Time Series Based Semi-Analytical Solution of Power Systems and its Application in Direct Methods

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Introduction

- A semi-analytical solution to power system differential equations.
- The multi-machine power system is decoupled into a set of independent single-machine-infinite-bus (SMIB) systems.
- Solving set of linear equations provides a semi-analytical solution to power system.
- The semi-analytical solution can replace Time Domain Simulation to determine the fault-on trajectory used in Direct Method

Decoupling

Decouplability Assumption

- A multi-machine power system can be always decoupled into a set of independent SMIB systems.

System model

- Constant impedance model for all loads
- Classic model for all generators in the System

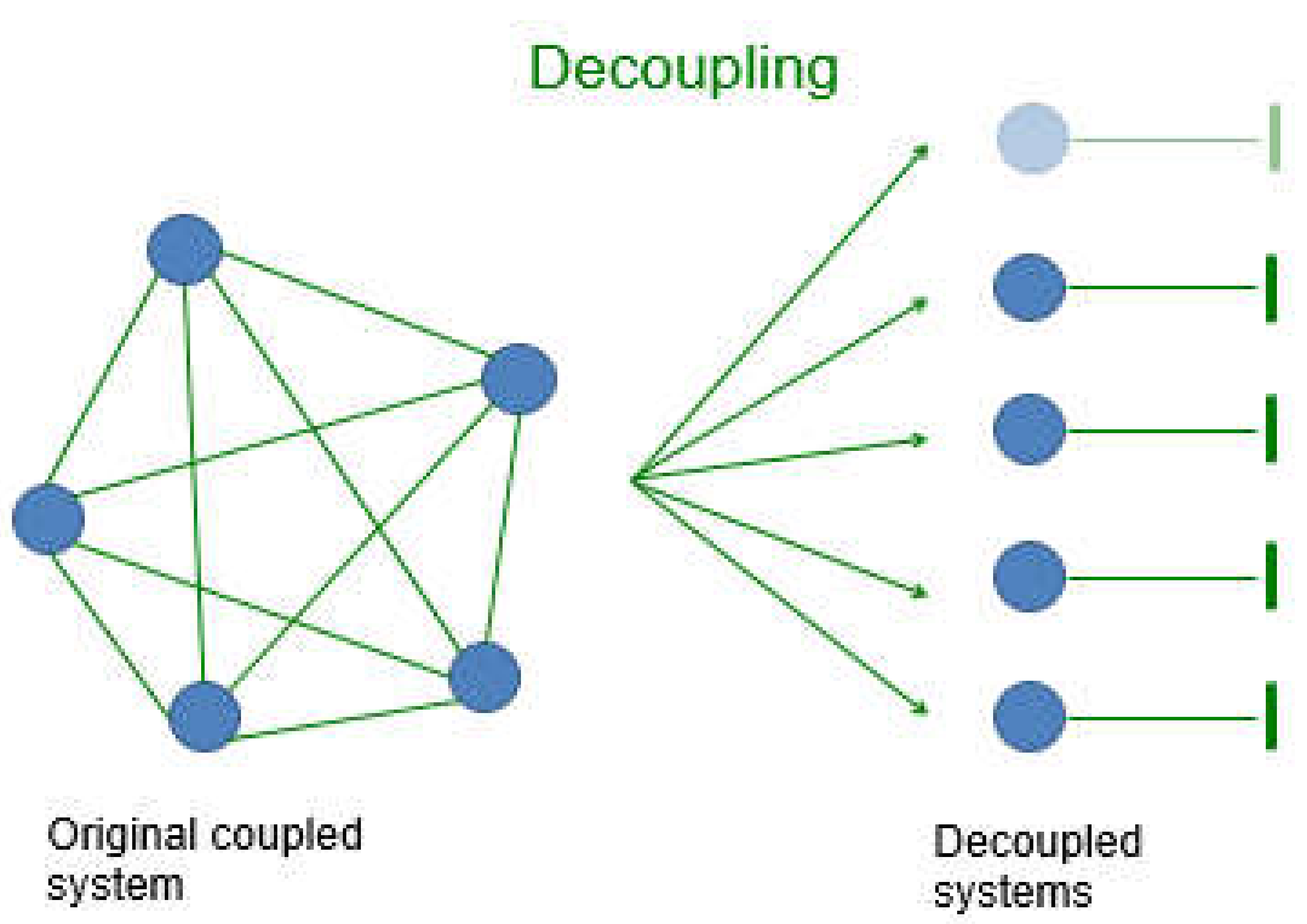
Principle

$$\begin{cases} \ddot{\delta}_1 = \dfrac{\omega_0}{2H_1}\left(P_{M,1} - E_1^2 G_1 - \sum_{j=1, j\neq 1}^{m}(C_{1j}\sin\delta_{1j} + D_{1j}\cos\delta_{1j})\right) \\ \ddot{\delta}_2 = \dfrac{\omega_0}{2H_2}\left(P_{M,2} - E_2^2 G_2 - \sum_{j=1, j\neq 2}^{m}(C_{2j}\sin\delta_{2j} + D_{2j}\cos\delta_{2j})\right) \\ \vdots \\ \ddot{\delta}_m = \dfrac{\omega_0}{2H_m}\left(P_{M,m} - E_m^2 G_m - \sum_{j=1, j\neq m}^{m}(C_{mj}\sin\delta_{mj} + D_{mj}\cos\delta_{mj})\right) \end{cases}$$

$$\ddot{q}_1 + \beta_1(\sin(q_1 + q_{10}) - \sin q_{10}) = 0$$

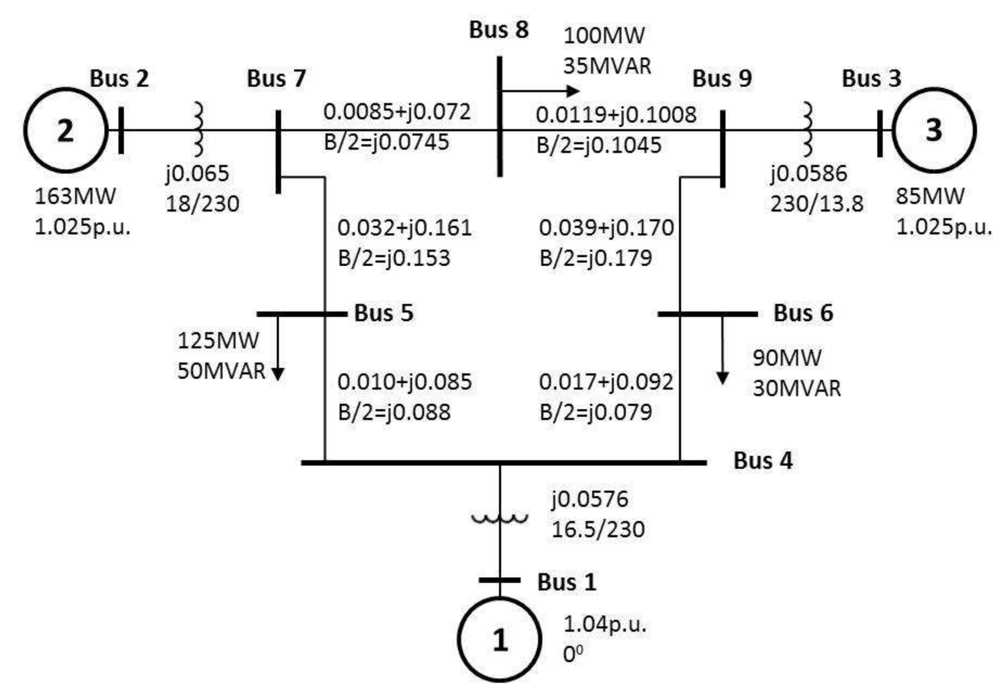
$$\ddot{q}_2 + \beta_2(\sin(q_2 + q_{20}) - \sin q_{20}) = 0$$

$$\ddot{q}_{m-1} + \beta_{m-1}(\sin(q_{m-1} + q_{m-1,0}) - \sin q_{m-1,0}) = 0$$

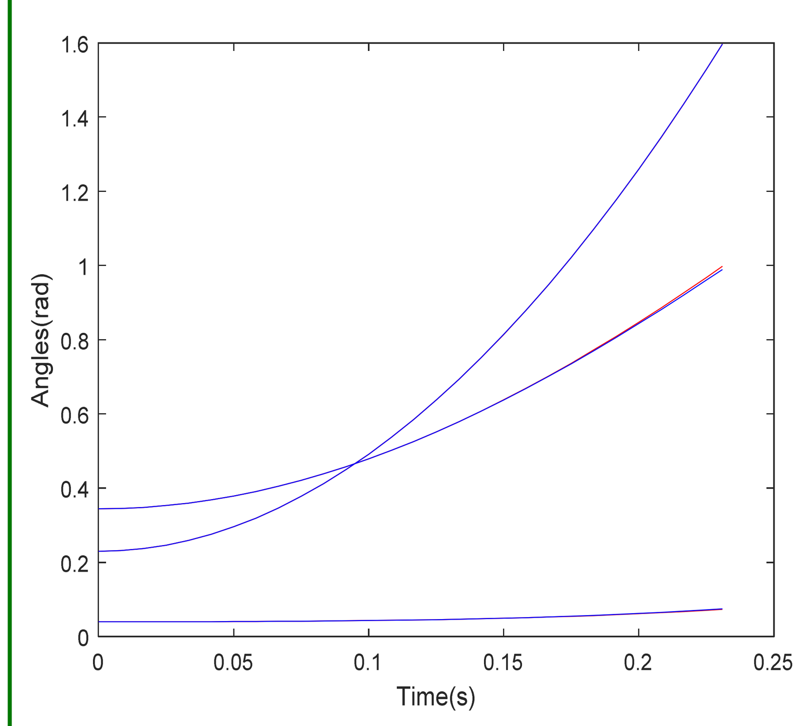


Case Studies

IEEE 3-machine 9-bus system



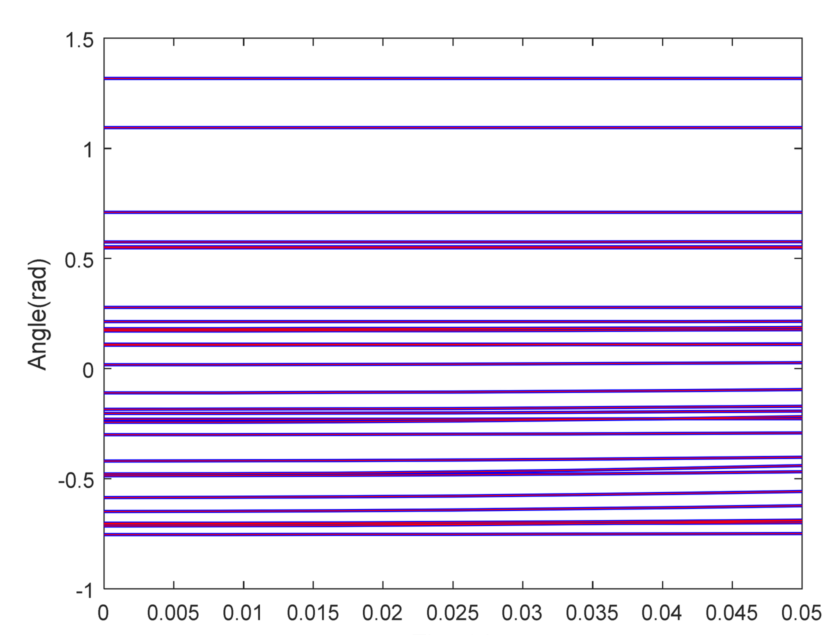
Graph of Time Domain vs. Proposed Method

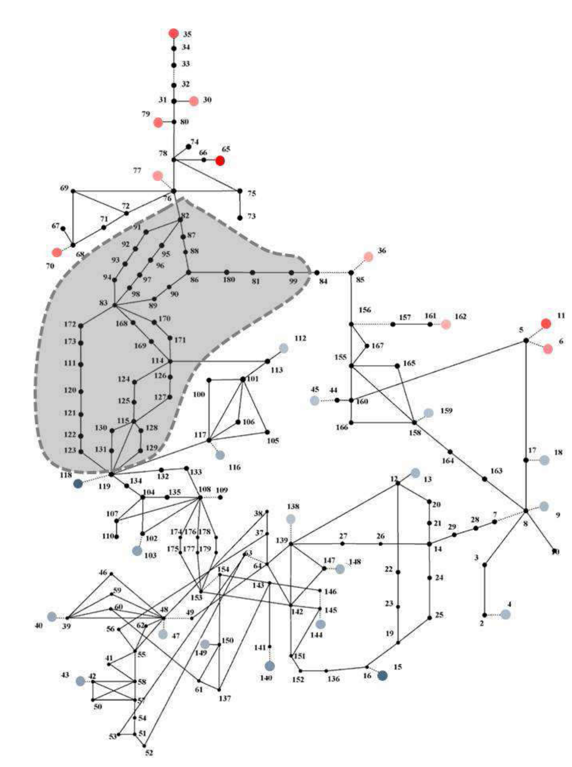


Accuracy Table

CCT	Error Index in Degrees (Fault Duration < CCT)	Error Index in Degrees (Fault Duration = CCT)
.179	0.001203	0.206169
.195	0.001203	0.344572
.231	0.000486	0.491853
.249	0.000486	0.771834
.297	0.001325	4.352642
.324	0.001325	7.209171
.329	0.000270	1.384967
.353	0.000721	6.686693
.430	0.000474	19.936106
.493	0.000474	41.573108

179-bus WECC system





- 20 critical line-tripping contingencies are ranked by DM-II.

Faulted Line	Fault Near Bus	Ranking by ΔV_n	ΔV_n	Ranking by CCT	CCT /s
31-80	80	1	-1.000	3	.0431
24-25	24	2	-0.978	1	.0264
22-23	23	3	-0.789	2	.0348
114-171	171	4	-0.417	4	.0489
115-127	127	5	-0.012	5	.0708
130-131	130	6	1.805	6	.0954
108-133	108	7	5.714	15	.3915
14-21	21	8	5.918	10	.2248
19-25	19	9	14.151	11	.2594
83-172	172	10	15.980	7	.1024
104-135	104	11	16.350	17	.5112
48-55	55	12	16.936	18	.5838
136-152	136	13	19.609	16	.4282
41-58	41	14	29.295	19	.7574
49-64	49	15	33.302	20	1.2278
69-72	69	16	33.541	8	.1376
82-87	82	17	69.042	9	.1784
115-127	115	18	129.190	12	.2857
111-173	173	19	176.947	14	.3756
82-91	91	20	247.318	13	.3154

References

[1] B. Wang, K. Sun and Xiaowen Su, "A decoupling based direct method for power system transient stability analysis," *2015 IEEE PESGM*, Denver, CO, 2015, pp. 1-5.

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