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Evaluating Time Step Effects in Shifted-Frequency Analysis for Converter-Dominated Power Systems

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***Abstract*—Modern power systems are increasingly dominated by power electronic converters, motivating simulation approaches that balance accurate representation of electromagnetic and control dynamics with feasible computational effort. Shifted-Frequency Analysis (SFA) using Dynamic Phasors (DP) provides an approach intermediate between Electromagnetic Transient (EMT) and Root Mean Square (RMS) simulations. This paper analyzes how time step selection affects shifted-frequency resistive companions for linear dynamic elements using the Trapezoidal Rule (TR) and Backward Euler (BE) integration methods. For both TR and BE, small time steps recover the corresponding EMT resistive companions written in DP variables, while large time steps yield the Quasi-Static Phasor (QSP) admittances. The main difference lies in the history current sources: for TR, their vanishing in the large time step limit requires a steady-state phasor assumption, whereas for BE they decay asymptotically for bounded signals. Using the open-source library DPsim, the paper further evaluates how these effects manifest in a non-linear converter-dominated system. In the numerical example, SFA-TR remains closer to the EMT reference at small time steps, whereas SFA-BE introduces numerical damping at RMS-size time steps and approaches the RMS response more closely.**

***Index Terms*—Dynamic phasors, electromagnetic transients, shifted-frequency analysis, power system dynamics.**

I. Introduction

The share of power electronic converters in modern power systems continues to grow. As a result, system dynamics is increasingly influenced by converter control rather than synchronous machine dynamics. Converter control systems operate over wide time scales and can interact with the electrical grid dynamics. This converter-grid coupling can lead to reduced damping of resonant phenomena at harmonic and sub-synchronous frequencies [1]. Representation of the grid dynamics is important for dynamic simulations and stability studies in which converter-grid interactions play a role.

Root Mean Square (RMS) simulation is an approach widely used for large-scale power system dynamic simulations. In RMS simulation, the electrical network is represented in the Quasi-Static Phasor (QSP) domain using complex algebraic equations, which neglect fast electromagnetic dynamics and not capture electromagnetic resonances of the network. Electromagnetic Transient (EMT) simulations, by contrast, represent electromagnetic dynamics in the time domain and are capable of capturing converter-grid interactions, but require small time steps, leading to high computational effort and limited suitability for long-term or large-scale simulations. These limitations motivate the exploration of alternative simulation approaches such as Shifted-Frequency Analysis (SFA), in which the electrical network is represented in the shifted-frequency domain using Dynamic Phasor (DP) variables.

DPs were introduced for modeling of power electronic circuits in [2] and later applied systematically in Nodal Analysis (NA) of electrical networks in [3]. The University of British Columbia group developed the theory behind SFA and derived machine models using DP variables [4], [5]. More recently, DPs have been applied to simulation and stability analysis of converter-dominated power systems: [6] evaluates the applicability of DP versus QSP calculus for stability analysis and reports limitations of QSP, while [7] compares EMT and DP simulations and shows computational benefits of DP when larger time steps are used. Prior work on DPs and SFA quantifies time step effects through numerical accuracy analyses that relate discretization error to integration step size, integration method, and signal bandwidth (frequency deviation) around the fundamental [3]–[5].

In this paper, we complement this perspective by analyzing how the simulation time step and the numerical integration method affect shifted-frequency resistive companions and consequently SFA simulation results. The main contributions are:

1) Evaluate analytically how shifted-frequency resistive companions obtained with Trapezoidal Rule (TR) and Backward Euler (BE) transition from EMT resistive companions to QSP admittances as the time step increases, and identify the difference in large time step limit for their history current sources.
2) Introduce and apply a relative-contribution metric for the EMT and QSP terms in the shifted-frequency capacitor admittance, showing that within the typical RMS-size time step range the admittance still retains a non-negligible EMT-related contribution.
3) Demonstrate with a simulation example of a load-step event in a non-linear converter-dominated system that these analytical findings remain relevant in simulation, and show the resulting practical tradeoff: SFA-TR remains closer to the EMT-TR reference at small time steps, whereas SFA-BE provides additional numerical damping and follows the RMS response more closely at large time steps.

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TABLE I: Electrical network equations in modeling domains

Domain	EMT	QSP	Shifted-Frequency
Variable	$x(t)$	$\langle x\rangle(t)$	$\langle x\rangle(t)$
Derivative	$\frac{\mathrm{d}x(t)}{\mathrm{d}t}$	$\left\langle \frac{\mathrm{d}x(t)}{\mathrm{d}t} \right\rangle \approx \mathrm{j}\omega\langle x\rangle(t)$	$\left\langle \frac{\mathrm{d}x(t)}{\mathrm{d}t} \right\rangle = \frac{\mathrm{d}\langle x\rangle(t)}{\mathrm{d}t} + \mathrm{j}\omega\langle x\rangle(t)$
Inductor	$v(t) = L\frac{\mathrm{d}i(t)}{\mathrm{d}t}$	$\langle v\rangle(t) \approx \mathrm{j}\omega L\langle i\rangle(t)$	$\langle v\rangle(t) = L\left(\frac{\mathrm{d}\langle i\rangle(t)}{\mathrm{d}t} + \mathrm{j}\omega\langle i\rangle(t)\right)$
Capacitor	$i(t) = C\frac{\mathrm{d}v(t)}{\mathrm{d}t}$	$\langle i\rangle(t) \approx \mathrm{j}\omega C\langle v\rangle(t)$	$\langle i\rangle(t) = C\left(\frac{\mathrm{d}\langle v\rangle(t)}{\mathrm{d}t} + \mathrm{j}\omega\langle v\rangle(t)\right)$

For reproducibility, all simulations are carried out using the open-source modeling and simulation library DPsim [8].

II. Modeling Domains

Converter-dominated power systems can be simulated using different approaches, each relying on specific assumptions regarding time-scale separation, signal representation, and model fidelity. Although the terminology used across the literature [2]–[8] varies, throughout this paper we use the term *modeling domain* to distinguish the mathematical representation of the electrical network, namely the *EMT time domain* used in EMT simulation, the *QSP domain* used in RMS simulation, and the *shifted-frequency domain* used in SFA simulation. In DPsim, these are referred to as the EMT, SP, and DP domains, respectively [8].

In the EMT time domain, voltages and currents are represented as instantaneous real-valued quantities, enabling explicit representation of electromagnetic transients, fast network interactions, and converter control dynamics. However, EMT simulations require very small time steps, typically in the microsecond range, and commonly represent the full three-phase network, leading to large system dimensionality. As a result, computational effort increases rapidly with system size and simulation duration, limiting EMT applicability to small or medium-sized systems or short time horizons.

In RMS simulation, electrical quantities are represented in the QSP domain using complex-valued fundamental-frequency phasors under a quasi steady-state assumption, neglecting fast electromagnetic transients. Although complex variables increase the number of real-valued equations, RMS models typically represent only the positive-sequence network, resulting in a substantially smaller system than three-phase EMT models. Together with millisecond-range time steps, this yields excellent computational efficiency and scalability, at the expense of reduced fidelity and the inability to capture fast converter-grid interactions and harmonic dynamics.

The shifted-frequency domain provides an intermediate representation. In this paper, we adopt the SFA approach of [4], in which the network dynamic equations are formulated and solved in terms of complex variables with shifted frequency spectrum. Beyond this specific formulation, there exists a broader family of DP approaches that represent electrical quantities by time-varying Fourier coefficients and may include multiple DP components [2], [3].

The differences between the EMT, QSP and shifted-frequency domains for electrical network equations are summarized in Table I. In the QSP and shifted-frequency columns,

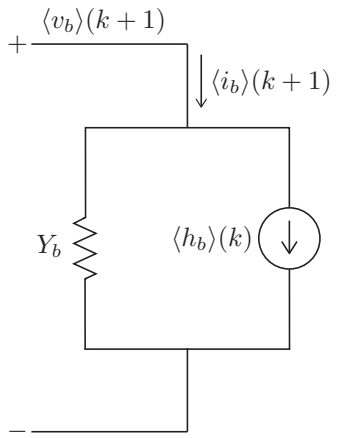


Fig. 1: Shifted-frequency resistive companion.

$\langle x\rangle(t)$ denotes the complex variable obtained by shifting the spectrum of the analytic signal by the angular frequency ω. In this paper, we refer to this variable as a DP variable in the context of the shifted-frequency domain. The difference between QSP and shifted-frequency domains lies in the modeling assumption: in the QSP domain the term $\frac{d\langle x\rangle(t)}{dt}$ is neglected, whereas in the shifted-frequency domain it is retained. For simulation, the differential equations in the EMT and shifted-frequency domains must be discretized in time. A widely used class of solution methods for this purpose is resistive companion nodal methods [9]. This group of methods applies numerical integration to replace dynamic components such as inductors and capacitors by resistive companions, so that the network can be solved using NA or Modified Nodal Analysis (MNA) at each time step.

III. Time Step Dependent Transition of Shifted-Frequency Resistive Companions

The shifted-frequency resistive companions for inductors and capacitors are Norton equivalent circuits consisting of a complex admittance and a history current source, as shown in Fig. 1. In this section, we compare how the time step size affects these resistive companions for two common implicit numerical integration methods: TR and BE. The notation in Fig. 1 and the resistive companion equations follow [10]. The index k denotes the discrete simulation time step. For a dynamic branch b, the shifted-frequency resistive companion is written in the generic form

$$\langle i_b\rangle(k{+}1) = Y_b\,\langle v_b\rangle(k{+}1) + \langle h_b\rangle(k), \tag{1}$$

where Y_b is the resistive companion admittance and $\langle h_b\rangle(k)$ is the history source determined from quantities at the previous time step. In the following, $b \in \{L, C\}$ denotes an inductor or capacitor branch.

Using the TR, the shifted-frequency companion admittances are

$$Y_L^{\mathrm{TR}} = \frac{\Delta t}{2L}\left(1 + \frac{j\omega\Delta t}{2}\right)^{-1}, \tag{2}$$

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$$Y_C^{\mathrm{TR}} = \frac{2C}{\Delta t}\left(1 + \frac{j\omega\Delta t}{2}\right). \tag{3}$$

The corresponding history sources are

$$\langle h_L^{\mathrm{TR}}\rangle(k) = Y_L^{\mathrm{TR}}\,\langle v_L\rangle(k) + \alpha\,\langle i_L\rangle(k), \tag{4}$$

$$\langle h_C^{\mathrm{TR}}\rangle(k) = -\alpha\,Y_C^{\mathrm{TR}}\,\langle v_C\rangle(k) - \langle i_C\rangle(k), \tag{5}$$

with

$$\alpha = \frac{1 - \frac{j\omega\Delta t}{2}}{1 + \frac{j\omega\Delta t}{2}}. \tag{6}$$

Using BE, the shifted-frequency companion admittances are

$$Y_L^{\mathrm{BE}} = \frac{\Delta t}{L}\left(1 + j\omega\Delta t\right)^{-1}, \tag{7}$$

$$Y_C^{\mathrm{BE}} = \frac{C}{\Delta t}\left(1 + j\omega\Delta t\right), \tag{8}$$

and the corresponding history sources are

$$\langle h_L^{\mathrm{BE}}\rangle(k) = \left(1 + j\omega\Delta t\right)^{-1}\langle i_L\rangle(k), \tag{9}$$

$$\langle h_C^{\mathrm{BE}}\rangle(k) = -\frac{C}{\Delta t}\,\langle v_C\rangle(k). \tag{10}$$

For brevity, the time step index k is omitted below, as all quantities in the history current source expressions are evaluated at the same simulation time step.

Small time steps (transition to EMT): For sufficiently small time steps, such that $\omega\Delta t \ll 1$, the approximations hold:

$$1 + \frac{j\omega\Delta t}{2} \approx 1, \qquad 1 + j\omega\Delta t \approx 1. \tag{11}$$

For TR, substituting (11) into (2) and (3) yields

$$Y_L^{\mathrm{TR}} \approx \frac{\Delta t}{2L}, \qquad Y_C^{\mathrm{TR}} \approx \frac{2C}{\Delta t}, \tag{12}$$

while $\alpha \approx 1$ and the history current sources reduce to

$$\langle h_L^{\mathrm{TR}}\rangle \approx \frac{\Delta t}{2L}\,\langle v_L\rangle + \langle i_L\rangle, \tag{13}$$

$$\langle h_C^{\mathrm{TR}}\rangle \approx -\frac{2C}{\Delta t}\,\langle v_C\rangle - \langle i_C\rangle. \tag{14}$$

These expressions correspond to the EMT-TR resistive companions, but written with DP variables.

For BE, substituting (11) into (7) and (8) yields

$$Y_L^{\mathrm{BE}} \approx \frac{\Delta t}{L}, \qquad Y_C^{\mathrm{BE}} \approx \frac{C}{\Delta t}, \tag{15}$$

and the history current sources are

$$\langle h_L^{\mathrm{BE}}\rangle \approx \langle i_L\rangle, \qquad \langle h_C^{\mathrm{BE}}\rangle = -\frac{C}{\Delta t}\,\langle v_C\rangle. \tag{16}$$

These expressions correspond to the standard EMT-BE resistive companions, but written with DP variables.

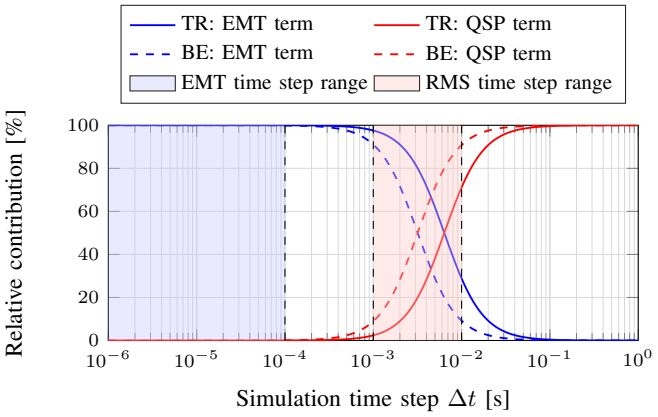


Fig. 2: Contribution of EMT and QSP terms to admittance of capacitor's shifted-frequency resistive companion.

Large time steps (transition to QSP): For sufficiently large time steps, such that $\omega\Delta t \gg 1$, the dominant-term approximations hold:

$$1 + \frac{j\omega\Delta t}{2} \approx \frac{j\omega\Delta t}{2}, \qquad 1 + j\omega\Delta t \approx j\omega\Delta t. \tag{17}$$

For TR, this leads to

$$Y_L^{\mathrm{TR}} \approx \frac{1}{j\omega L}, \qquad Y_C^{\mathrm{TR}} \approx j\omega C. \tag{18}$$

In this case, $\alpha \approx -1$, and under steady-state phasor conditions where $\langle i_L\rangle = Y_L^{\mathrm{TR}}\langle v_L\rangle$ and $\langle i_C\rangle = Y_C^{\mathrm{TR}}\langle v_C\rangle$, the history current sources vanish:

$$\langle h_L^{\mathrm{TR}}\rangle \approx 0, \qquad \langle h_C^{\mathrm{TR}}\rangle \approx 0. \tag{19}$$

For BE, the same asymptotic admittance limits are obtained:

$$Y_L^{\mathrm{BE}} \approx \frac{1}{j\omega L}, \qquad Y_C^{\mathrm{BE}} \approx j\omega C. \tag{20}$$

However, in contrast to the TR case, the BE history current sources decrease in magnitude as Δt increases:

$$\left|\langle h_L^{\mathrm{BE}}\rangle\right| = \left|\left(1 + j\omega\Delta t\right)^{-1}\right| \cdot \left|\langle i_L\rangle\right| \approx \frac{1}{\omega\Delta t}\,\left|\langle i_L\rangle\right|, \tag{21}$$

$$\left|\langle h_C^{\mathrm{BE}}\rangle\right| = \left|\frac{C}{\Delta t}\right| \cdot \left|\langle v_C\rangle\right|. \tag{22}$$

Thus, for bounded voltages and currents, $\langle h_L^{\mathrm{BE}}\rangle \to 0$ and $\langle h_C^{\mathrm{BE}}\rangle \to 0$ as $\Delta t \to \infty$, without requiring a steady-state phasor relationship between $\langle v\rangle$ and $\langle i\rangle$.

Admittance transition: Fig. 2 illustrates the EMT-to-QSP transition for the capacitor admittance. Rearranging (3) and (8), gives:

$$Y_C^{\mathrm{TR}} = \frac{2C}{\Delta t} + j\omega C, \qquad Y_C^{\mathrm{BE}} = \frac{C}{\Delta t} + j\omega C. \tag{23}$$

In both cases, the admittance consists of an EMT term proportional to $C/\Delta t$ and a QSP term $j\omega C$. Since these two

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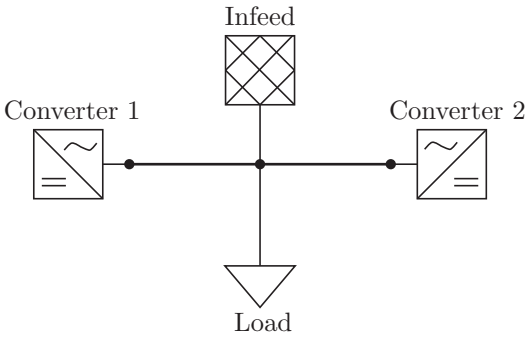


Fig. 3: Power system topology.

terms are orthogonal in the complex plane, the plotted relative contributions are computed from their squared magnitudes as:

$$\eta^{m}_{\mathrm{EMT}}(\Delta t) = \frac{\left|\frac{a_m C}{\Delta t}\right|^2}{\left|\frac{a_m C}{\Delta t}\right|^2 + |j\omega C|^2} \cdot 100\%, \tag{24}$$

$$\eta^{m}_{\mathrm{SP}}(\Delta t) = \frac{|j\omega C|^2}{\left|\frac{a_m C}{\Delta t}\right|^2 + |j\omega C|^2} \cdot 100\%, \tag{25}$$

where $m \in \{\mathrm{TR}, \mathrm{BE}\}$, with $a_{\mathrm{TR}} = 2$ and $a_{\mathrm{BE}} = 1$. The results are shown over a wide range of Δt, including typical EMT- and RMS-size ranges.

Interpretation: The time step dependent transition of shifted-frequency resistive companions between EMT and QSP depends on the applied numerical integration method. For both TR and BE, small time steps recover the corresponding EMT resistive companions with DP variables, while large time steps yield the QSP admittances $1/(j\omega L)$ and $j\omega C$. The difference lies in the history current sources. For TR the history terms vanish in the large Δt limit only under a steady-state phasor assumption, whereas for BE they decrease inversely with Δt and vanish asymptotically for bounded signals even outside steady state. According to the adopted admittance transition metric, the shifted-frequency admittance within the typical RMS-size time step range still retains a non-negligible EMT term contribution and therefore does not yet fully converge to the QSP admittance.

IV. Numerical Evaluation in a Non-Linear Converter-Dominated System

The purpose of the numerical examples is to assess to what extent the analytically derived transition of the shifted-frequency resistive companions between the EMT and QSP domains extends to SFA simulations of non-linear, converter-dominated power systems. Simulations are performed using DPsim version 1.2.1.

A. Test System

The investigated power system, based on the topology presented in [11] and shown in Fig. 3, consists of two converter stations connected via transmission lines to an infeed and a load. The infeed is modeled as a Thevenin equivalent representing connection to a system with large (infinite) inertia.

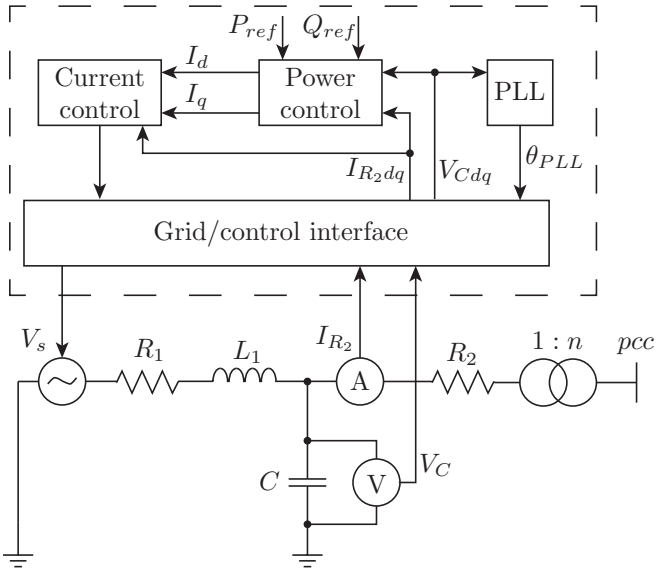


Fig. 4: Converter model.

This representation provides a voltage and frequency reference and intentionally excludes electromechanical swing dynamics. The load is modeled as a passive resistive element with time-varying resistance to enable step changes. Transmission lines are represented by π-equivalent circuits. Converters are modeled using average-value converter models with grid-following control, including electrical circuits, control systems, and interface blocks, as illustrated in Fig. 4. Grid-following control relies on a Phase-Locked Loop (PLL) for synchronization. In the present DPsim implementation, a single global simulation time step is used for both the electrical network equations and the converter control equations. The grid/control interface supplies the control system with the grid voltages and currents from the previous solution step of the electrical network equations, introducing one time step delay.

The power system is implemented in three modeling domains: (i) EMT (three-phase), (ii) QSP (single-phase SP in DPsim), and (iii) shifted-frequency (single-phase DP in DPsim). A single-phase shifted-frequency formulation is selected because DPsim version 1.2.1 provides a complete set of component models in this domain only in this formulation. Consequently, the shifted-frequency equation system size is smaller than in a three-phase formulation, reducing computational effort, but the model is restricted to balanced, positive-sequence behavior and does not capture phase asymmetries or mutual coupling. Across all three modeling domains, the same component types (e.g., π-equivalent lines) and the same converter control architecture and parameters are used, ensuring that observed differences originate from the modeling domain and time step rather than from differences in component selection or control design. In DPsim, the EMT and shifted-frequency domain resistive companions use TR. To obtain the SFA-BE results reported below, we modified the DPsim source code of the shifted-frequency inductor and capacitor models according to (7), (8), (9) and (10).

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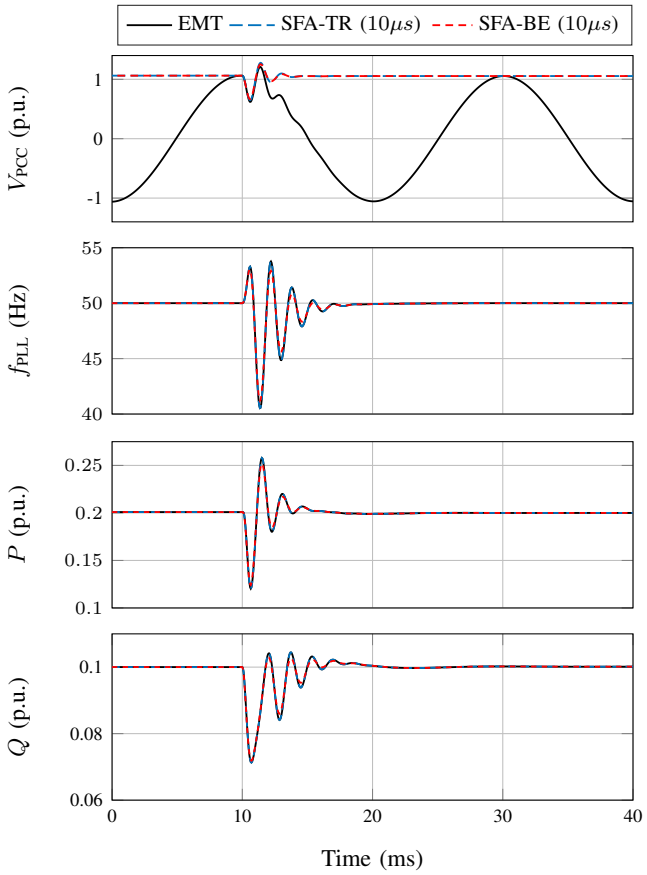


Fig. 5: Results of simulation with EMT-size time step ($\Delta t = 10$ μs).

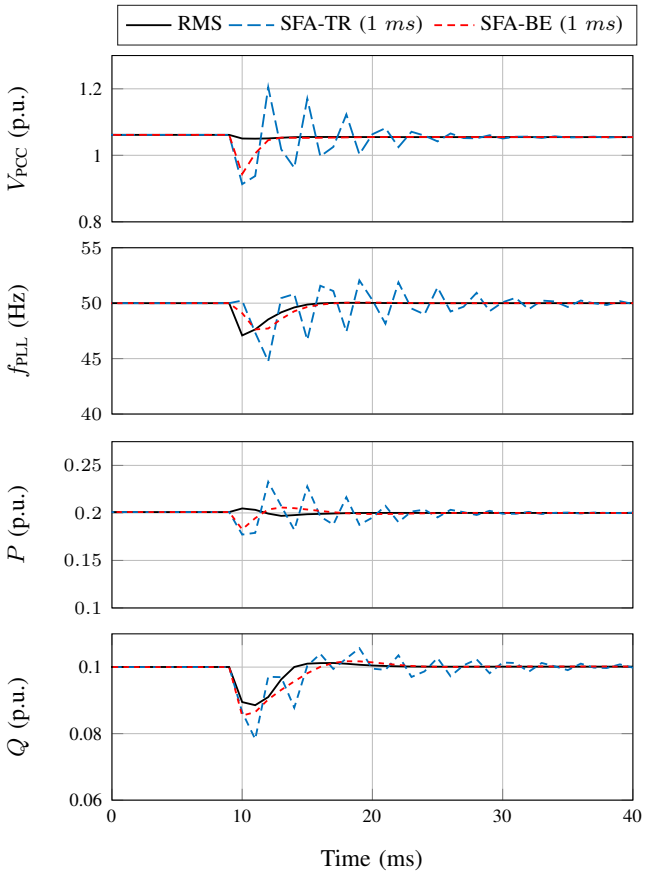


Fig. 6: Results of simulation with RMS-size time step ($\Delta t = 1$ ms).

TABLE II: RMSE and maximum absolute deviation of converter 1 variables for SFA simulations against reference

Simulation	f_{PLL} (Hz)		P (p.u.)		Q (p.u.)	
	RMSE	Max. dev.	RMSE	Max. dev.	RMSE	Max. dev.
Reference: EMT from Fig. 5						
SFA-TR (10 μs)	5.77e-04	3.90e-03	3.53e-06	1.67e-05	9.22e-06	2.02e-05
SFA-BE (10 μs)	1.60e-01	8.44e-01	9.09e-04	5.82e-03	3.63e-04	1.91e-03
Reference: RMS from Fig. 6						
SFA-TR (1 ms)	1.26e+00	3.78e+00	1.05e-02	3.34e-02	3.11e-03	1.22e-02
SFA-BE (1 ms)	3.59e-01	2.01e+00	4.28e-03	2.20e-02	1.24e-03	4.32e-03

B. SFA with EMT- and RMS-size Time Steps

Two simulation cases are considered. In the first case, the SFA simulations use an EMT-size time step of $\Delta t = 10$ μs and are compared against the EMT reference obtained with the same time step. The EMT reference considered here uses TR, which is a standard choice of integration method for EMT simulation. Therefore, it is not a method-independent analytical reference, but a practical reference for assessing how SFA converges to a standard EMT simulation as Δt decreases. In the second case, the SFA simulations use an RMS-size time step of $\Delta t = 1$ ms and are compared against the RMS simulation obtained with the same time step. In both cases, the system is subjected to the same load-step disturbance at $t = 10$ ms, in which the load is increased from 0.5 p.u. to 1.0 p.u. The simulation results in Fig. 5 and Fig. 6 show the converter 1 Point of Common Coupling (PCC) voltage V_{PCC} (phase A is shown for EMT), PLL frequency f_{PLL}, the converter active power P and reactive power Q calculated from the logged converter control's dq voltages and currents. Table II summarizes the corresponding Root Mean Square Error (RMSE) and maximum absolute deviation (max. dev.) metrics for SFA simulation results against EMT and RMS references.

Fig. 5 shows that, for an EMT-size time step, both SFA-TR and SFA-BE simulations reproduce the EMT response closely. This is consistent with the analytical result that, for sufficiently small time steps, the shifted-frequency resistive companions recover the corresponding EMT resistive companion with DP variables. At the same time, the metrics in Table II indicate that the SFA-TR remains closer to the EMT-TR reference.

Fig. 6 shows that, for an RMS-size time step, the SFA simulations do not fully converge to the RMS response during the transient, but reach the same steady-state point. In particular, the SFA-TR in Fig. 6 exhibits oscillations with reduced damping and lower frequency than the response in Fig. 5. These oscillations can be interpreted as numerically distorted transients, which is consistent with the tendency of TR to produce numerical oscillations near discontinuities

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TABLE III: Execution time comparison (per unit)

Simulation	EMT	SFA-TR	RMS
Network phases	3	1	1
System size	75	50	50
$\Delta t = 1$ ms	–	1.00	0.80
$\Delta t = 10$ μs	176.94	97.98	79.19

in EMT simulations, while BE suppresses such oscillations through numerical damping [12]. This is also reflected in the SFA-BE response, which does not include oscillations and approaches the RMS response more closely than the SFA-TR, according to the metrics in Table II. These observations are consistent with the analytical results of Section III. First, for time steps in the RMS range, the shifted-frequency admittance still retains a non-negligible EMT-related contribution. Second, in the SFA-BE the dynamic memory of history current sources is suppressed with increasing Δt.

C. Execution Time Comparison

The power system is simulated for one second of system time using EMT- and RMS-size time steps. Table III reports the execution time, normalized in per unit to the SFA-TR case with $\Delta t = 1$ ms, together with the dimensions of the network equation systems solved by the MNA solver. Each reported execution time is the average of five executions of the same simulation. Converter control equations in DPsim are solved outside the MNA solver, hence the reported system size refers only to the electrical network, while the execution time also includes the control computations. All simulations are performed with the same solver, numerical libraries, and hardware.

For the same time step, the single-phase SFA-TR is faster than the EMT mainly because the system size is smaller. In this example, shifted-frequency equations and QSP network equations of RMS simulation are solved for a single phase with complex variables, whereas EMT is solved for three phases with real variables, resulting in two-thirds of the EMT network dimension in this example. RMS remains slightly faster than SFA-TR because SFA additionally evaluates history terms. A full three-phase SFA formulation would increase the system size and would therefore rely on larger time steps to achieve a computational advantage over EMT.

V. Conclusions

This paper examines how simulation time step and numerical integration method affect shifted-frequency resistive companions. It is shown that the time step dependent transition of shifted-frequency resistive companions between EMT and QSP in the large Δt-limit depends on the applied numerical integration method. The adopted relative contribution metric for admittance transition further demonstrates that the shifted-frequency admittance of a resistive companion using TR or BE does not yet fully converge to the QSP admittance within the typical RMS-size time step range.

In the numerical simulation example at an EMT-size time step, both SFA-TR and SFA-BE reproduce the EMT reference closely. At an RMS-size time step, SFA-TR exhibits oscillations with reduced damping and lower frequency. At large time steps SFA-BE damps these oscillations and follows the RMS response more closely. However, SFA-BE does not provide a universal replacement for SFA-TR because at small time steps it deviates from the EMT reference more. Thus, SFA-TR is preferable when fidelity to the EMT reference at small time steps is the main objective, while SFA-BE is advantageous when additional numerical damping is needed at larger time steps. Two practical directions for further development of SFA in tools such as DPsim follow from these observations: (i) time step adaptation, in which smaller time steps are used during and shortly after discontinuities, and (ii) the exploration of integration methods that better balance accuracy at small time steps with numerical damping at larger time steps.

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