

Powering 270 V DC Equipment from 230 V AC Aircraft Bus

Kaz Furmanczyk and Mark Stefanich
 Crane Aerospace & Electronics

ABSTRACT

Aircraft electrical power consumption has dramatically increased in recent years. Technological advancements have led to the replacement of traditional hydraulic and pneumatic systems with electrically powered devices. In addition, new functions such as deicing and entertainment systems have been added, which further increases the demand for electrical power. As power needs increase, voltage or current, or both, must be increased. Increased current can be the least desirable result as it leads to larger and heavier wires. To mitigate the issue of wire weight and distribution losses, the latest "More Electric Aircraft" have adopted 230 V ac as the main power bus voltage. However, this presents a problem as a significant amount of existing electrical aircraft equipment (actuators, pumps, etc.) have been designed to use 270 V dc power, which is obtained by a direct rectification of 115 V ac power. Two hundred seventy volts dc cannot be as simply produced from a 230 V ac bus.

This paper provides details on new practical ATRU topologies that convert 3-phase 230 V ac into 270 V dc. Designs of 12-pulse and 18-pulse ATRUs are addressed. A design example of 230 V ac to 270 V dc ATRU is covered in the paper. Also, performance results from demonstration hardware, including power quality, regulation, efficiency, and reliability are provided.

CITATION: Furmanczyk, K. and Stefanich, M., "Powering 270 V DC Equipment from 230 V AC Aircraft Bus," *SAE Int. J. Aerosp.* 5(2):2012, doi:10.4271/2012-01-2223.

INTRODUCTION

Historically, obtaining 270 V dc from direct rectification of 115 V ac was acceptable (in spite of high current distortions), when usage of 270 V dc electrical power needs were minimal. As power demands for 270 V dc have increased, replacing direct rectification with low distortion power conversion equipment has become necessary. One solution to improve power conversion quality is to use an Auto-transformer Rectifier Unit (ATRU) in place of direct rectification. ATRUs have a low part count and are highly reliable. However, existing ATRU designs offer a low weight advantage only when input ac and output dc voltages are compatible in magnitude with each other (such as 270 V dc obtained from 115 V ac). On aircraft with a 230 V ac distribution system, the dc voltage from direct rectification or ATRU output would be 540 V dc. Therefore, most practical existing ATRU designs convert 115 V ac to 270 V dc, or 230 V ac into 540 V dc. Since many existing aircraft equipment operate on 270 V dc, there is a need for low weight effective power conversion from 230 V ac to 270 V dc. This paper addresses new ATRU design approaches, converting 230 V ac into 270 V dc, which result in low weight units suitable for aerospace applications.

DESIGN CONSIDERATIONS

Autotransformer Rectifier Unit (ATRU) is one of the simplest power conversion techniques with reduced effect on AC current distortion. This technology is commonly used in aerospace applications. A conceptual block diagram of a multiphase ATRU is shown in [Figure 1](#).

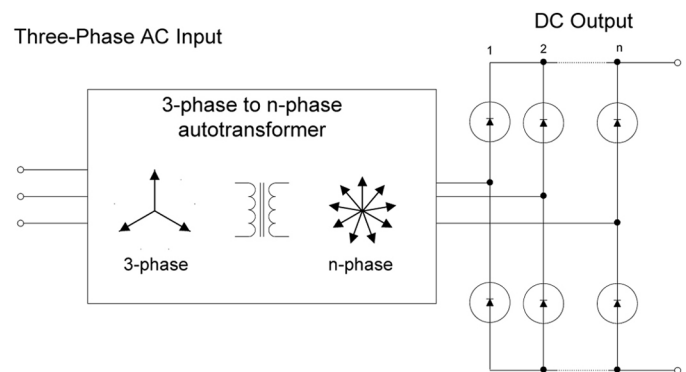
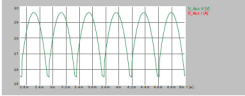
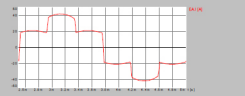
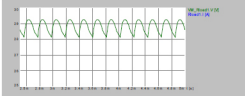
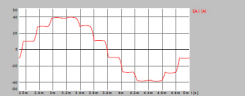
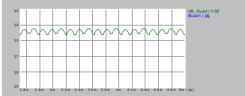
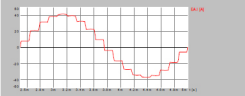
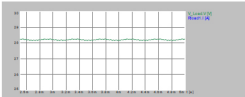
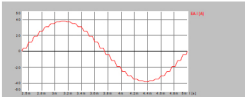


Figure 1. Multiphase ATRU Block Diagram

With an increasing number of conversion phases, the AC input current waveform becomes closer to sinusoidal with reduced input harmonics. In addition, the DC output has

reduced ripple at a higher fundamental ripple frequency. Simulated results of input current and output ripple are shown in [Table 1](#).

Table 1. Multiphase Conversion Performance Summary

Design Approach	Output Voltage Ripple [% p-p]	Input Current THD [%]
6-pulse	14 	28-33 
12-pulse	3.4 	9-14 
18-pulse	1.52 	6-9 
30-pulse	0.55 	2.5-3.5 

Current harmonic limits imposed by DO-160G can be met by 12-pulse ATRU designs. To meet individual harmonic limits for higher power units (above 5 kVA) imposed by major aerospace OEMs, 18-pulse or higher conversion is required. Thirty-pulse designs achieve very low current distortion and are good candidates for applications where CE101 emission limits of MIL-STD-461 are imposed.

CONVENTIONAL ATRU DESIGNS

Most commercial aerospace power quality requirements can be satisfied with 12-pulse or 18-pulse ATRU design approaches. This paper shows an example of a typical, conventional 12-pulse ATRU, converting 115 V ac to 270 V dc and its modification to convert 230 V ac to 270 V dc. Details of current waveforms and power rating analyses are provided for comparison with the new, more optimum ATRU, described in the next paragraph.

To obtain power conversion from 3-phase ac into dc, having 12-pulse characteristics, first the power needs to be converted in an autotransformer from three phases into six phases and then converted into dc in full bridge configuration. For proper 12-pulse operation, additional zero-sequence blocking devices, line reactors and/or interface transformers need to be added into ATRU power train. A representative practical example of a conventional 12-pulse ATRU is shown in [Figure 2](#).

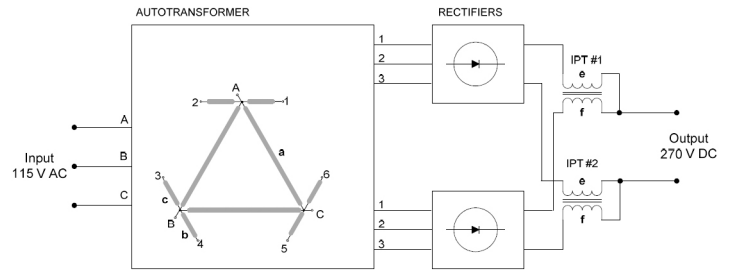


Figure 2. Simplified Schematic of a Typical 12-pulse ATRU, Converting 115 V ac to 270 V dc

The ATRU, as shown in [Figure 2](#), typically converts 115 V ac, 3-phase power into 270 V dc power. The same autotransformer configuration supports conversion of 230 Vac, 3-phase into 540 V dc. Conversion of 115 V ac to 270 V dc, or 230 V ac to 540 V dc results in the smallest autotransformer design since the magnitude of ac voltages is compatible with direct ac rectification of 115 V ac or 230 V ac to obtain 270 V dc or 540 V dc respectively. A typical autotransformer for those conversions weighs about 30% as compared to fully isolated transformer with the same power rating. This is very attractive feature for aerospace applications, where weight is a driving factor. However, an autotransformer quickly loses its weight advantage when additional power needs to be processed in the autotransformer windings to obtain dc voltages other than those compatible with direct rectification.

To convert 230 V ac into 270 V dc, the amplitudes of autotransformer output voltages need to be scaled to obtain 270 V dc after the rectification. [Figure 3](#) shows electrical schematics of a modified ATRU converting 230 V ac to 270 V dc. Additional windings (marked as **d**) were added to the autotransformer to scale the output voltages.

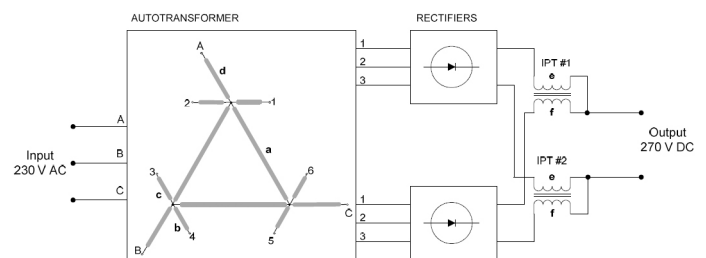


Figure 3. Simplified Schematic of a Modified 12-pulse ATRU, Converting 230 V ac to 270 V dc

[Figure 4](#) shows simulated current waveforms in each of the autotransformer winding as referenced on the schematic in [Figure 3](#). ATRU size and losses are directly related to the total power processed by the autotransformer. Usually the voltage across the windings is sinusoidal, or nearly so, but the current will vary dependent on the ATRU topology. Therefore an autotransformer's "Total Power Processed" is a

good indicator for comparing different ATRU topologies for the weight, losses and cost.

An ideal, two winding transformer processes a minimum of twice the rated power. First, the power is processed by the primary winding and next by the secondary winding. More complex, phase-splitting transformers or autotransformers have windings with unequal ratings. However, an equivalent “Total Power Processed” can be calculated by adding products of rms voltage and rms current in each winding.

Table 2 summarizes the power processed by each of the autotransformer windings and the “Total Power Processed” by the 5 kW ATRU, having traditional topology as shown in Figure 3. In this case, the “Total Power Processed” is 8,245 VA. A good design will strive to minimize this number.

Table 2. kVA Rating of the Traditional ATRU, Converting 230 V ac to 270 V dc

Winding	Voltage [V rms]	Current [A rms]	Power [VA]	Number of coils	Total Power [VA]
a	197.9	4.9	970	3	2909
b	31.9	7.6	242	3	727
c	31.9	7.6	242	3	727
d	123.7	8.3	1027	3	3080
e	22	9.1	200	2	400
f	22	9.1	200	2	400
Total Power Processed [VA]					8245

NEW ATRU TOPOLGIES FOR CONVERTING 230 V AC INTO 270 V DC

As shown in the previous chapter, it is possible to modify the conventional ATRU to convert 230 V ac into 270 V dc. However, the design does not achieve optimal weight for aerospace applications. Further research and development in this area resulted in the invention of new ATRU topologies for converting 230 V ac into 270 V dc. An electrical schematic of a new ATRU 12-pulse topology is shown in Figure 5.

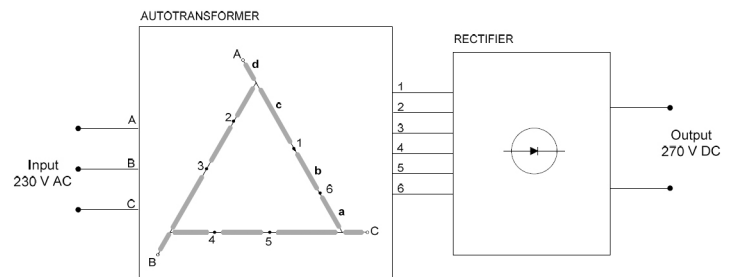


Figure 5. Simplified Schematic of a New 12-pulse ATRU, Converting 230 V ac to 270 V dc

This new ATRU topology does not need to implement any balancing inductors or interface transformers. Autotransformer windings are connected in a delta configuration. Six strategically located taps are taken directly from the delta windings, eliminating completely the need for stud windings. The rms current in stud windings is usually high due to the rectangular shape of the waveform-this significantly influences the autotransformer size and weight. Current waveforms in the autotransformer windings are shown in Figure 6.



Figure 4. Simulated Current Waveforms in the Autotransformer Windings of Traditional 12-pulse ATRU, Converting 230 V ac to 270 V dc