Effect of switching frequency on the performance of Ground Power Supply Unit

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Abstract—Simulation of Ground Power Supply Unit is very important to test the performance and effectiveness of the systems under different scenarios. It can provide a safe and cheaper test bed to operate and evaluate the performance of the system before realizing it in the physical world. In this paper the effect of switching frequency on the performance of a ground power supply unit based matrix converter is studied. Simulation results from a 7.5KVA converter presented at different switching frequencies.

Keywords: Power converter simulation, Matrix Converter, switching frequency,

I. INTRODUCTION

Simulation is the imitation of a real system or process through a series of equations that represent the relations between the input and the output. The act of simulating a system generally entails considering a limited number of key characteristics and behaviors within the physical system of interest, which is otherwise infinitely complex and detailed.

Power converter simulation allows us to examine the behavior of the system under different scenarios. Power converter simulation can provide a safe and relatively cheaper test bed to operate, evaluate and optimize the performance of the system before realizing it in the physical world [1].

There is a growing interest in the use of static power conversion techniques to provide very high-performance ac power supplies for use in many applications such as uninterruptible power supplies, automatic voltage regulators, programmable ac source and Ground Power Units (GPU) for aircraft [2-3].

SABER is a powerful tool for design and simulation of a power systems. It is unique multi-technology, multi-domain simulation software oriented to the mixture signal. It has become industry standard in many transnational corporations in the world [4].

Schematic of the four-leg Matrix Converter model is shown in figure 1. The system consists of 5 main parts [3, 5]. These parts are:

- Input power supply.
- Input filter.
- Bidirectional switches.
- Output filter and load.
- Modulation and control.

The subsystems such as input power supply, input filter, bidirectional switches, output filter and three phase load are modelled using the existing components in Saber standard library.

The last block in the GPU model is the modulation and controller block. It consists of controller routine, modulation routine and PWM generator routine. This modulation and control block is programmed using MAST programming language in SABER.

In this paper, the simulation of four leg matrix converter is presented at different switching frequencies. The papers will start by introducing the ground power unit, after that simulation parameters will be discussed, then the simulation results at different switching frequency will be presented and discussed, finally the conclusion will be presented.

Figure 1 Matrix converter structure.

II. POWER CONVERTER MODELING AND SIMULATION

Power converter modelling can be categorized into four main levels depending on the required accuracy and simulation time of the model [6]:

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II. POWER CONVERTER MODELING AND SIMULATION

Power converter modelling can be categorized into four main levels depending on the required accuracy and simulation time of the model [6]:
Starting from the bottom of figure 2, component level modelling is used to model each component in the system including high frequencies, electromagnetic fields and EMC behavior. Using this detailed device modelling requires very small simulation step sizes, thus the simulation time will be long.

The next level is the behavioural level. This level of modelling has relatively short simulation times compared with the detailed device modelling level. The behaviour modelling level includes lumped parameter subsystem models with frequencies up to 100’s of KHz, including the converter switching frequency [7].

The following level is the functional level in which the system components are modelled to show only the main system dynamic frequencies, “low frequency transient behavior up to 100-150Hz”. This mentioned modelling level is targeted at power system dynamics, stability, response to loads and start-up. The aim is to model the power system either in its entirety or in sections sufficiently large to obtain a holistic generator-to-load dynamic overview in this GPU application [8].

The last modelling level is the architectural level. These models compute steady state power flow and is used for cost, weight, cabling studies and, most significantly, event modelling and power system reconfiguration[8-9].

A. **Ground power unit simulation**

GPU simulation is important to test the effectiveness of the proposed controller. Referring back to the different modelling levels, the main system frequency is 400Hz therefore the behavioral model level is adopted to simulate the system and get a result as close as possible to the practical results whilst maintaining a reasonably short simulation time.

B. **System parameters**

The main system parameters as shown in figure 3 are shown below as follows:

- **Input supply voltage**: three phase supply, 50Hz, 240Vrms (line to line).
- **Output power**: 7.5KW.
- **Output voltage**: Three phase, 115 Vrms (line to neutral).
- **Output frequency**: 400 Hz.
- **Switching frequency**: 12800Hz
- **Output filter**: Lo=583uH, Co=35uF.
- **Input filter**: Lin=600uH, Cin=2uF

The above listed parameters have been selected to test the GPU based Matrix Converter. The converter output voltage and frequency is set to 115V and 400Hz respectively.

The selection of the switching frequency is a trade-off between efficiency, component size and transient response. Higher switching frequency is desirable and it will reduce the inductors and capacitors size and increase the transient response of the voltage regulation by having larger control bandwidth. However, converter efficiency will be lower due to increased conduction and switching losses.

III. **EFFECT OF SWITCHING FREQUENCY ON POWER CONVERTER PERFORMANCE**

Selecting the appropriate switching frequency for the Matrix Converter is a trade-off between performance and devices switching losses. Increasing the switching frequency will reduce the output voltages total harmonic distortion (THD)
and reduce the size of the output filter. However, as the switching frequency increases the losses in the devices increases[10].

In the practical implementation of Matrix Converters, the input voltage and the output currents have some ripple due to the switching frequency. The modulation process is not continuous and this will have the potential to generate low frequency components in the input current and in the output voltage spectra[11]. The following simulation results show the effect of changing the switching frequency on the output voltage and input current waveforms.

Figure 4 shows the simulation results of the effect of changing the switching frequency to the output voltage spectra. As expected, increasing the switching frequency has significant impact on output voltage quality[7].

The low and high frequency components are normally exist in the input current and the output voltage waveforms. The low frequency components are due to several reasons such as the modulation method, the switching ripples in the input current and voltage waveforms, because of the digital implementation of the controller and modulation algorithms and due to the nonlinearities of the Matrix Converter itself. All of the above have the potential to generate low frequency components in the output voltage and input current spectra.

The high frequency components are normally generated due to the switching frequencies and it can be seen very clearly in the input current waveform. This high switching frequency can be minimized by using an input filter at the input side to provide a path to the high frequency components.

The lower the switching frequency the more the distortion of the output voltage and input current waveforms, and the bigger the filters and it becomes more difficult to control the converter especially at 400Hz applications where the controller bandwidth becomes low. Circuit setup shown in figure 3 is used throughout the study of the effect of the switching frequency on the Matrix Converter performance. The input filter the output filter, the modulation and the controller details are all fixed during the study. The following sections will present the simulation results of the four-leg Matrix Converter for different switching frequency starting from 8kHz to 12.8kHz and finally with 25.6kHz.

### A. Simulation results using 8kHz switching frequency

Figure 5 to figure 9 shows the simulation results of the four-leg Matrix Converter using 8 kHz switching frequency. As shown in figure 5 the output voltage waveforms are nearly sinusoidal with some ripples. Figure 6 shows the spectrum of the output voltage with THD of 1.13%.
Figure 6 Output voltage spectra using an 8kHz switching frequency.

Figure 7 shows the simulation results of the output voltage for the Matrix Converter using 8 kHz switching frequency. It can be seen that there is a phase shift between the reference and the output voltage waveforms, and the tracking error of ±20 Volt due to the limited controller bandwidth when using the 8 kHz switching frequency.

Figure 8 and figure 9 shows the simulation results of the three phase filtered input current for the four-leg Matrix Converter using 8 kHz switching frequency. As shown in figure 8 the input current is distorted. As can be seen in figure 9 there is a high frequency harmonics around the switching frequency and the total harmonic distortion is 9.3%.

Figure 8 Three phase input current waveforms using an 8kHz switching frequency.

Figure 9 Filtered input current spectra for an 8kHz switching frequency.
B. Simulation results using 12.8kHz switching frequency

The effect of increasing the switching frequency on the output voltage and input current waveforms for the four-leg Matrix Converter using 12.8 kHz switching frequency are shown in figure 10 to figure 14. It can be seen from the figures that the output voltage and the input current waveforms quality is better compared with the previous results with 8kHz switching frequency.

Figure 10 and figure 11 shows the simulation results of the output voltage waveforms for the four-leg Matrix Converter. It can be seen from the figures that the output voltage is sinusoidal with a THD of 0.89%

![Figure 10 Three phase output voltage waveforms using a 12.8kHz switching frequency.](image)

Figure 10 Three phase output voltage waveforms using a 12.8kHz switching frequency.

![Figure 11 Output voltage spectra using a 12.8 kHz switching frequency.](image)

Figure 11 Output voltage spectra using a 12.8 kHz switching frequency

Figure 12 shows the simulation results of the output voltage compared with the reference required voltage. It can be seen that the output voltage tracks the reference with a relatively good tracking, with a tracing error of ±6V.

![Figure 12 Output voltage tracking of phase A for a 12.8kHz switching frequency.](image)

Figure 12 Output voltage tracking of phase A for a 12.8kHz switching frequency.

Figure 13 and figure 14 shows the simulation results of the three phase filtered input current for the four-leg Matrix Converter using 12.8kHz switching frequency. As can be seen, the input current is still distorted with a THD of 5.02%. It is very clear that using higher switching frequency the waveform quality of the output voltage and the input current are much better. Figure 14 shows the harmonic components around the switching frequency and around the cut-off frequency of the input filter which is about 2.455kHz.

![Figure 13 and figure 14](image)
C. Simulation results using 25.6kHz switching frequency

Simulation results of the four-leg Matrix Converter using 25.6 kHz switching frequency is shown in figure 15 to figure 19. It can be seen that the output voltage and current waveforms quality are much better than the previous results. Figure 15 and figure 16 shows the output voltage waveforms and spectra. It can be seen that the output voltage waveform in sinusoidal with THD of 0.52%. And the low and high order harmonic components are significantly reduced, and the output voltage ripples are minimized with the use of 25.6kHz switching frequency.

Figure 17 shows the simulation results of the output voltage compared with the reference voltage. It can be seen that the output voltage tracks the reference voltage, with a tracking error less than ±4V.
Figure 17 Output voltage tracking of phase A for a 25.6kHz switching frequency.

Figure 18 and figure 19 shows the simulation results of the three phase filtered input current for the four-leg Matrix Converter using 25.6 kHz switching frequency. As shown in figure 18 and figure 19 the input current is still distorted with a THD of 4.3%. It is very clear that by increasing the switching frequency to 25.6kHz the waveform quality of the output voltage and the input current are improved. Figure 19 shows that there are harmonic components around the switching frequency and around the cut-off frequency of the input filter which is about 2.455kHz.

Figure 18 Three phase input current waveforms using a 25.6kHz switching frequency.

Figure 19 Input current spectra for a 25.6kHz switching frequency.

To sum up, Table 1 shows the effect of increasing the switching frequency on Matrix Converter performance. As can be seen, increasing the converter switching frequency will reduce the output and input voltages and currents THD, reduce the tracking error.

Table 1 The effect of increasing the switching frequency on Matrix Converter performance.

<table>
<thead>
<tr>
<th>Switching frequency</th>
<th>8000 Hz</th>
<th>12800 Hz</th>
<th>25600 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output voltage THD</td>
<td>1.13%</td>
<td>0.89%</td>
<td>0.52%</td>
</tr>
<tr>
<td>Input current THD</td>
<td>9.34%</td>
<td>5.02%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Output voltage tracking error</td>
<td>±22</td>
<td>±6</td>
<td>±3.5</td>
</tr>
</tbody>
</table>
IV. CONCLUSION

In this paper, a simulation study for Matrix Converter system was carried out using the SABER simulation package. Results show that increasing the switching frequency tends to reduce both of the input current and the output voltage THD and the associated low frequency ripples in the waveforms and good tracking to the reference signal can be achieved.

V. REFERENCES

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