Semi-Analytical Electromagnetic Transient Simulation Using Differential Transformation

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INTRODUCTION

Background: EMT simulation could capture more detailed fast dynamics. However, simulation of a large-scale power system with full EMT models is very time-consuming because of the required tiny time step at μs scale and high system dimension in three-phase frame.

Motivation: To speed up state-space-based EMT simulations, this paper proposes a Differential Transformation based semi-analytical method that repeatedly utilizes a high-order semi-analytical solution of the EMT equations at longer time steps.

Differential Transformation Method

Considering a smooth function *f*(*t*), its k^{th} order DT is defined as:

$$F(k)=\frac{1}{k!}\left[\frac{d^k f(t)}{dt^k}\right]_{t=t0}$$

Also, from the Taylor series, we have:

$$f(t)=\sum_{k=0}^{\infty}F(k)\,(t-t_0)^k$$

Final semi-analytical solution:

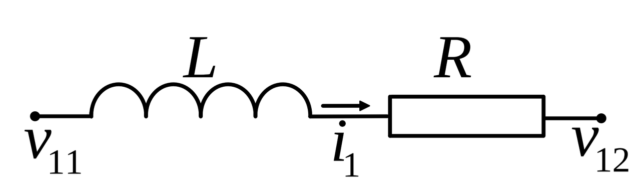
$$f(t)\approx\sum_{k=0}^{i}F(k)\,(t-t_0)^k$$

Table I. Differential Transform Formulae

	Original function	Transformed function
#1	$f(t)=c$, c is constant	$F(k)=c\eta(k),\ \eta(k)=\begin{cases}1 & k=0\\ 0 & k\neq 0\end{cases}$
#2	$f(t)=cg(t)$	$F(k)=cG(k)$
#3	$f(t)=g(t)\pm h(t)$	$F(k)=G(k)\pm H(k)$
#4	$f(t)=g(t)h(t)$	$F(k)=\sum_{m=0}^{k}G(k)H(k-m)$
#5	$f(t)=\frac{dg(t)}{dt}$	$F(k)=(k+1)G(k+1)$
#6	$f(t)=\sin(h(t))$, $g(t)=\cos(h(t))$	$F(k)=\sum_{m=0}^{k-1}\frac{k-m}{k}G(m)H(k-m)$, $G(k)=-\sum_{m=0}^{k-1}\frac{k-m}{k}F(m)H(k-m)$

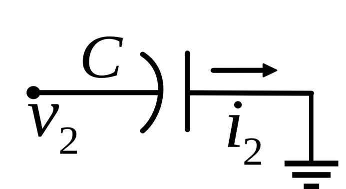
EMT Models

- Voltage-behind-reactance synchronous generator model
- SEXS exciter model
- TGOV1 turbine-governor model
- Pi section represented transmission line model
- Constant *R-L-C* represented load or shunt model



$$\frac{di_1}{dt}=L^{-1}(v_{11}-v_{12}-Ri_1)$$

Fig.1 A serial resistor-inductor circuit



$$\frac{dv_2}{dt}=C^{-1}i_2$$

Fig.2 A grounding capacitance circuit

CASE STUDY

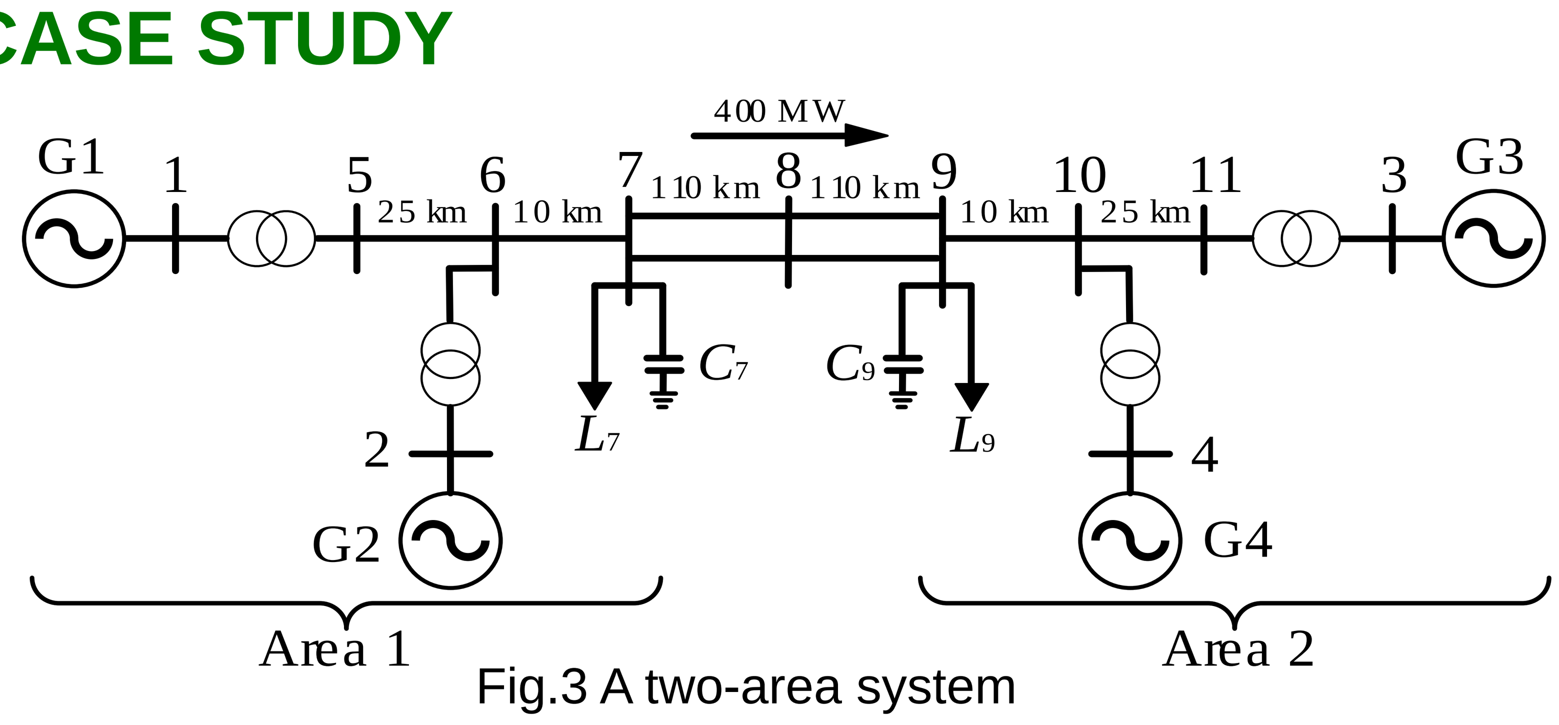


Fig.3 A two-area system

TABLE II. Comparison Between Different Methods

Error (p.u.)	Modified Euler		4th order Runge-Kutta		DT (30th order)		Trapezoidal-rule	
	Time step (μs)	Time cost (s)	Time step (μs)	Time cost (s)	Time step (μs)	Time cost (s)	Time step (μs)	Time cost (s)
10^{-2}	1.0	1045	10	200	330	53	400	92
10^{-3}	0.5	2100	5	360	306	57	400	230
10^{-4}	0.5	4215	3	550	284	62	400	600

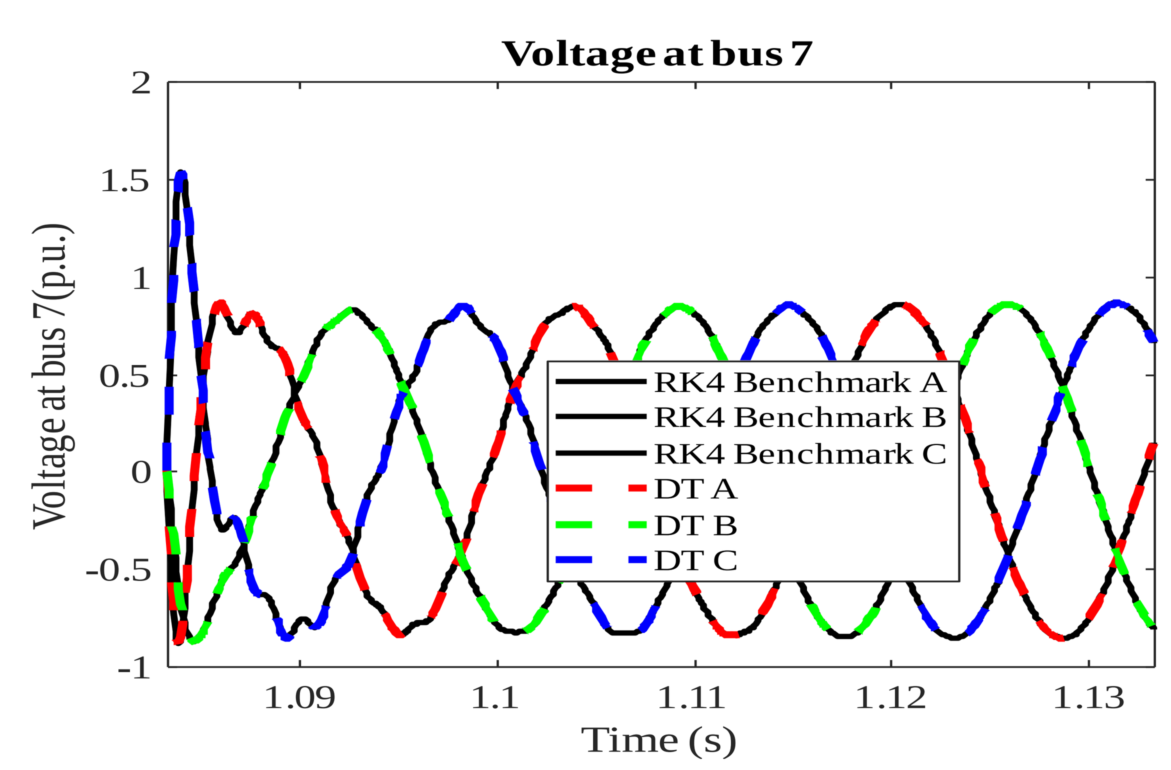


Fig.4 Three-phase voltage at Bus 7

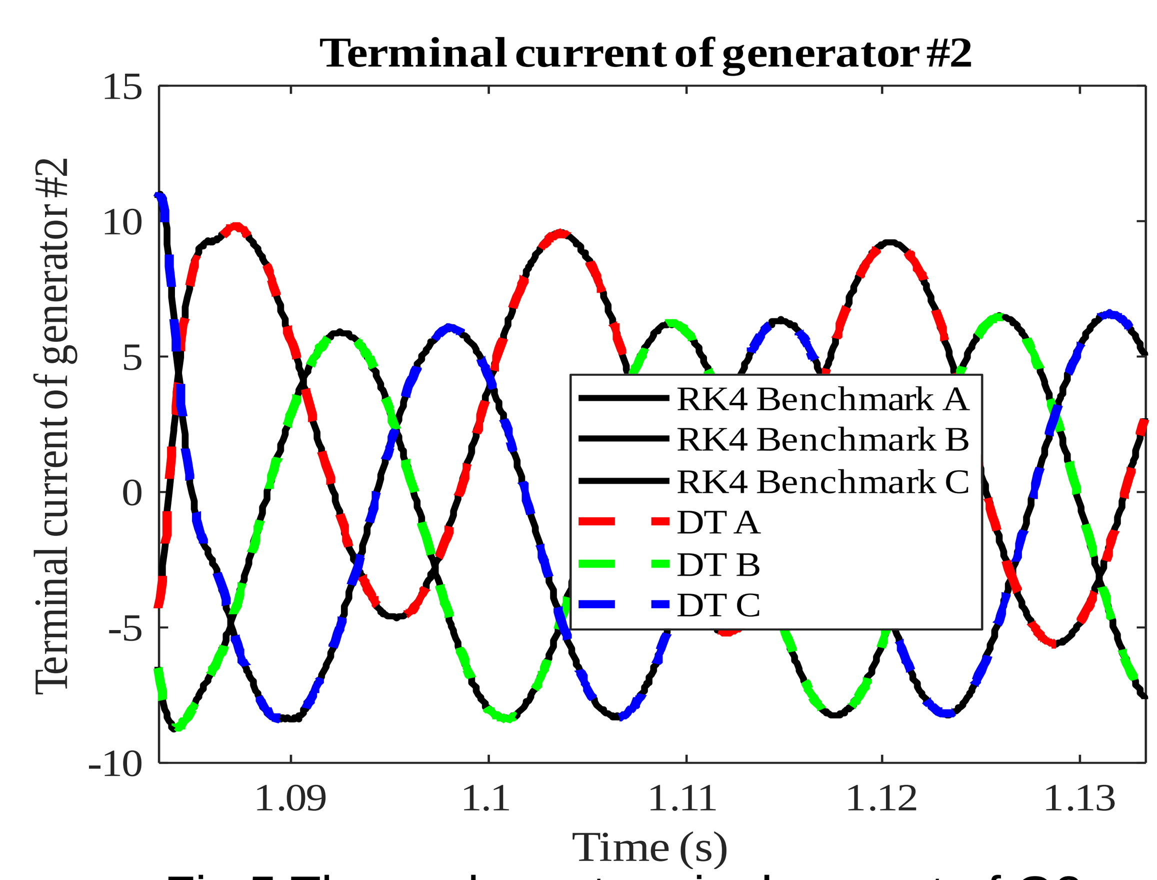


Fig.5 Three-phase terminal current of G2

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