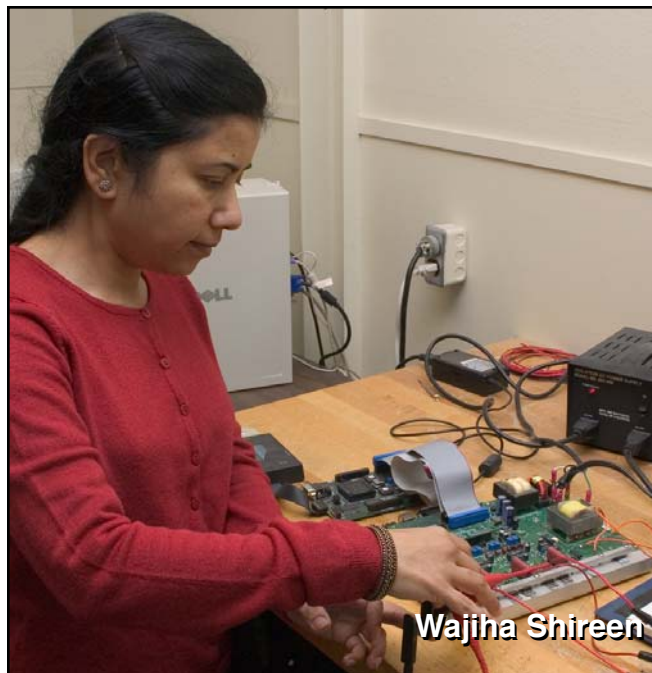


An AC-DC-AC Converter with Smaller DC-link Capacitor for Space Power Distribution Systems

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Abstract—Power conditioning equipment used in a space power system contributes to the total system mass, reliability, and cost. This research is focused to reduce weight and improve the reliability of an AC-DC-AC converter used in a large number of the power conditioning stages in a typical space power system. Systems have different load requirements.



POWER DISTRIBUTION DESIGNS FOR VARIOUS SPACE POWER systems are driven by source characteristic, load requirements, and subsystem functional requirements. The power distribution system is to provide an interface between the power source and the user load with maximum efficiency (including power conditioning, distribution and control). Primary consideration in the selection of power distribution in space power systems is minimization of both the system mass and power losses. Additional criteria used in the selection are survivability, cost, reliability, and power quality.

The power conditioning stage between the source and distribution or between the distribution and the load efficiently interfaces with various source types with different distribution systems having a wide variety of load requirements. For example, the power source in a space power system can be a photovoltaic array source that produces DC voltage or a solar dynamic generator that produces low-frequency three phase AC voltages. The power distribution system can be chosen to be DC, 400 Hz AC, or 20 kHz AC. Loads in a typical space power system such as radar, communications, motors, and computers have a wide variety of power requirements which include low to high voltage DC (5V-270 VDC), low frequency single phase AC (115 Vrms, 60 Hz), and high frequency three phase AC (120-440 Vrms, 400 Hz). Hence, in addition to providing flexible electric power of high quality, the power conditioning method and associated equipment (power converters, filters etc.), have a significant effect on the total power system mass, reliability and cost in a space power system.

Various power distribution schemes are being investigated for space power systems.^{1,4} The decision of an appropriate distribution bus voltage for a space power distribution system is based on the goals of minimizing the total system mass, power losses, and risk. Power can be delivered from the associated source to provide either DC, low frequency AC (3 phase, 400 Hz) or high frequency AC (single-phase, 20 kHz) power.

Some researchers claim that, the 20 kHz system is better from the standpoint of reduced size and weight of magnetic components.^{1,2} In an extensive study on space power distribution systems, researchers concluded that the DC bus has advantages over the 20 kHz system in the areas of cost, reliability, fault tolerance, integration, and power quality.³ In any space power distribution system using a DC bus distribution, AC-DC-AC converters will play a significant role in determining the total system cost, weight, and reliability.

Figure 1 shows a block diagram representation of a power conditioning stage, where the input is a low frequency ac source which is converted to DC by an AC to DC converter (rectifier) stage. The DC voltage obtained is again converted to single phase or three phase AC voltage of required magnitude and frequency in a DC to AC converter (inverter) stage. The DC link in any AC-DC-AC converter is normally equipped with an electrolytic capacitor which provides decoupling between the rectifier and the inverter. However, the DC link capacitor is a large, heavy, and expensive component. Moreover, the DC bus capacitor is the prime factor of degradation of the system reliability. For space power distribution systems, factors cited above pose even more critical problems.

Research has been reported involving both the elimination of the DC-link filter capacitor and reduction in capacitor size in an AC-DC-AC converter.^{5,7} In Takahashi and Itoh,⁶ a circuit has been proposed in which the capacitor in the DC-link was extremely reduced in capacity. A voltage source inverter without DC-link components for induction motor drives has been proposed.⁷ The implementation of all the above methods requires significant changes in the rectifier-inverter power circuit configuration which also involves complex control with the added concern of system stability. Earlier schemes tried to eliminate the DC bus capacitor altogether, which increase the complexity and the cost of the system.

Goals of the Project

The objective of this project is to reduce the weight and improve the reliability of an AC-DC-AC converter utilized in a large number of power conditioning stages in a typical space power system. A Digital Signal Processor (DSP)-based modified space vector pulse width modulation (PWM) technique is being proposed that will allow use of a smaller DC-link capacitor without affecting the output performance of the converter is proposed. The proposed method implemented in AC-DC-AC converter applications will result in the following advantages:

1. Reduction in capacitor size (20%-30%).
2. Significant reduction in total system cost and significant improvement in system reliability by the use of smaller link capacitor.
3. Reduced converter weight and volume.
4. Modification to the existing AC-DC AC converter topology unneeded.
5. Digital control by a DSP to provide fast transient response, high performance and increased reliability.
6. A digital controller insensitive to the environment, offering stable operation under most operating conditions.
7. The DSP based controller, being programmable, easily upgraded or modified to meet specific system requirements.

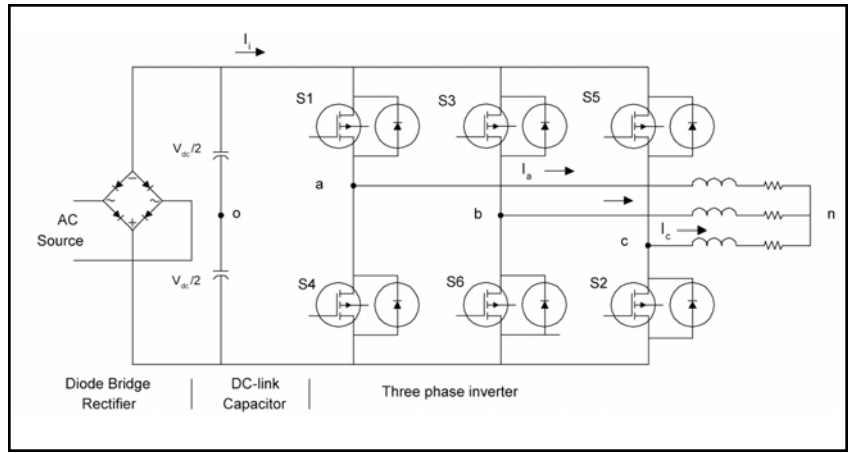


Figure 1. Block diagram representation of an AC-DC-AC converter

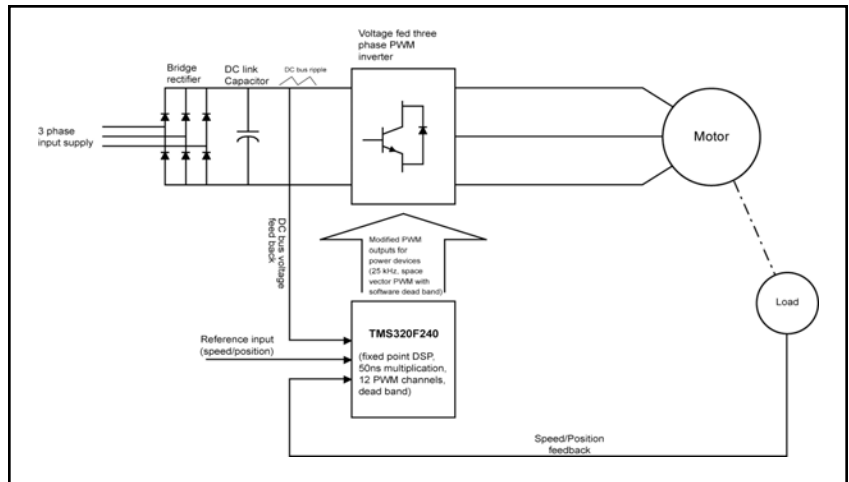


Figure 2. A closed loop V/Hz motor drive system with the proposed DSP based control

Results

Figure 2 shows a conventional AC-DC-AC converter consisting of a diode rectifier, DC-link, and a PWM inverter used in a closed loop V/Hz motor drive. A similar experimental set-up in the laboratory was used to test the proposed technique. The DSP-based controller (TMS320F240) was used to implement the proposed technique, which allowed the use of a smaller DC-link capacitor without affecting the output performance of the rectifier-inverter system. The use of smaller link capacitor introduced a ripple on the dc-bus voltage. The DC-link voltage ripple was sensed and fed as an input to the DSP controller.

The controller changes the inverter switching strategy in real time in accordance to the variation (ripple) on the dc bus voltage. If the dc bus voltage is increasing, the inverter needs to be operated at a lower modulation and vice versa. For the closed loop V/Hz system, two additional inputs to the DSP controller are the reference input and speed feedback. The output of the DSP stage will be PWM control signals for the inverter switches.

Figure 3 shows the DC bus voltage and its frequency spectrum when a 1500 μF DC link capacitor was used in the experimental setup. Experimental results detailed in the oscilloscope picture in Fig. 3 show that the DC-bus voltage is ripple

free; only the DC component is observed in its frequency spectrum. When the DC-link capacitor was reduced to 47 μF , it resulted in a ripple on the DC bus voltage, as can be seen in Fig. 4. The frequency spectrum in Fig. 4 shows the presence of a 120 Hz component in addition to the DC component.

The ripple present in the DC-bus voltage due to the use of a smaller DC-link capacitor, is reflected at the inverter output; researchers noted that the magnitude of the fundamental component of the inverter output varies with time. Figure 5 shows the line-to-line voltage of the inverter output and its corresponding frequency spectrum at two instants of time. One shows the fundamental component at its maximum magnitude (13 V), and the other shows the fundamental component at its minimal magnitude point (11.25V).

Figure 6 shows the inverter line-to-line output voltage with smaller DC-link capacitor (47 μF), but with the DSP-based control algorithm in effect. Figure 6 shows the output voltage at two different instants and it reveals that the magnitude of the fundamental component is maintained at a constant value even in the presence of a significant DC-link voltage ripple. The DC-link voltage is as shown in Fig. 4. That means that

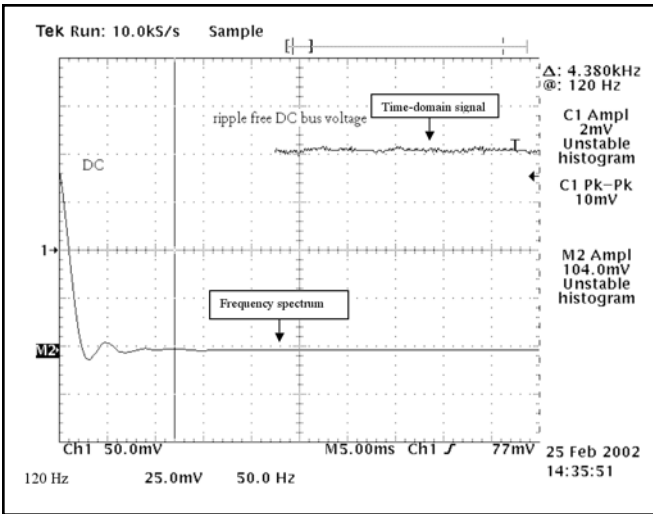


Figure 3. DC bus voltage and its frequency spectrum with a 1500 μ F DC link capacitor

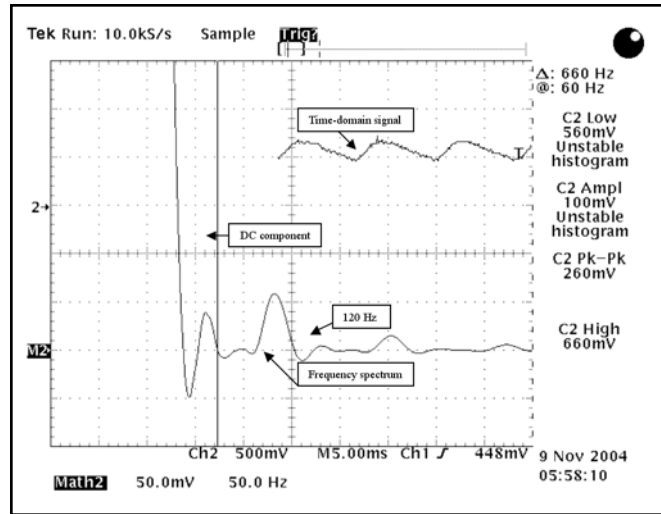


Figure 4. DC bus voltage and its frequency spectrum with a 47 μ F DC link capacitor

with the proposed method the inverter output voltage can be made immune to the variation in the DC link voltage at the inverter input by using a smaller DC-link capacitor.

Experimental results from the proof of concept laboratory prototype validate findings that, with the help of a DSP controller, a smaller DC-link capacitor can be used without affecting the output voltage. Work is in progress to determine the limitations of the technique and to identify the optimum DC-link filter value that can be effectively handled by the proposed control.

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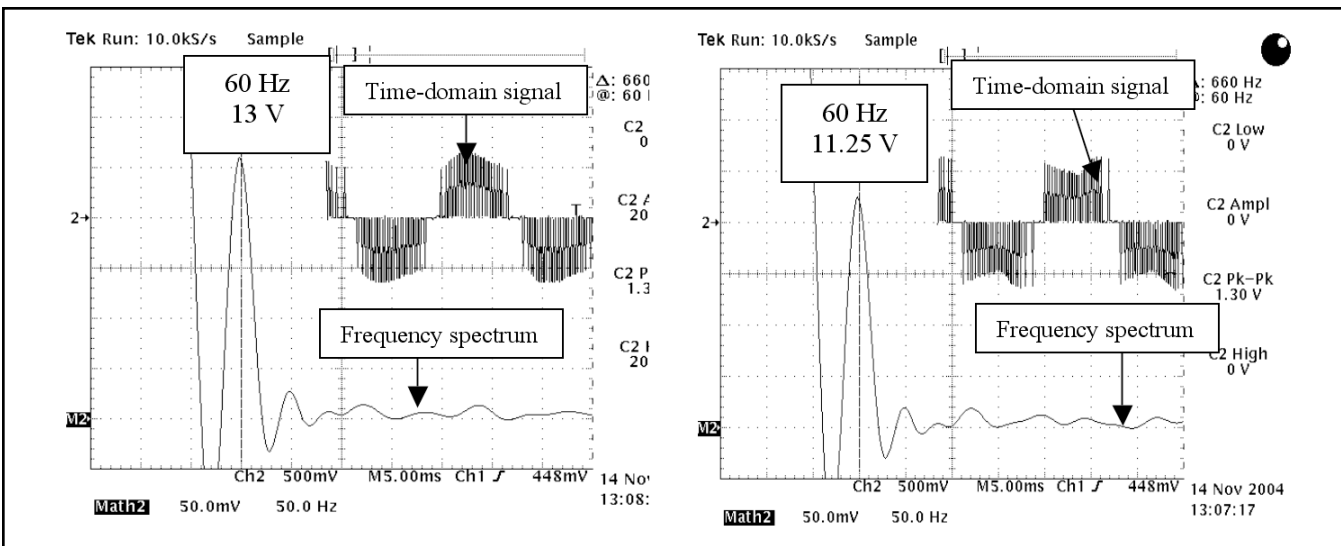


Figure 5. Inverter line-to-line to line output voltage showing the variation in the magnitude of the fundamental component

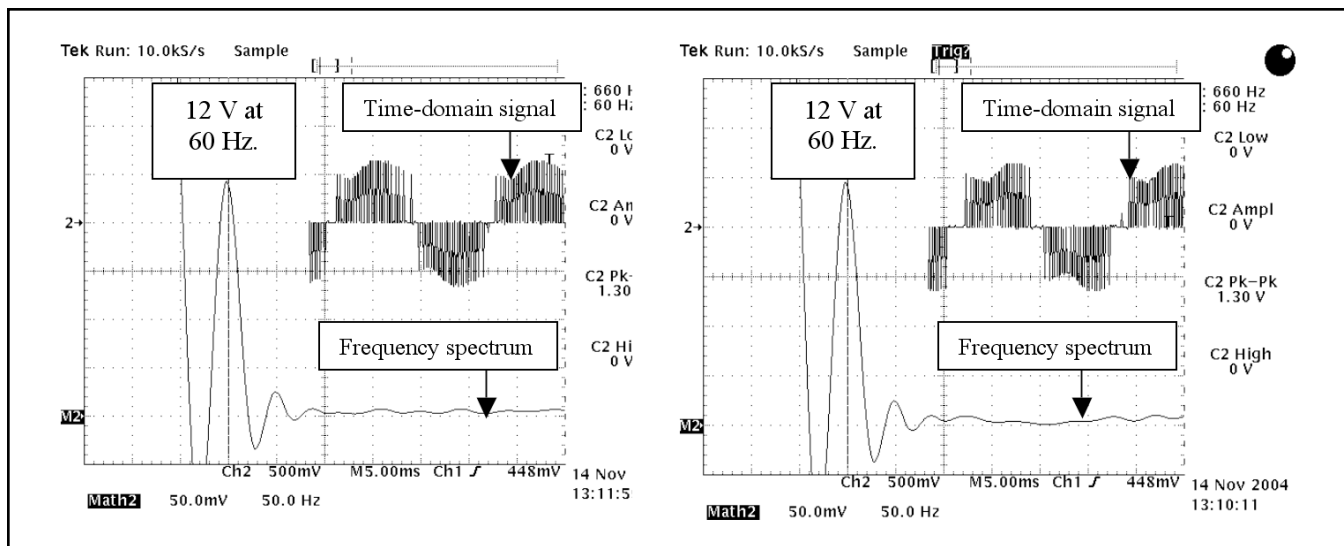


Figure 6 Inverter output voltage at different instants of time with the proposed DSP control.

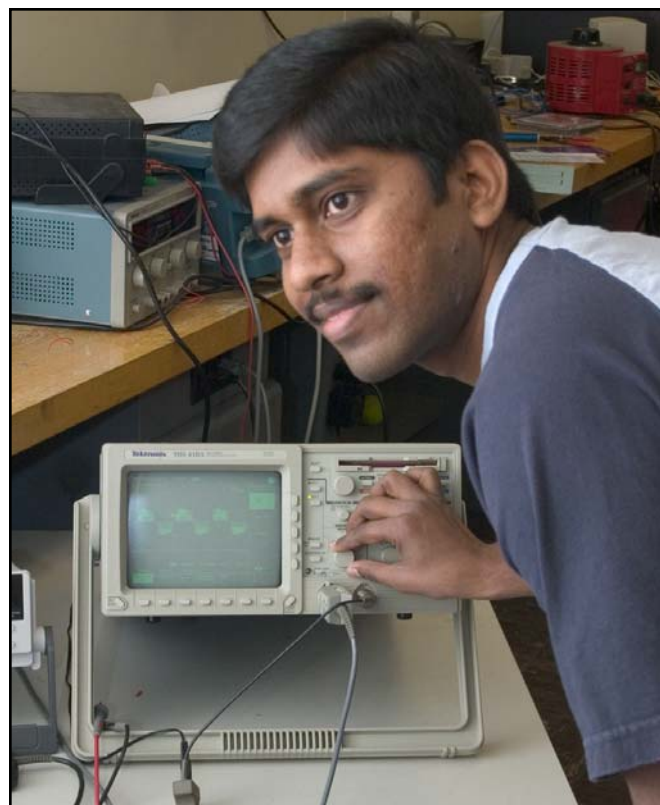
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