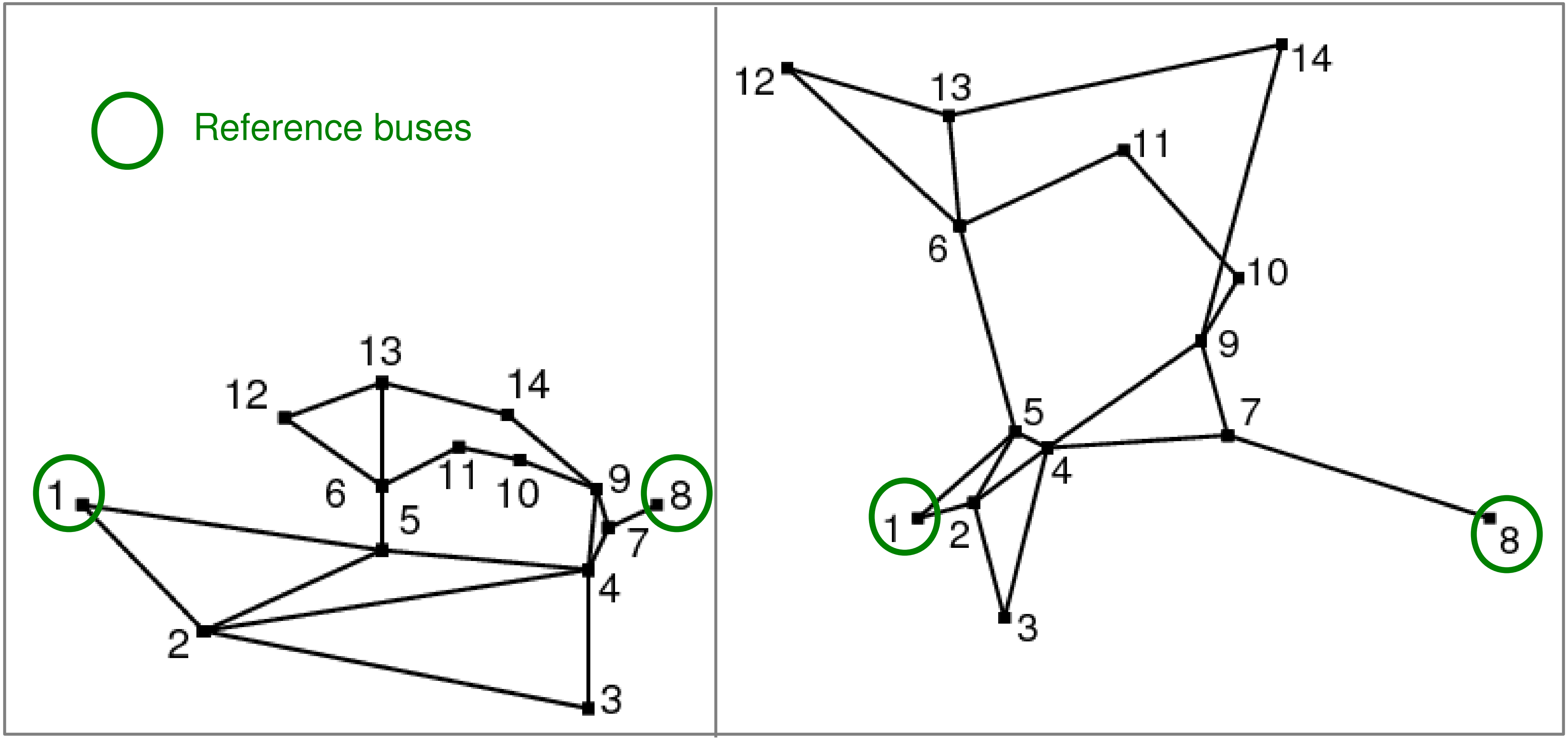
Pseudo-geographical representation of the reduced impedances between buses



Geographical representation

Pseudo-geographical representation

4. Illustrations on the IEEE 14 bus system

Pseudo-geographical representation of the voltage sensitivities of the buses

- the voltage sensitivity of a bus is the voltage variation following the loss of a generator.

- to each bus is associated a vector collecting its voltage variations.

Voltage variations at bus i :

$$\Delta V_i = \begin{pmatrix} \Delta V_i^1 \\ \Delta V_i^2 \\ \vdots \\ \Delta V_i^{n_g} \end{pmatrix}$$

Voltage variation at bus i when generator 2 is lost

- the information contained in vectors ΔV_i is then converted into ***interbus distances***.

Distance between buses i and j :

$$d_{ij} = \sqrt{\sum_{g=1}^{n_g} \left(\Delta V_i^g - \Delta V_j^g\right)^2} \, .$$

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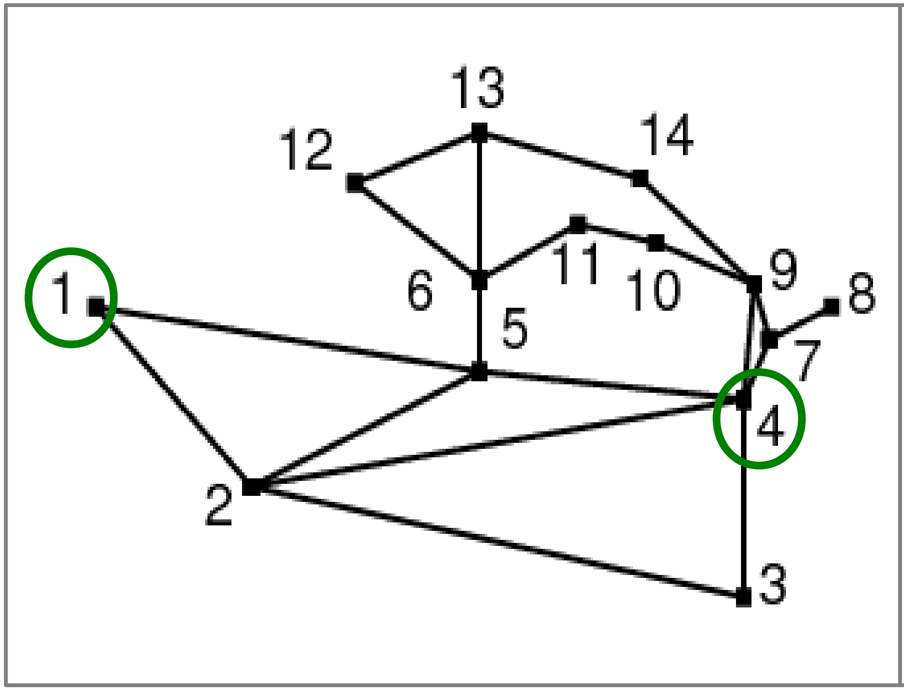
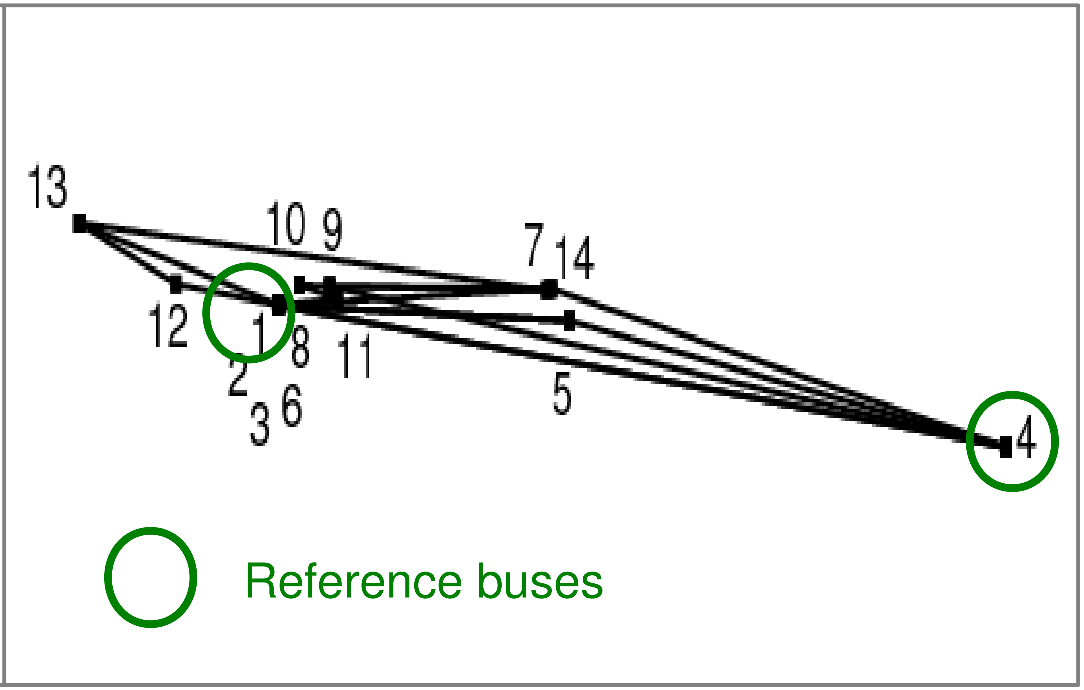
Pseudo-geographical representation of the voltage sensitivities of the buses



Geographical representation



Pseudo-geographical representation

5. Conclusion

- We have proposed a new approach for visualizing power system data, expressed as distances between buses.

Prospects of application of this framework:

- The created representations could complement existing visualization tools for planning and operation of a power system.