1999 International Conference on Power Systems Transients

STUDYING HARMONIC PROBLEMS USING A DESCRIPTOR SYSTEM APPROACH

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Background

- Harmonic voltage performance of a system depends on the location of its poles and zeros mainly with respect to the characteristic harmonic frequencies
- Knowledge of the poles, zeros and their respective sensitivities to system parameters
- Identification of changes in the system which will reduce harmonic voltage levels

Difficulties

- The construction of the state matrix for practical systems is not a simple task.
- Methods based on state matrix formulations present some limitations regarding network topology and not automatically deal with state variables redundancy

Descriptor System Approach

$$\mathbf{T}\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$

$$\mathbf{y} = \mathbf{C}\mathbf{x}$$

- Overcomes the computational difficulties associated with the state matrix method.
- Automatically deals with state variable redundancies
- Can be efficiently applied to large-scale networks of any topology

Objectives

- Application of the Descriptor System Approach to study harmonic problems

Results

- Network Model

$$\left[\begin{array}{c|c}\mathbf{T}_1 & \mathbf{0} \\ \hline \mathbf{0}^T & \mathbf{0}_q\end{array}\right]\cdot\left[\begin{array}{c}\dot{\mathbf{x}}_1 \\ \hline \dot{\mathbf{v}}_{nodal}\end{array}\right]=\left[\begin{array}{c|c}\mathbf{A}_1 & \mathbf{A}_2 \\ \hline \mathbf{A}_3 & \mathbf{0}_q\end{array}\right]\cdot\left[\begin{array}{c}\mathbf{x}_1 \\ \hline \mathbf{v}_{nodal}\end{array}\right]+\left[\begin{array}{c}\mathbf{0} \\ \hline \mathbf{I}\end{array}\right]\cdot\mathbf{i}_{nodal}$$

$$\mathbf{v}_{nodal}=\left[\mathbf{0}^T \mid \mathbf{I}\right]\cdot\left[\begin{array}{c}\mathbf{x}_1 \\ \hline \mathbf{v}_{nodal}\end{array}\right]$$

- Impedance as a transfer function

$$\mathbf{Z}=\mathbf{C}\cdot\left(s\cdot\mathbf{T}-\mathbf{A}\right)^{-1}\cdot\mathbf{B}$$

Harmonic Impedance

$$Z_{kk} = \text{diag}\left[\left(\text{s} \cdot \mathbf{T} - \mathbf{A}\right)^{-1}\right]_{(2 \cdot n_l + k)} = \frac{\det\left(s \cdot \mathbf{T}_k - \mathbf{A}_k\right)}{\det\left(s \cdot \mathbf{T} - \mathbf{A}\right)}$$

- The system poles correspond to the generalized eigenvalue problem associated with the matrix pair {**A**,**T**}

$$\det\left(s \cdot \mathbf{T} - \mathbf{A}\right) = 0 \Leftrightarrow \mathbf{A} \cdot \mathbf{v}_i = \lambda_i \cdot \mathbf{T} \cdot \mathbf{v}_i$$

- The zeros, associated with the self impedance of node *k*, correspond to the generalized eigenvalue problem associated with the matrix pair {$\mathbf{A}_k$,$\mathbf{T}_k$}

Sensitivity Analysis

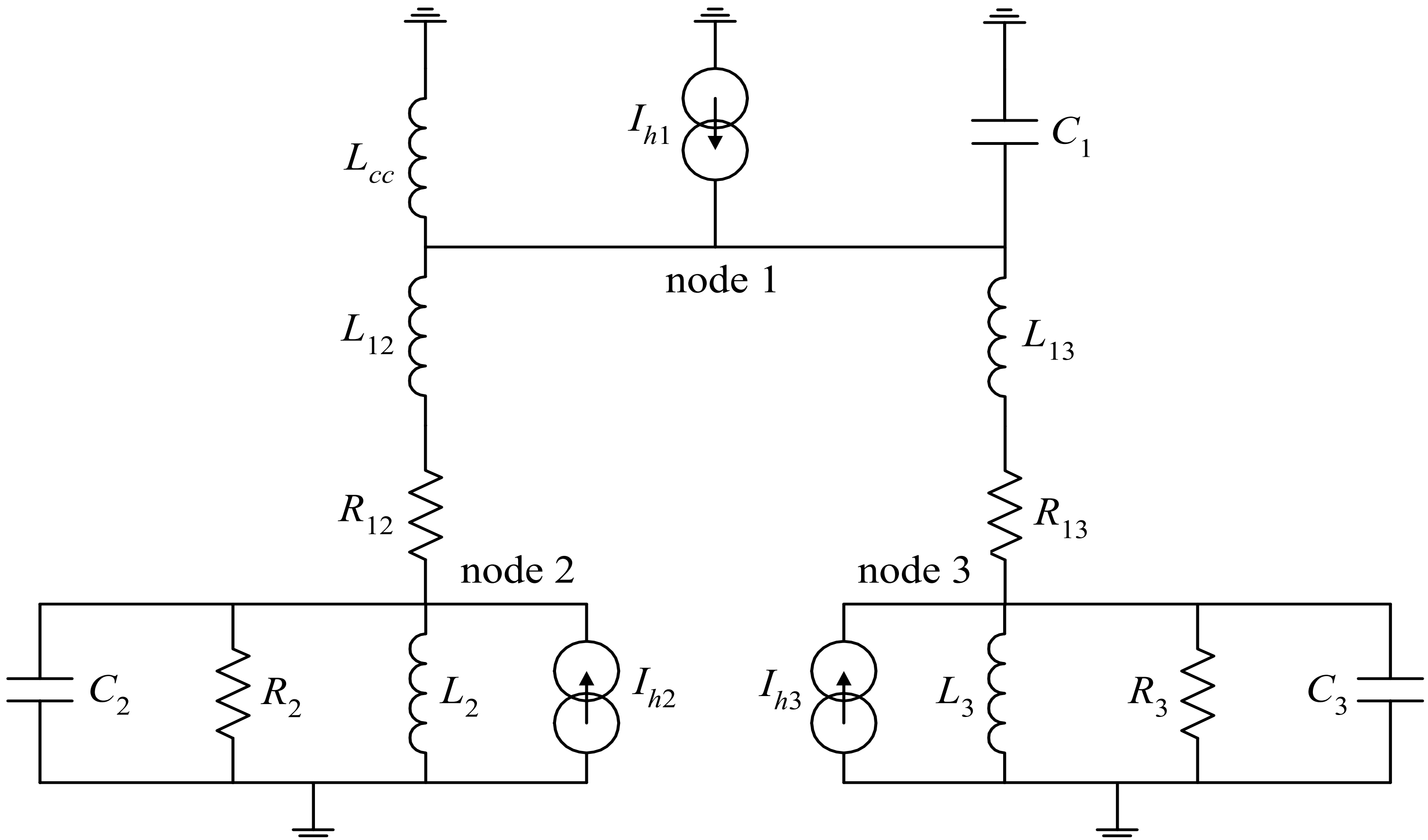
- Sensitivity

$$\frac{\partial \lambda_i}{\partial \alpha_j} = \frac{\mathbf{w}_i \cdot \left(\frac{\partial \mathbf{A}}{\partial \alpha_j} - \lambda_i \cdot \frac{\partial \mathbf{T}}{\partial \alpha_j} \right) \cdot \mathbf{v}_i}{\mathbf{w}_i \cdot \mathbf{T} \cdot \mathbf{v}_i}$$

- Eigenvalue Variation

$$\Delta \lambda_i = \alpha_j^0 \cdot \frac{\partial \lambda_i}{\partial \alpha_j} \left(\alpha_j^0 \right) \cdot \frac{\Delta \alpha_j}{\alpha_j^0}$$

Test System

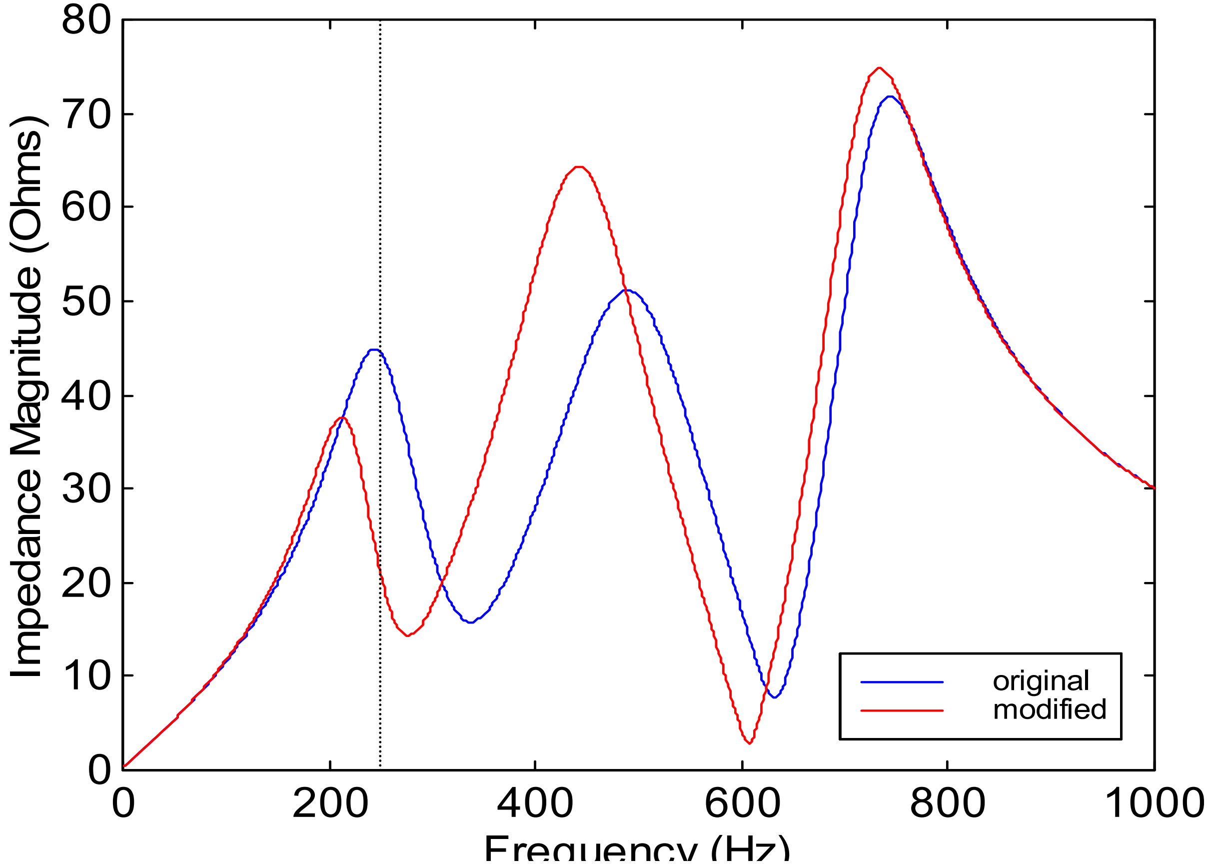


L_{cc}
I_{h1}
C_1
node 1
L_{12}
L_{13}
R_{12}
R_{13}
node 2
node 3
C_2
R_2
L_2
I_{h2}
I_{h3}
L_3
R_3
C_3

Poles and Zeros Sensitivities

	Poles			Zeros					
				Node 1		Node 2		Node 3	
	1	2	3	1	2	1	2	1	2
f(Hz)	252	489	722	425	565	332	633	382	704
L_{cc}	-633	-68	-312	0	0	-302	-501	-551	-292
L_2	-18	-22	-11	0.0	-41	0	0	-33	-15
L_3	-22	-12	-1	-30	0	-29	-5	0	0
L_{12}	-11	-493	-1551	0	-1820	-248	-415	-232	-1819
L_{13}	-119	-949	-492	-1325	0	-470	-1080	-368	-199
C_1	-284	-74	-1295	0	0	-237	-1523	-533	-1188
C_2	-158	-732	-697	0	-1689	0	0	-685	-912
C_3	-339	-719	-178	-1317	0	-799	-452	0	0

Shifting Poles and Zeros



$C_{3original}=11.9\ \mu F$

$C_{3new}=19.56\ \mu F$

Reduction of 47% in the impedance magnitude at 250 Hz

Conclusions

- State-space based formulations obtain the same frequency domain results as the conventional methods based on nodal formulation and more:
  - Identification of elements mostly involved in specific resonances
  - Determination of the necessary changes in system elements in order to shift the location of poles and/or zeros to desired positions
  - Optimum allocation of capacitor banks and/or passive filters

Conclusions

- Descriptor system approach allows:
  - Simple and efficient computational implementation
  - Ability to model systems of any topology and containing state variable redundancies
  - Applicability to large-scale networks, due to the very sparse matrices involved and the availability of powerful sparse eigensolution algorithms applied to descriptor systems

Sparse Structure of Matrix A