

AEROSPACE INFORMATION REPORT

AIR6139

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Ways of Dealing with Power Regeneration onto an Aircraft Electrical Power System Bus

RATIONALE

The technology move to More Electrical Aircraft power architectures has significantly increased the number of loads which may regenerate electrical energy as well as the overall magnitude of the power generated on aircraft. At the time of writing, electrical specifications for aircraft systems do not allow significant regeneration onto the electrical system. This specification has resulted in all the motor drives with regenerative loads employing a large resistor and associated cooling in order to dissipate the regenerated energy. These resistors have to be rated for worse case operation, resulting in the weight of the equipment being far from optimized.

1. SCOPE

This SAE Aerospace Information Report (AIR) considers the issue of power regeneration into the EPS of an aircraft. A series of options for dealing with this regenerative power are considered and arranged in categories. Advantages and disadvantages of each solution, including the existing solution, are included. Validated simulation results from representative Electrical Power systems are presented in order to demonstrate how some of the solutions may operate in practice and how power quality can be maintained during regeneration. The impact on changes to the electrical generation system are also highlighted in this AIR, as these changes may have an impact on the solution deployed and the wider impact on the design of engines and auxiliaries.

This AIR reviews concepts and excludes detailed discussions on power system design. These concepts relate to the More Electric Aircraft, cover both AC and DC systems and can be applied to both normal operating conditions or as fault mitigation.

1.1 Purpose

This AIR considers ways of dealing with power regeneration into the Electrical Power system (EPS) of an aircraft. Some types of loads, notably actuators and motors, regenerate energy under certain operating conditions. The technology move to More Electrical Aircraft power architectures has significantly increased the number of loads which may regenerate electrical energy as well as the overall magnitude of the power generated on aircraft. At the time of writing, electrical specifications for aircraft systems do not allow significant regeneration into the EPS. This specification has resulted in all the motor drives with regenerative loads employing a large resistor, switch, and associated cooling in order to dissipate the regenerated energy. These resistors have to be rated for worst case operation, resulting in the weight of the equipment being far from optimized.

2. REFERENCES

There are no referenced publications specified herein.

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3. DEFINITION OF REGENERATION

Regeneration is defined as electrical energy returned to the supply from loads. This typically occurs during deceleration of motors where the energy source is the kinetic energy stored in the motor rotor. Regeneration can also occur when aerodynamic forces drive electric actuators back to their failed position. In motor drives, a brief period of regeneration occurs when the rotational speed of a motor is reduced. In each case, mechanical energy is transformed into electrical energy by the drive electronics via the power converter. It is normal practice in industrial applications to return this energy to the supply or dissipate the energy in braking resistors depending on economic, weight and volume trades. Indeed, this technique is essential in industrial settings where one motor drive works against another, such as drawing wire.

4. CURRENT PRACTICE

The current practice in dealing with regeneration in aircraft is to effectively state that regeneration onto the EPS is not allowed. This results in loads having to incorporate blocking diodes, dissipation resistors or with motors, a control scheme that cycles the motor between driven and coasting to absorb the energy on the DC link. Actuators are more problematic and typically can only incorporate large dissipation resistors in order to cope with the worst case regenerative condition. These dissipation resistors are added into the common DC link of the converter (see example shown in Figure 1). The semiconductor switch is modulated on and off in order to dissipate the regenerative energy as heat in the resistor. The switch's duty cycle and/or switching frequency is typically based on converter output or DC link voltage. These dissipation resistors add considerable weight and volume to the power converters used in such applications. In many actuator examples, the dissipation resistor and associated cooling could amount to 50% of the power converter weight and volume. In addition, the resistor, switch, and associated drive circuitry add complexity to the drive design, with an inevitable decrease in overall actuator reliability due to increased converter component count and operating temperatures caused by the dissipated energy.

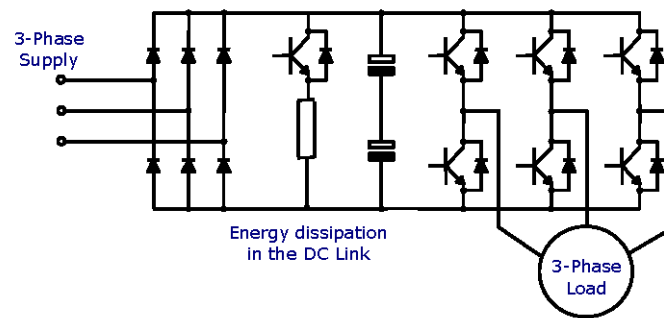


FIGURE 1 - POWER CONVERTER WITH DC LINK ENERGY DISSIPATION

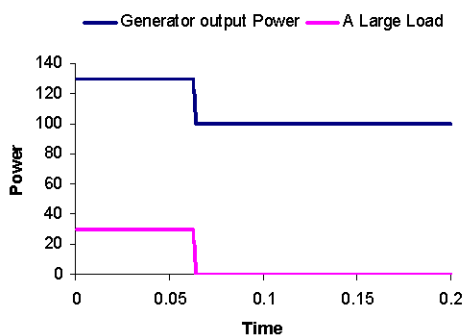


Figure 2a. a large load being removed from the aircraft power system

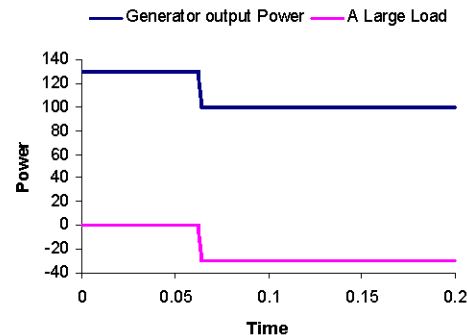


Figure 2b. a large load regenerating into the aircraft power system

FIGURE 2 - IMPACT OF A REGENERATIVE LOAD ON THE REQUIRED GENERATED POWER

It should be noted that if a relatively large load begins to regenerate, the time average impact on the power generated is the same as the shedding of a large load, as shown in Figure 2 (assuming that regenerated energy is allowed into the aircraft EPS), although large loads being removed will not happen as frequently as regeneration from, for example, actuators. These two simple examples are very similar from the point of view of the generator power flow and control. This philosophy extends to more complex situations as long as there are more power consuming demands than regeneration (net power consumption) at any given time. A protection system could be used to avoid this potentially dangerous situation; some of these options are discussed in more detail in the sections below.

5. APPROACHES FOR DEALING WITH REGENERATED ENERGY

This section considers and categorizes a wide range of options for dealing with regenerated energy, and may be included in future power quality specifications. Each option requires its own infrastructure and control, and the chosen technique would need to be justified in terms of weight, volume, reliability, and failure modes effects and criticality. There are a number of options that could allow the power quality [voltage regulation] of the EPS to be maintained whilst allowing loads to regenerate power when required:

- a. Centralized Energy Storage - allow regeneration into the aircraft bus and store any energy not used by another EPS load
- b. Centralized Energy Dissipation - allow regeneration into the aircraft bus and have energy dissipation on the power bus for when other loads are not present
- c. Local Voltage Control - allow regeneration into the aircraft bus, but only if the voltage at the point of common coupling is within defined limits
- d. Return Energy to Source - allow regeneration into the aircraft bus and use the generator as a motor if required, the regenerative energy would be returned to the engine, generator and/or gearbox as an increase in rotational kinetic energy
- e. Separate Bus for Regenerative Energy - do not allow regeneration onto the main aircraft bus, but add an additional, relatively unregulated bus to distribute regenerated power
- f. Local Energy Dissipation (most common practice)— do not allow regeneration onto the aircraft bus and ensure that each item of equipment has energy dissipation if required
- g. Local Energy Storage - do not allow regeneration onto the aircraft bus and have energy storage within each piece of equipment
- h. Hybrid Structure with Local Dissipation - do not allow regeneration onto the main aircraft bus, but hide the potentially regenerative loads behind a uni-directional power converter such as a TRU.

These and other methods of processing regenerated energy can yield a small overall power saving on the aircraft EPS versus conventional practice, but this saving is small in comparison to the capacity of the overall electrical system. For the purpose of this AIR, the impact of the power savings will be considered negligible.

a. Centralized Energy Storage

It is possible to arrange each power bus to have an energy storage facility in order to store the regenerated energy for use later. This energy storage would have to be controlled centrally in conjunction with the control of the generator in order to maintain good control of the bus voltage and to limit energy into bus faults. This energy storage could take many forms: rechargeable batteries, regenerative fuel cells, capacitors, flywheels, etc. This stored energy can then be used later in the flight to supplement generator power. There may be additional benefits related to system stability by having this source of energy storage on the bus.

Centralized or distributed energy storage may require large peak power levels which may be design drivers for the batteries. Peak charging current is critical for these batteries. In electrical or hybrid cars, the battery is already large, so the regeneration requirement doesn't make it bigger. For aircraft power systems, the regeneration requirement will drive the size of the battery.

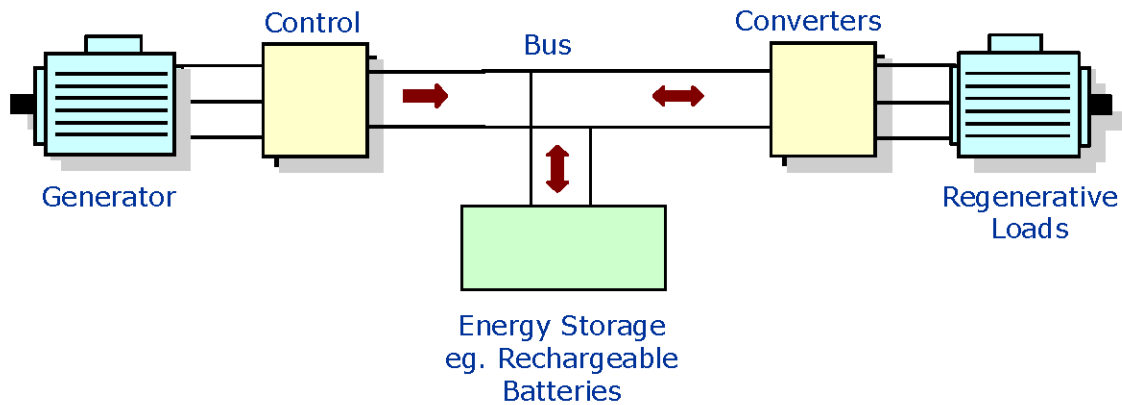


FIGURE 3 - CENTRALIZED ENERGY STORAGE

b. Centralized Energy Dissipation

Each power bus could have some form of energy dissipation circuit. This energy dissipation circuit would be used if the amount of regenerative power is higher than the power being taken by other loads. Using this centralized control method would allow the voltage on the bus to be controlled during any regeneration event. The use of a centralized energy dissipation circuit may reduce the size and weight of equipment when compared to dissipating the energy in every regenerative load. The control provided would also yield a benefit in that other loads could potentially use the regenerated energy. It is also possible that existing equipment could be used to provide this energy dissipation. For example, the Wing Ice Protection System [WIPS] heating mats on the aircraft wings could be used for energy dissipation during regeneration. In theory, only limited extra equipment would have to be added; In practice, however, system reliability constraints may require dedicated, and redundant, regenerated energy dissipation circuits for this critical function.

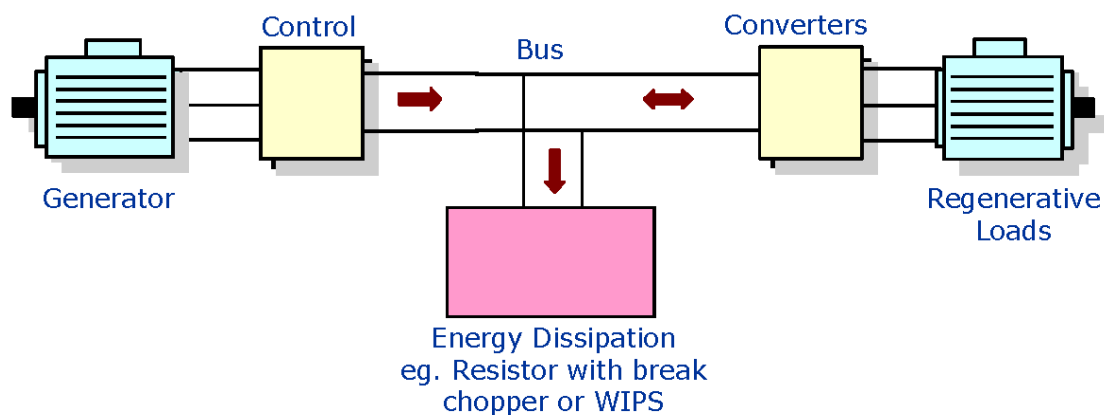


FIGURE 4 - CENTRALIZED ENERGY DISSIPATION

c. Local Voltage Control

Most power converters used in aerospace applications require some form of supply voltage measurement for their control and modulation. It would, therefore, be possible to allow loads to regenerate, but to specify that they must not increase the bus voltage at the point of connection above a specified level by means of limiting the power that the load puts onto the bus. The problem with this approach is the definition of the voltage level and the fact that if the load cannot regenerate all the power it would like to it will suffer from a lower performance under certain conditions or will have to include an internal energy dissipation element. If internal energy dissipation is needed then the benefit of allowing regeneration will be significantly reduced. This technique is most useful if another regenerated energy handling technique has failed, but a total loss of the given utility is unacceptable.

d. Return Energy to Source

Another solution to this problem could be to allow regeneration onto the aircraft bus and then to make it the responsibility of the generator to control the bus voltage, even under regeneration. As many generators can also be used as motors, it is typically possible for the generator to return the regenerative energy to the engine's rotational kinetic energy.

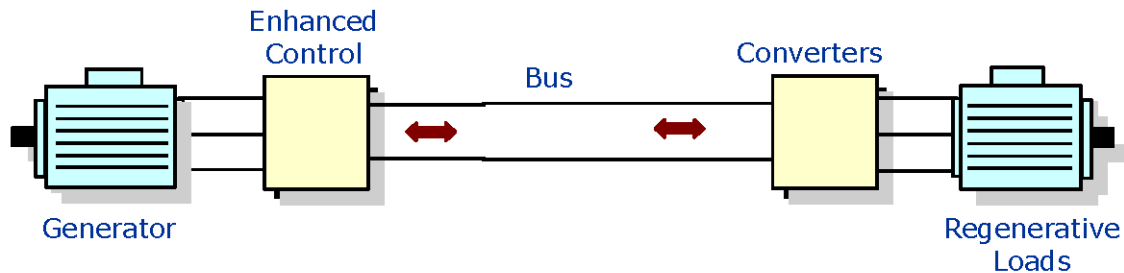


FIGURE 5 - RETURN ENERGY TO THE SOURCE

Obviously this solution would require a change in the approach to power generation and control for aircraft applications, but the technology used has been tried and tested in industrial applications over many years, so the risk is not excessive. The advantage of this solution is that no additional hardware will be required apart from modification in the control of the generator. A significant risk to this option is that a continuous path from the regenerating load to a source must be guaranteed under all conditions. Also, this option may not work with all gearbox designs.

e. Separate Bus for Regenerative Energy

It has been suggested that an additional 'regen' bus could be provided for regenerative energy. This bus would be used to move regenerated power from the regenerative loads to other loads which need power. However, the additional bus would add significant weight to the power distribution in the aircraft and would require addition complexity in the power converters. Cooperation in the control of the electrical loads would also be required, probably making this option unattractive for many aircraft platforms.

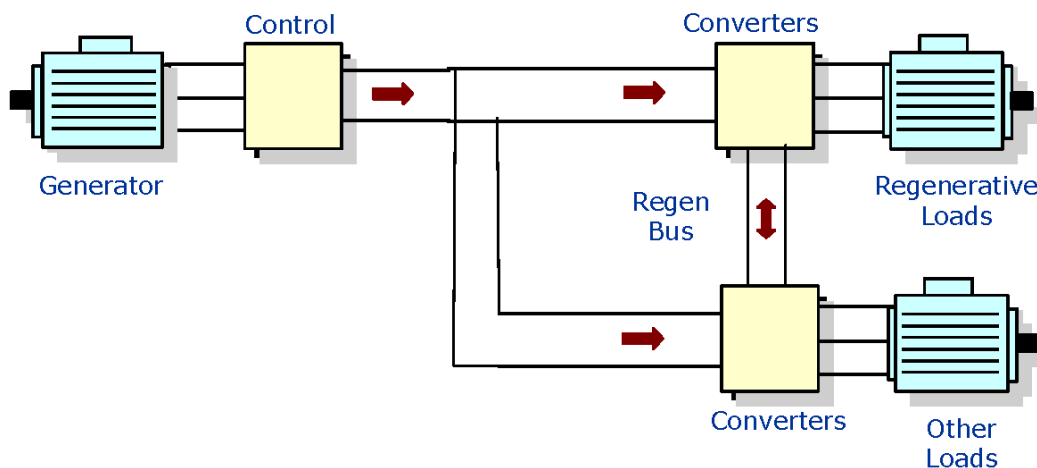


FIGURE 6 - SEPARATE BUS FOR REGENERATIVE ENERGY [A 'DIRTY' BUS]