Pseudo-geographical representations of power system buses by multidimensional scaling

Florence Fonteneau-Belmudes, Damien Ernst, Louis Wehenkel

Department of Electrical Engineering and Computer Science
University of Liège, Belgium

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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:

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

(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:

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

(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)
3. Computational method

Second stage: similarity transformation, illustration

Translation of the MDS map along vector $t$

Geographical map (+) and MDS map (o)
Second stage: similarity transformation, illustration

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Rotation of the MDS map of angle $\Theta$ around node 1

Geographical map (+) and MDS map (o)
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Rotation of the MDS map of angle $\Theta$ around node 1

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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.
4. Illustrations on the IEEE 14 bus system

Pseudo-geographical representation of the reduced impedances between buses

Geographical representation

Pseudo-geographical representation
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 \( i \):

\[
\Delta V_i = \begin{pmatrix}
\Delta V_{i1}^1 \\
\Delta V_{i2}^2 \\
\vdots \\
\Delta V_{in}^{ng}
\end{pmatrix}
\]

➢ the information contained in vectors \( \Delta V_i \) is then converted into interbus distances.

Distance between buses \( i \) and \( j \):

\[
d_{ij} = \sqrt{\sum_{g=1}^{ng} (\Delta V_{ig}^g - \Delta V_{jg}^g)^2}.
\]

4. Illustrations on the IEEE 14 bus system
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Pseudo-geographical representation of the voltage sensitivities of the buses

Geographical representation

Pseudo-geographical representation

Reference buses
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.