Practical solutions of numerical noise problems at simulation of switching transients to ship electric power systems

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Abstract

Simulation of switching transients in electric energy systems requires accurate modeling of most of the components involved. The problems are studied via dedicated computer programs like the well-known EMTP which provide the extra option to synthesize associated user-defined models. In this paper, this capability of EMTP is exploited so that a representative ship electric propulsion scheme is modeled while the interest is focused on the elimination of numerical noise problems emerged during the simulations.

Keywords: Power Systems Transients, EMTP, Numerical Analysis, Numerical Noise

1. Introduction

Although electric power has been introduced on shipboard since the beginning of 20th century, nowadays, the advent of All Electric Ship (AES) concept, i.e. the complete electrification of any major or minor system, is regarded as the inevitable challenge towards increased flexibility, manoeuvrability and machinery efficiency [1-5]. Similarly to all power grids, several studies have to be performed for the electric energy system of a ship amongst the most significant of which is the electromagnetic transient analysis, like switching transients or power quality analysis.

The common method followed by all computer programs, is initially to construct the network conductance matrix, i.e. a mapping of the topology with the electric circuit component numerical figures. Then a set of algebraic-differential equations involving state-variables **x**, inputs **u** and outputs **y** is formed, with its linear version being [6]:

$$\frac{d}{dt}\underline{x} = A.\underline{x} + B.\underline{u} \qquad (1)$$

$$\underline{y} = C.\underline{x} + D.\underline{u} \qquad (2)$$

However, the set of equations (1) and (2) are most often non-linear and can be formed as follows:

$$\frac{d}{dt}(A_1\underline{x}) = A_2.\underline{x} + B.\underline{u} \qquad (3)$$

$$\underline{y} = C(\underline{x}) + D.\underline{u} \qquad (4)$$

The solution method of equations (3)-(4) varies in general, consisting in numerical integrations at discrete time steps in conjunction with iterative solutions of non-linear algebraic equations [6,7]. The most popular, reliable and accurate algorithm is the one based on simple trapezoidal integration in conjunction with predictor-corrector iterations, as applied to the well-known Electromagnetic Transients Program (EMTP). In the case of ship electric propulsion schemes, the set of equations (3) and (4) is proven to be stiff [8], urging for either introduction of variable-step integration methods or usage of extremely small integration steps. However, the former can not be directly adopted to any EMTP platform, while the latter can result in the production of numerical noise. This paper moves towards investigating a compromise between the two aforementioned alternatives taking advantage of the user interface capabilities offered by EMTP. As a study case, a pilot propulsion unit comprising a three-phase asynchronous motor driven by a power electronics converter is considered.

2. Modeling in EMTP-MODELS

Although an extended number of mathematical models for almost all power system components has been developed such as transmission lines and cables, machines, transformers, circuit breakers and controlled switches, controller modules, several elements related to ship propulsion have not been developed or integrated yet [8]. Thus, no power converter models are readily available but they have to be composed piece-by-piece via controlled switches, whereas the universal machine models developed, though fairly flexible, they have not covered yet the recently developed motors used for ship electric propulsion like the transverse or axial flux ones.

On the other hand, the user can synthesize arbitrarily defined models (sources or components) via a programming language environment called MODELS [7]. More specifically, referring to MODELS-driven component called ''94-type element'', the user defines the arbitrary voltage-current relationship of a multi-terminal element which communicates with the rest of the system comprising ''conventional'' models. The integration step of this element can be set by the user in a rather independent way of the rest of the system modeled, therefore it can be limited by constant upper or lower limits or it can even be variable dynamically set. Similarly, referring to MODELS driven source models, 60-type source is a non-linear voltage or current source the output of which is define via programming in MODELS. Taking advantage of this option an alternative modeling approach has been initiated according to which, all power components with models non-available in EMTP or even non-reliable can be modeled via MODELS[8], see Fig. 1.
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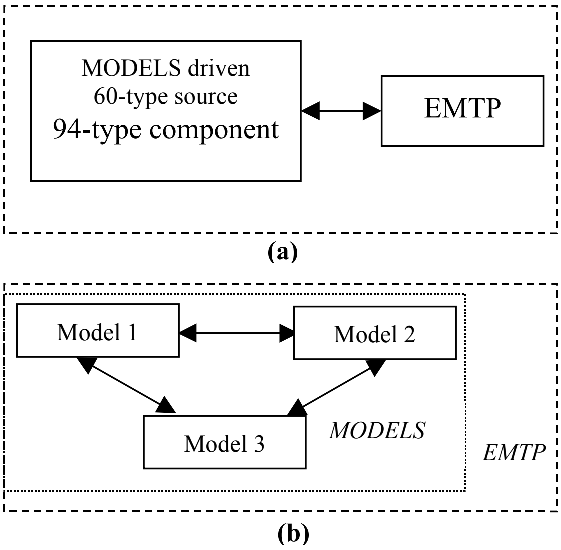
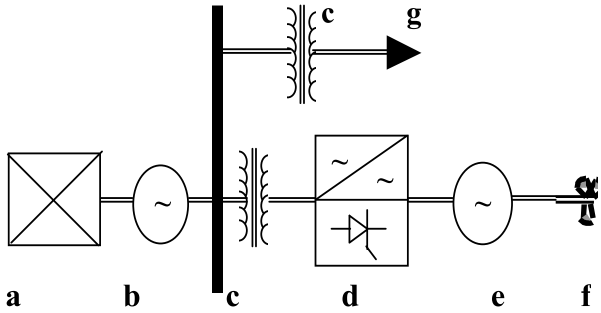


Figure 1. Alternative approach of EMTP simulations
- **(a)** Some components are modeled via MODELS
- **(b)** All components are modeled via MODELS

Moreover, in case of contradictory integration steps between two or more elements due to e.g. stiffness, all these ''problematic'' components can be modeled via separate models, each one of which is integrated at a different time-step.

3. Modelling Ship Electric Propulsion schemes in EMTP

A typical ship electric network serving both propulsion and other auxiliary demands is depicted in Figure 2, where in the case of electric propulsion, the set of propulsion motors is the greatest portion of total electric load.



- **a.** prime mover (Diesel engine or Natural Gas/COGEN)
- **b.** synchronous generator
- **c.** power transformer
- **d.** motor drive (frequency converter, PWM or cyclo-converter)
- **e.** propulsion motor (inductive)
- **f.** propeller
- **g.** other power load demands (pumps, compressors, winches, lighting, auxiliaries)

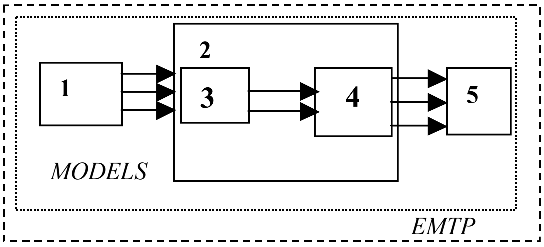
Figure 2. Typical ship electric network

Modeling in MODELS environment has been primarily chosen due to the aforementioned lack of propulsion motor models. Thus, as in EMTP there are not available any models developed for permanent magnet, multi-phase non-conventional flux machines used for propulsion, they can not be modeled but via MODELS [8]. On the other hand, power converters driving propulsion motors require careful modeling. More specifically, some high valued resistances have to be placed in parallel to switches or in cascaded shunt positions between any non-linear elements so that any numerical noise is eliminated [6,7,9]. Furthermore, anti-parallel thyristor switching has to be programmed accurately while snubber circuits used as damper networks during switching transitions have to be included too. It is highlighted that the numerical parameter values of the snubber circuits in most cases have to be considerably different than the actual ones so that no numerical noise occurs [9-11]. These values are found, in general, empirically by trial and error approach.

In this paper the possibility of eliminating the numerical noise developed during the circuit solution by properly adjusting the integration time-step is sought instead of determining auxiliary component values. Referring to propulsion motor models they require the smallest possible time-step, whereas power converter models require a fairly larger step so that no numerical distortion occurs.

4. Study case

A representative ship propulsion scheme is considered as shown in Figure 3. More specifically, a three-phase asynchronous motor is driven by a power converter comprising a non-controlled 6-diode rectifier in series to a 6-pulse Pulse Width Modulation inverter. The motor starts up at time 0 and absorbs an inrush current [10,12].



1. AC Power Supply unit
2. Power Converter
3. Rectifier
4. PWM inverter
5. Motor + propeller model

Figure 3. Study case of an asynchronous propulsion motor modelled in MODELS facility of EMTP (motor nominal characteristics: 3kV, 15 MW,4 poles, 120 rpm) (PWM characteristics: 3 kV, Fin=50 Hz, Fout=4 Hz, Mf=0.9)

The influence of the integration time-step of the separate models is investigated first. Thus, the integration time-step of the motor model is set to be bounded by an upper limit of **10μs**, whereas the time-step of the supplying system model (including AC system and PWM converter) takes three different values, i.e. **0.5 ms, 0.1 ms and 0.03 ms** respectively. In Figures 4-6 the PWM output voltage for the three different combinations of integration time-steps are presented.

It can be clearly seen that the smaller the integration time-step the worst the numerical oscillations. In the case of 0.03 ms in particular, the output waveform is distorted in a rather random manner. For this study case, a time-step of 0.5 ms leads to waveforms sufficiently close to the theoretical ones [10,12]. Furthermore, the corresponding phase currents absorbed by the motor during start-up are presented in Figures 7-9.

It can be seen that the main waveform pattern of the current is not distorted at the same extent as in the case of the PWM output voltages. Therefore, the essential time-step limitation is imposed by the PWM converter model. It is highlighted however, that as mentioned above the motor model can not be integrated but by a comparatively small time-step such as 10μs. Any effort to increase this time-step leads to numerical overflow. Furthermore, the PWM time-step can not be reduced considerably further without spoiling the accuracy significantly.

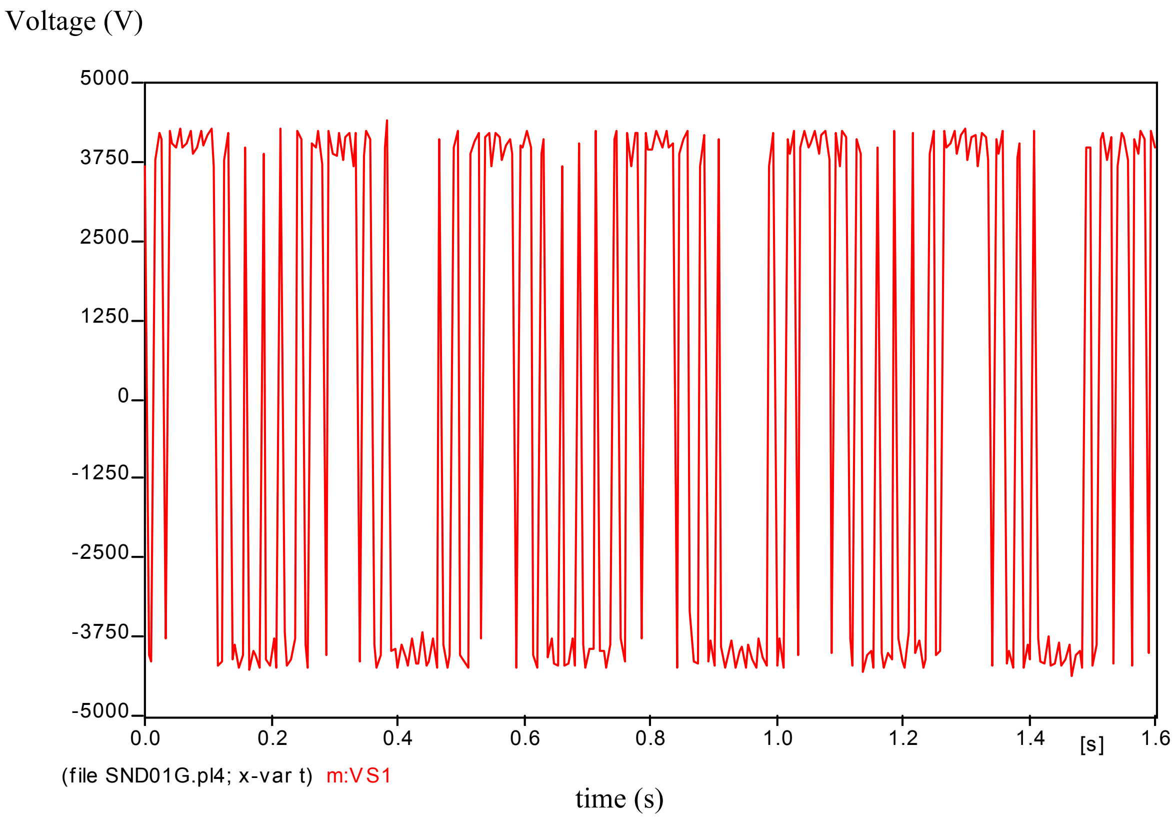


Figure 4. PWM output voltage in the case of 0.5 ms integration time-step

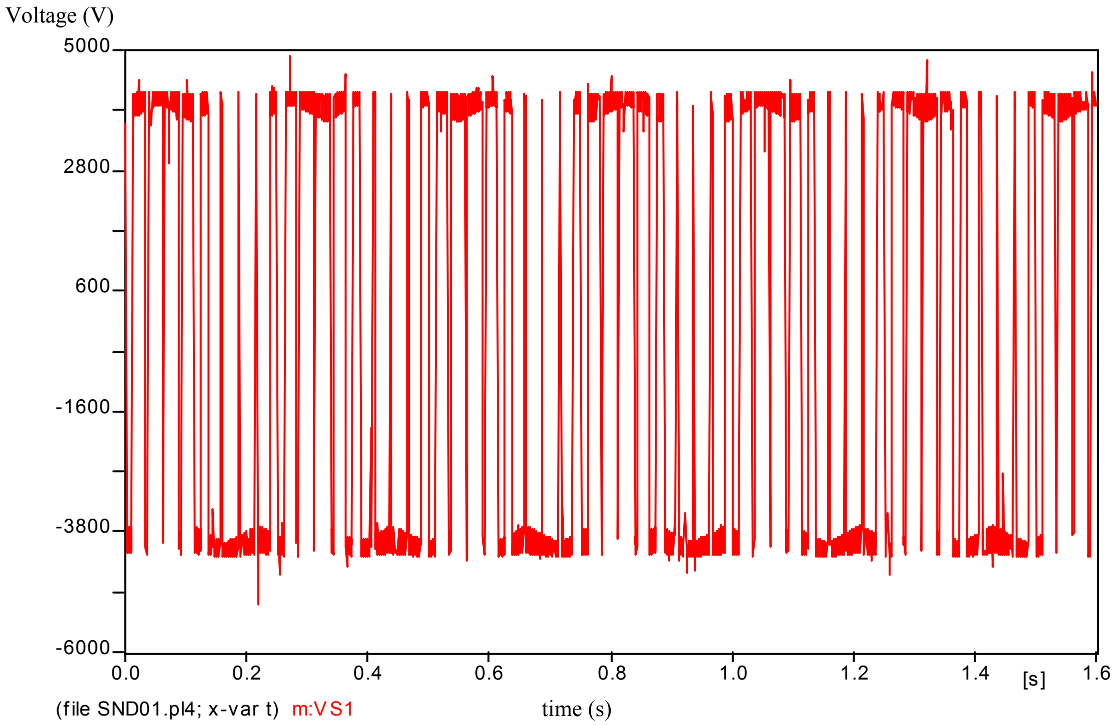


Figure 5. PWM output voltage in the case of 0.1 ms integration time-step

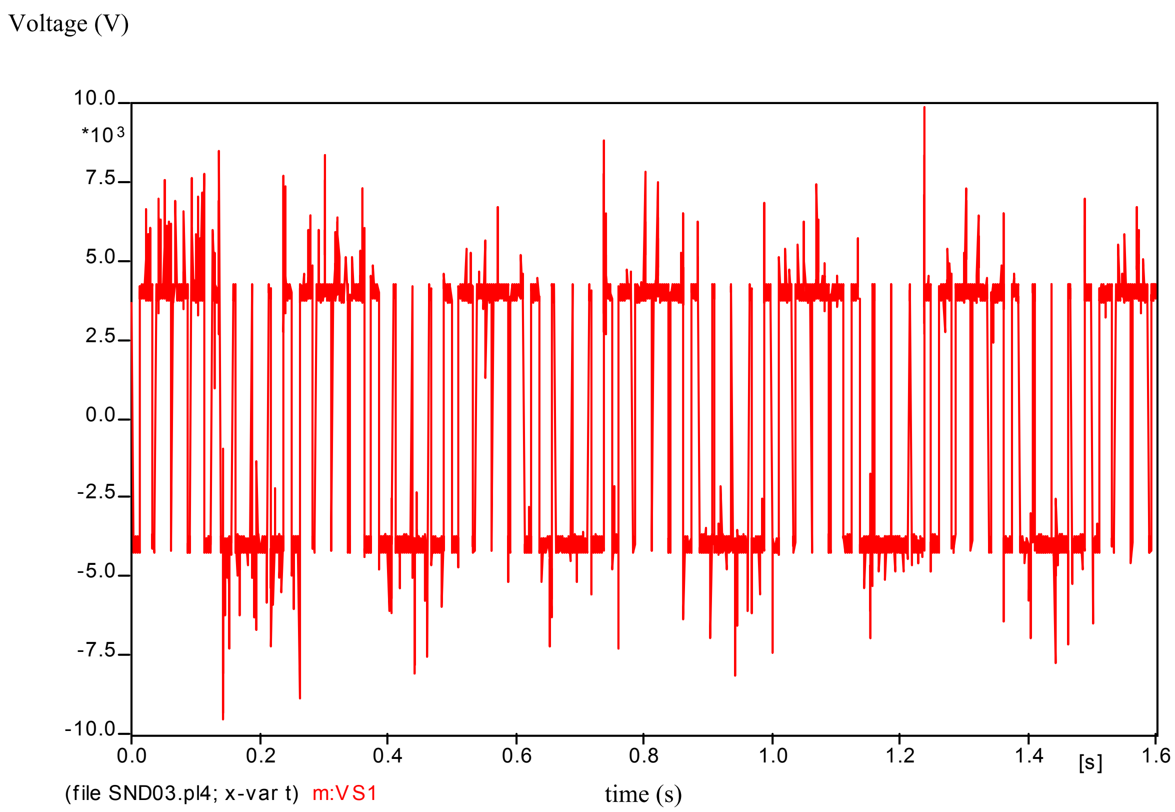


Figure 6 PWM output voltage in the case of 0.03 ms integration time-step

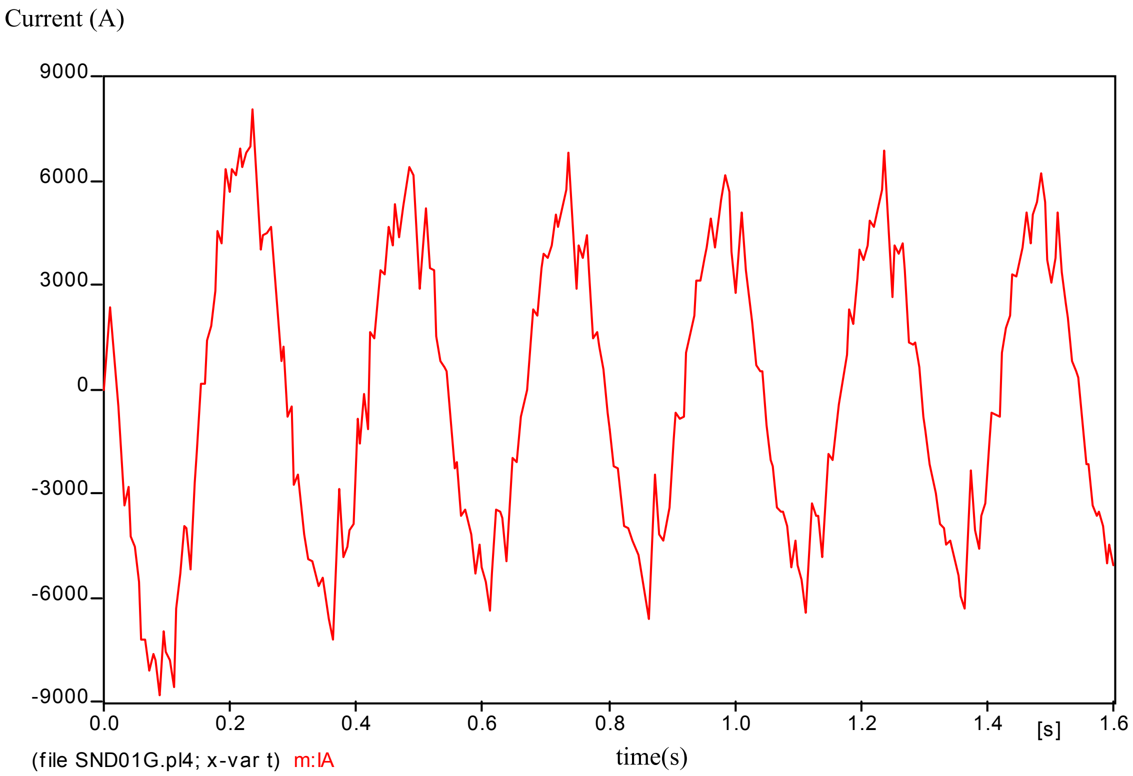


Figure 7 Inrush motor current in the case of 0.5 ms integration time-step

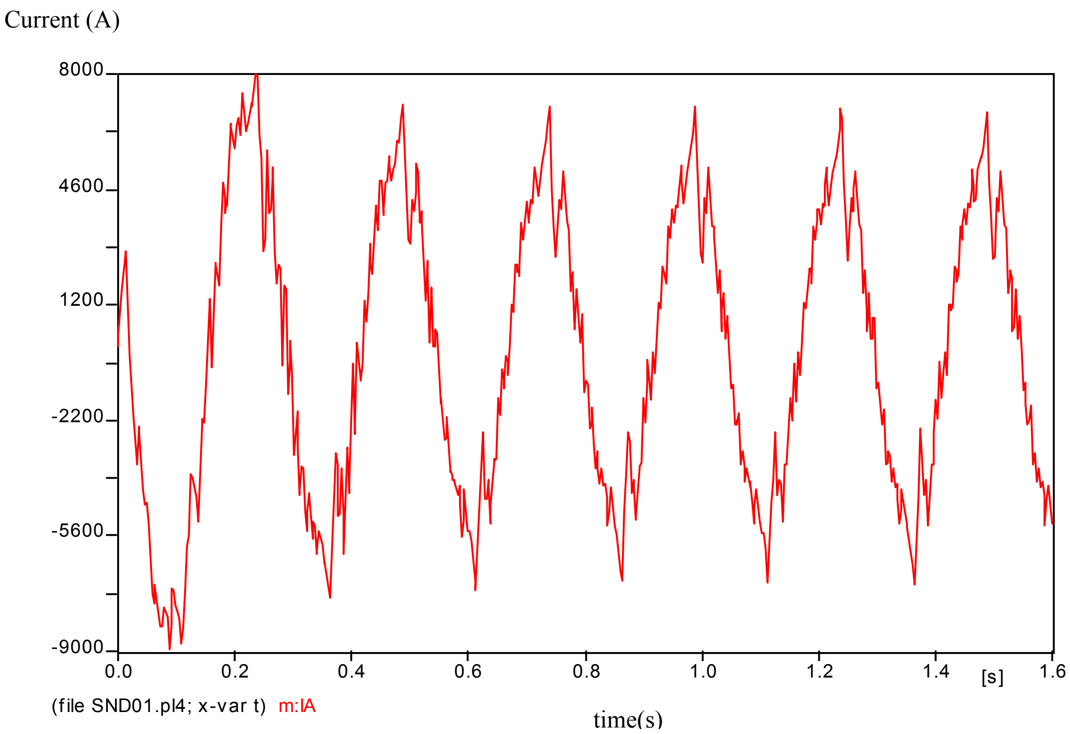


Figure 8 Inrush motor current in the case of 0.1 ms integration time-step

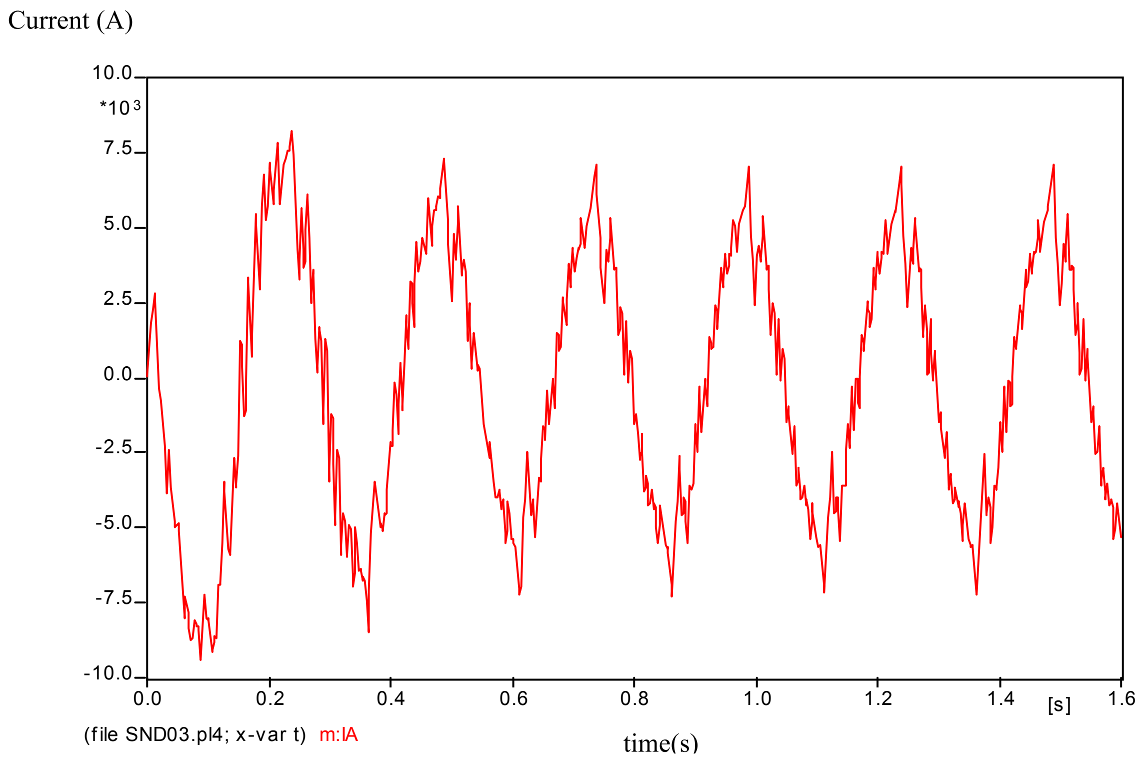


Figure 9 Inrush motor current in the case of 0.03 ms integration time-step

5. Conclusions

In this paper, the possibility of eliminating numerical noise without spoiling the accuracy of the results of computer simulation of power system transients is investigated. It is shown that the well-known program EMTP and its MODELS-facility in particular can be exploited so that each ''problematic'' component is modeled separately and via different integration step. The latter is used in a ship electric propulsion motor start-up study case, where satisfactorily accurate results can be obtained only by using this option of model-dependent as well as user defined integration step offered by MODELS.

6. References

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