Thyristor Converter Simulation and Analysis

S. Y. Zhang

AGS Department, Brookhaven National Laboratory
Upton, NY 11973

Abstract- In this paper we present a simulation on thyristor converters. The simulation features non-linearity, non-uniform firing, and the commutations. Several applications such as a current regulation, a converter frequency characteristics analysis, and a power line disturbance analysis will be presented.

I. Introduction

A thyristor converter is often modeled as a zero-order hold, a first order or second order Pade approximations, or a time delay. The applications of these models are restrictive according to the circumstances. First of all, the thyristor converter is a device that is in nature controlled by firings. Therefore the converter is a nonuniformly sampling element. Secondly, the sampled bridge sine waveforms produce different small signal gains according to the firing angles and the converter voltage output levels. In the third, other phenomena such as commutations sometimes change the converter phase and gain characteristics dramatically.

To a large class of thyristor converter applications we may eventually need a simulation that helps in the analysis as well as in the system design.

In this paper we present a simulation programmed in a high level language MATLAB. The MATLAB is basically designed for linear system analysis and signal processing. The simulation package consists of two aspects. One aspect represents the nonlinearities of the converter caused by the bridge waveforms, thyristor firings, and commutations, and another aspect contains the linear system analysis and signal processing.

We also present in this paper with some applications such as a current regulation analysis, an analysis of the converter frequency characteristics, and an analysis of the power line disturbance effect for a thyristor converter magnet driver.

II. Simulation

In the thyristor converter simulation, we adopt the ramp comparator firing principle. The simulations are based on a 3 phase AC power supply system, and the fundamental parameters for the converter simulation can be listed as the follows. 1). Number of pulse. 2). Amplitude and phase of the bridge sine waveform for each phase or each pulse. 3). Simulation steps and times. 4). Fundamental bridge waveform frequency. 5). Firing range. 6). Ramp slope. 7). Ramp position. 8). Input signal.

With a setting of all these parameters, we can have a fundamental simulation that does not include any commutation, distortion, and voltage or current regulations. Since the commutation affects the system power factor, the voltage ripple, and causes additional phase delay in the regulation loops, it is important in the thyristor power conversion system analysis. Taking advantage of the computing, we use prevalent conditions in the simulation to determine the commutation. For example, at each step we update the load current by using the linear system analysis commands and then use it along with the bridge voltage waveform to calculate the commutation. Thus, possible errors generated from the converter output current and voltage estimations can be eliminated.

The parameters that are necessary in the converter simulation with commutations are the follows. 9). Load transfer function. 10). Bridge line inductances. Also possible the circuit resistances and the thyristor voltage drops.

Very often a converter is controlled by either a voltage or a current regulation loop. To simulate a high order dynamic system that includes nonlinear components is a hard task. For a thyristor converter, however, there exists a simple solution. It is interesting to notice that after firing the converter voltage is simply determined by the bridge sine waveform until the next firing. This provides considerable convenience in the converter regulation simulation. Taking the advantage, the simulation is in fact executed periodically alike an open loop calculation that saves significant computations and therefore gives rise to a

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possibility to realize the simulation.

The parameters necessary for the regulated converter simulation are therefore the follows. 11). The transfer function of the voltage senser and the filter. 12). The transfer function of the regulator.

With all these parameters defined, in Fig.1 we show the simulation for a 24 pulse converter that is controlled by a voltage feedback loop and is driving a magnet. Fig.1a is with a low loop gain, and Fig.1b shows the result with high loop gain.

III. Current Regulation

We simulate a 12 pulse converter current regulation system under certain conditions. In this simulation, using popular models to the thyristor converter such as the first order phase delay and the second Pade approximations to the time delay with the statistical sampling time gives rise to untrue stability margin and oscillation frequency.

In fact, the models used to analyze the system should be modified according to the operation conditions that include the number of pulse, the converter voltage output, the bridge voltage, and the commutations. In this simulation, for example, the results are quite different if we include the effect of the commutations. In Fig.2 we show the two converter current waveforms with the same conditions except the latter is with a current commutation, that helps to stabilize the system. We may conclude that in a system analysis which utilizes models the converter simulation can be used to modify a model and then use it to verify the design.

IV. Frequency Characteristics

It is often of interest to know the thyristor converter frequency response characteristics. These properties include the phase delay and gain variation to signals with different frequencies, i.e. the Bode plot; the phase delay and gain variation to signals with the same frequency but different phases; and the gain variation at different converter voltage output levels. With digital Fourier transform, the simulation provides a possibility for a thorough study of these issues.

Due to the limited data available in the simulation, the analysis technique is different from the real time test. The following problems deserve attentions in the frequency domain analysis.

The error introduced in the digital Fourier transform usually belongs to the picket-fence effect, the aliasing and the leakage. Letting the sampling time be very small compared with the interested signal frequencies and enlarging the sampling data number can easily solve all the problem. Unfortunately both implies to increase the number of the data, and that is a difficult object in simulation. It is therefore necessary to find a solution that will suit the conditions in the simulation and yield only tolerable errors. First, we should define a number of simulation steps that is suitable for FFT package. Secondly, we should define a sampling period that along with the sampling data number gives rise to a frequency resolution that matches the input signals. This will greatly reduce the error caused by the picket-fence effect and the leakage. Third, of course, the useful signals in the analysis should be placed close to the origin of the frequency range of the Fourier analysis in order to avoid possible aliasing.

V. Power Line Disturbance Simulation

A thyristor converter directly powered from the power line is sensitive to the variations from the power grid and the local power stations. Due to the limited converter sampling frequency the disturbances may affect the load current immediately and then the disturbance is corrected gradually by regulations. A test for the effect of such a disturbance is difficult, while a simulation becomes a straightforward means in the analysis.

To reject the power line disturbances, a voltage regulation loop becomes necessary. We show an example for a sophisticated converter system that is proposed for the Brookhaven AGS Booster Accelerator main magnet. The system consists of 6 stations, each station is a 1000V 24 pulse converter. In the operation, the stations turn on subsequently, and when the magnet current reaches the peak the converters turn to energy invert. The magnet current repeatability requirement is very critical to the particle beam extraction and therefore the power line disturbance should be eliminated to the minimum. In Fig.3, we show the simulated converter voltage output waveform. In Fig.4, we show the magnet current error ratio due to a 1 percent step power line disturbance that occurred at 8ms from the beginning of the cycle, that present a 0.12 percent repeatability for the disturbance. We may conclude that some other technique is necessary in order to further improve the magnet current repeatability that is required to be under 0.1 percent.

References

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Figure Captions

Fig. 1a Converter Voltage Waveform with Low Loop Gain

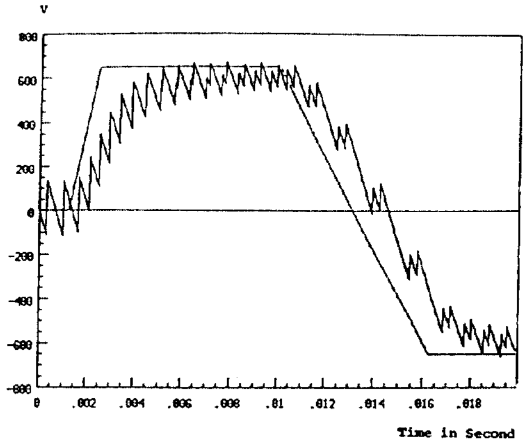

Fig. 1b Converter Voltage Waveform with High Loop gain

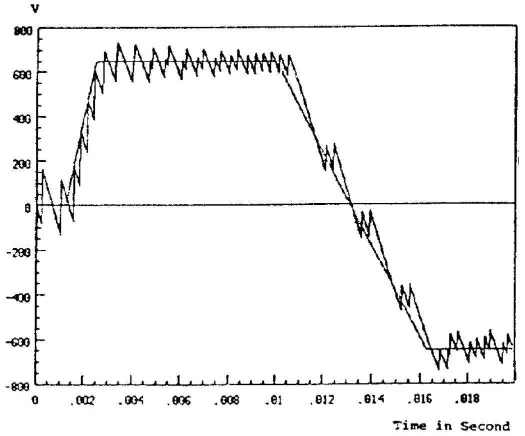

Fig. 2a Current Regulation, without Commutation. From Top to Bottom, Gain is from Low to High.

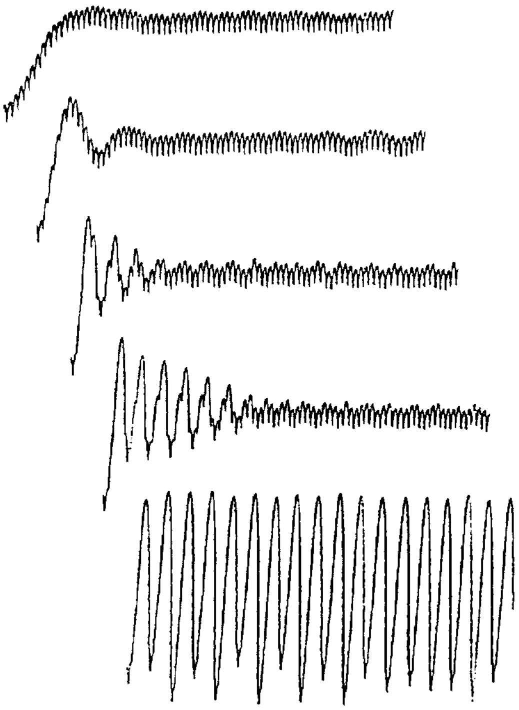

Fig. 2b Current Regulation, with Commutation. From Top to Bottom, Gain is from Low to High.

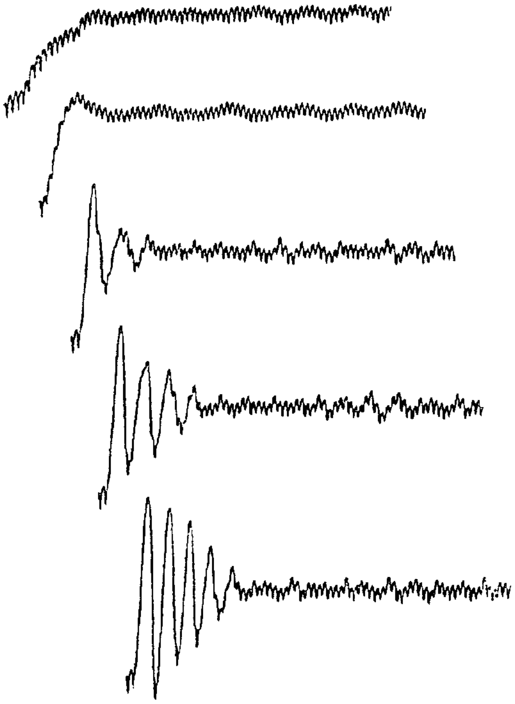

Fig. 3 AGS Booster Main Magnet Voltage Waveform

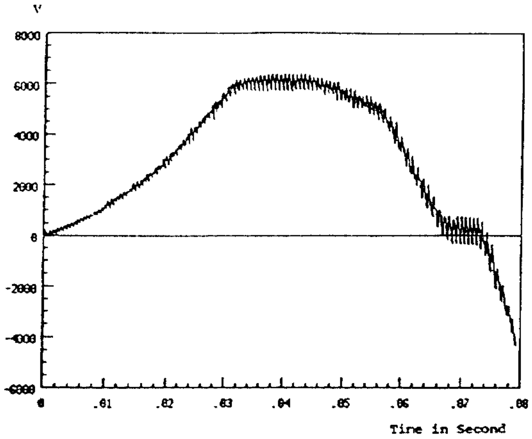

Fig. 4 Current Error Ratio due to Power Line Disturbance