



Ground-operated Energy Recovery System for Landing Aircraft

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Outline

- Background, motivation and economic potential
- Energy conversion
- Power conditioning
- Simulation results
- Future works

Background

- The UK Research Councils' Energy Programme, led by the EPSRC, organised a sandpit to Generate and Develop Innovative Approaches to Airport Operations in Nov. 2008.
- The objectives of the sandpit is to generate innovative research proposals relevant to airport operations, which has been identified as a gap in the portfolio of the Research Councils' Energy Programme in energy and transport.
- The primary drivers for this initiative are energy use and CO2 emissions reduction.
- The concept presented here is the outcome of the sandpit. It has great potential to reduce CO2 emissions and to improve energy usage and air quality.

Motivation

For an aircraft, weighing $m = 40$ tonne $= 4 \times 10^4$ kg with a touching down speed of $v_0 = 150$ mph $= 0.44704 \times 150 = 67$ m/s, the kinetic energy stored in the aircraft is

$$E = \frac{1}{2}mv_0^2 = 2 \times 10^4 \times 67^2 = 8.98 \times 10^7 \text{ Joule.}$$

Assume that the landing process takes about $T = 30$ sec, then the average rate of energy transfer is about

$$P = \frac{E}{T} = \frac{8.98 \times 10^7}{30} \approx 3 \text{ MW.}$$

If there is a landing every two minutes, e.g. at London Heathrow Airport, then the average power is 750 kW.

Economic potential

- Since the drag coefficient of aircraft is very small and the mass is very big, the recovering efficiency could be made relatively high. For similar applications in railway, currently see 31.3% efficiency; for cars, the efficiency is lower because of the higher drag coefficient, lighter weight and lower efficiency in processing the electricity recovered.
- Assume that the overall recovering efficiency achieved is 25%, the electricity to be generated during each landing is 6.25 kWh. Heathrow handles over 469,000 air transport movements a year and assume that half are landing. The potential electricity generated a year is 1465.6 MWh. This is equivalent to an annual carbon saving of 630 tonnes.

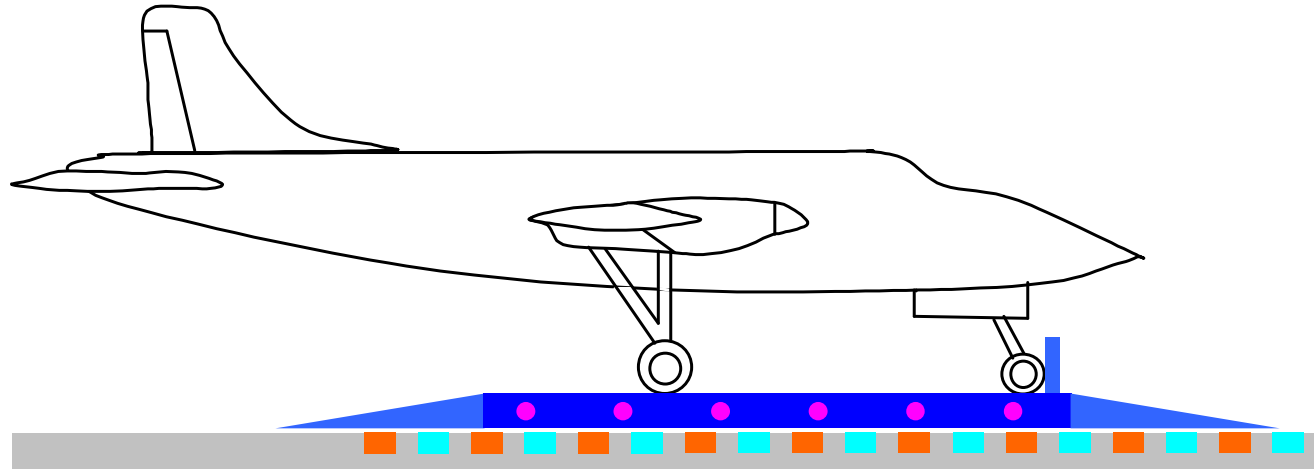
Other benefits

- The facility can be used for assisted take-off, which will considerably reduce the impact of carbon emission and improve air quality.
- Extending the facility to taxiway so that engineless taxiing and pushing back can be implemented, which will considerably improve the energy efficiency involved as the engine are designed to run at high speeds and the efficiency of the engine is very low at low speeds. The running of the engine also causes environmental issues such as increased emissions, noise, bad air quality etc.
- Reducing the amount of fuel to be carried for takeoff and landing/taxiing, which considerably reduces the energy consumption when travelling in the air.

Energy conversion

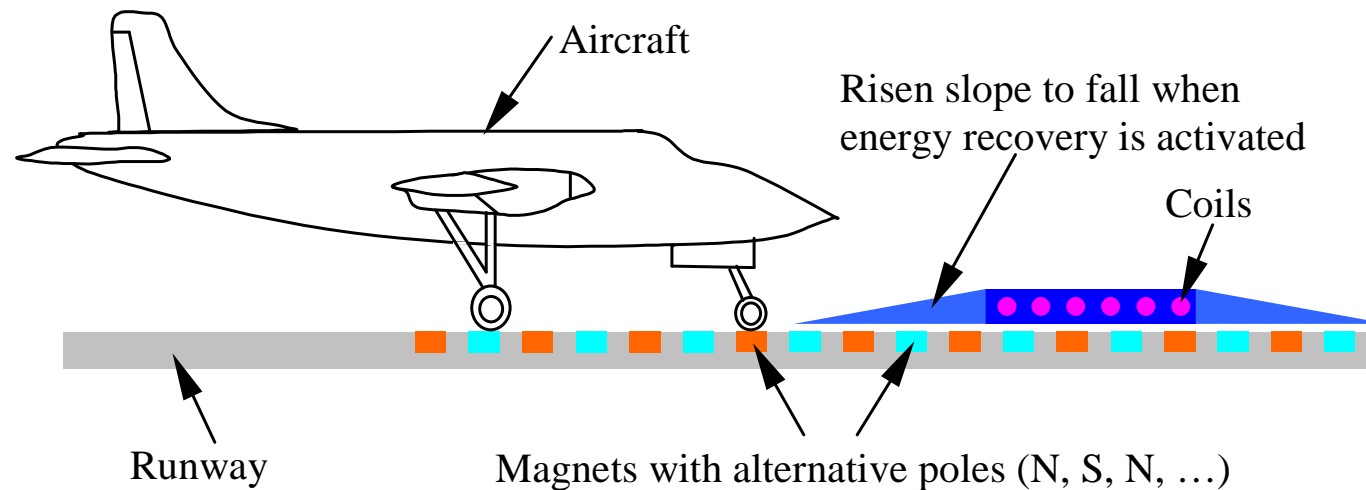
- Kinetic energy can be converted into electricity by using electric machines.
- One way is to mount a rotating machine on the undercarriage and then feed the electricity generated to the aircraft. By doing this, no work needs to be done to the runway and there is no need to involve the airport. The problem is how to store the recovered energy in the aircraft, as storing energy efficiently is still an open technical problem. In particular, for aircraft, this means considerable increase of weight in limited space.
- Another way is to change aircraft/runway into a linear machine and the interaction between the aircraft and the runway generates electricity.

Technical route I



Once the aircraft is landed, it moves onto the parking vehicle, which is equipped with coils underneath. Because of the inertia of the landing aircraft, the parking vehicle keeps moving forward. The electricity generated in the coils can then be processed by a power conditioning and control system on the ground. The generated electricity can be stored locally or fed back to the grid.

Technical route II



The aircraft does not move onto the vehicle but just pushes the vehicle forward. If there is a fault, the slope can be maintained and the aircraft can run over the vehicle or simply the vehicle can be removed from the runway. For this variant, it is possible to install rotary electric machines on the wheels of the vehicle. No changes need to be made to the runway and this is likely the easiest route to implement the concept.

Safety

Safety measures taken to minimise the impact when the aircraft touches the vehicle is the determining factor for success and special attention should be paid. One possible way is to drive the vehicle to an appropriate speed before the aircraft touches the vehicle. As there is no need to make changes to aircraft, there is no added weight to cause fuel penalty. It can be installed, managed and operated by airports only.

Modelling of the linear machine

The analysis of linear machine is quite similar to that of rotary machines. In general, linear dimensions and displacements replace angular ones and forces replace torques. The model described here is obtained according to the model of rotary synchronous machines developed in [Zhong and Weiss, 2009], assuming that the distance of travel is d , the speed is v and the acceleration is a .

The generated phase-a voltage is

$$e_a = 2\pi \frac{v}{\beta} K_f \sin \frac{2\pi d}{\beta},$$

where K_f is a constant and β is the distance between two N -poles (or two S -poles), i.e., twice the pole pitch. The other two phases are displaced by 120° . The electromagnetic force is

$$F_e = \frac{2\pi}{\beta} K_f \left(i_a \sin \frac{2\pi d}{\beta} + i_b \sin \left(\frac{2\pi d}{\beta} - \frac{2\pi}{3} \right) + i_c \sin \left(\frac{2\pi d}{\beta} - \frac{4\pi}{3} \right) \right)$$

and the movement of the linear machine is governed by

$$ma = F_t - F_e,$$

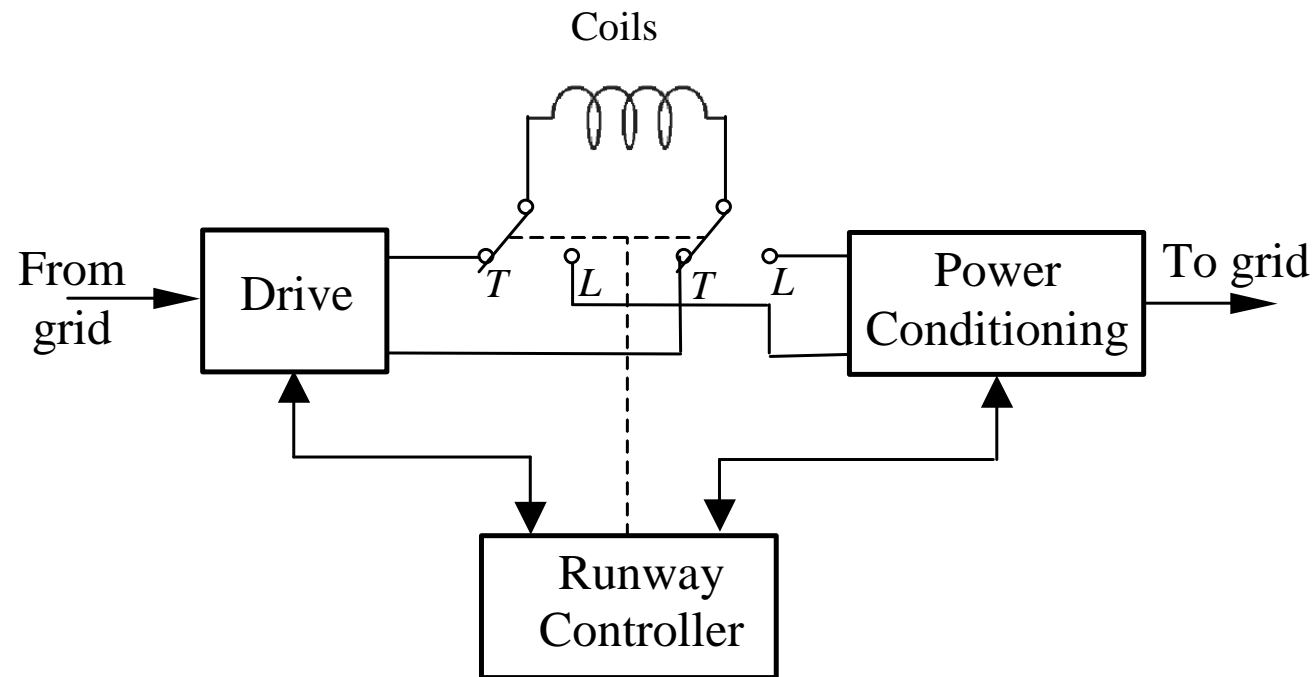
where m is the total mass of all the parts moving together and F_t is the thrust applied to the machine. Here, F_t is normally zero.

Power conditioning and control: Why?

- The electricity generated has a variable voltage and a variable frequency because the speed of the aircraft decreases when the time goes. Also the speed, mass and braking force of one aircraft are different from those of another.
- Moreover, aircraft land discontinuously, which means that the electricity generated is impulsive. Hence, there is a need to have a power conditioning and control system to process the electricity recovered from the landing aircraft.

Power conditioning and control: sketch

Two operation modes: Landing (L) and taxiing/takeoff (T).



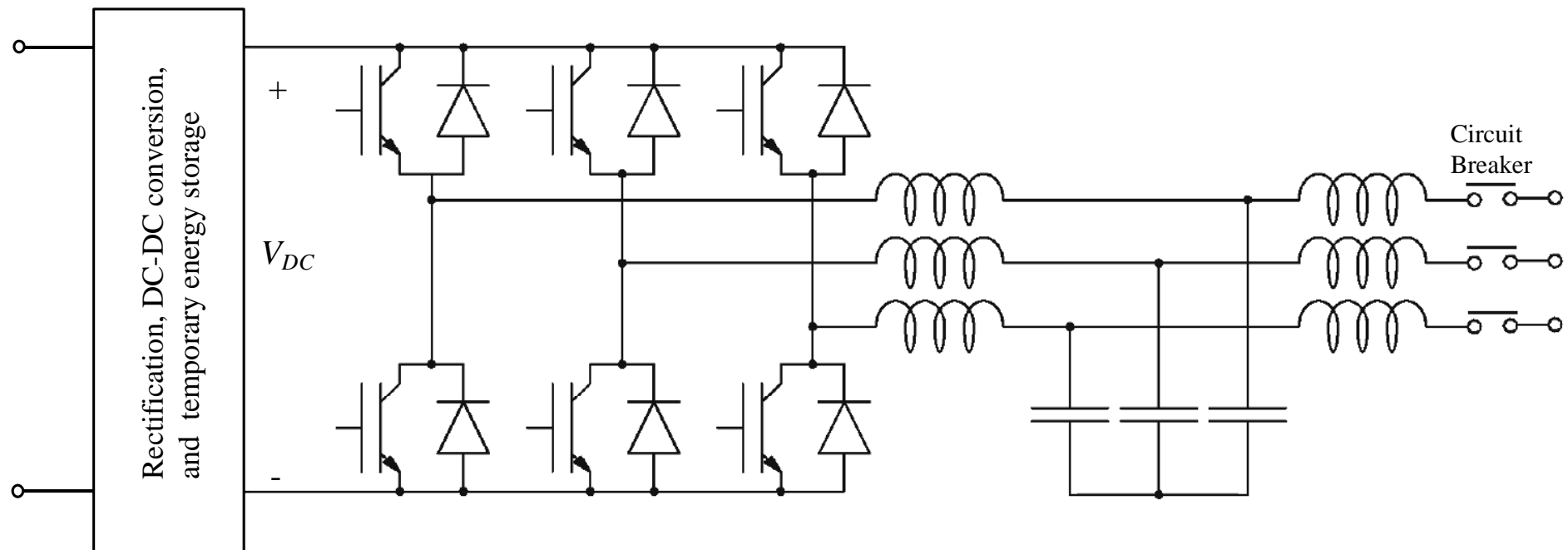
Power conditioning device



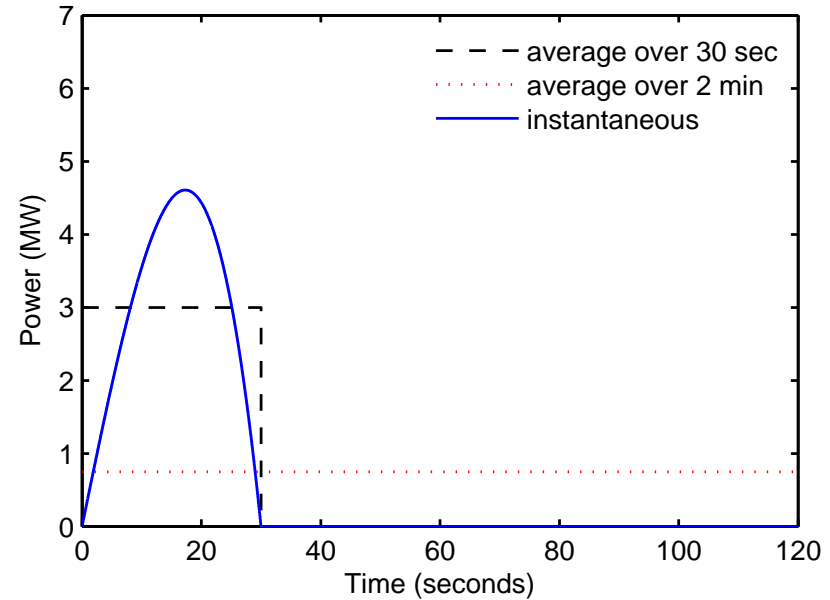
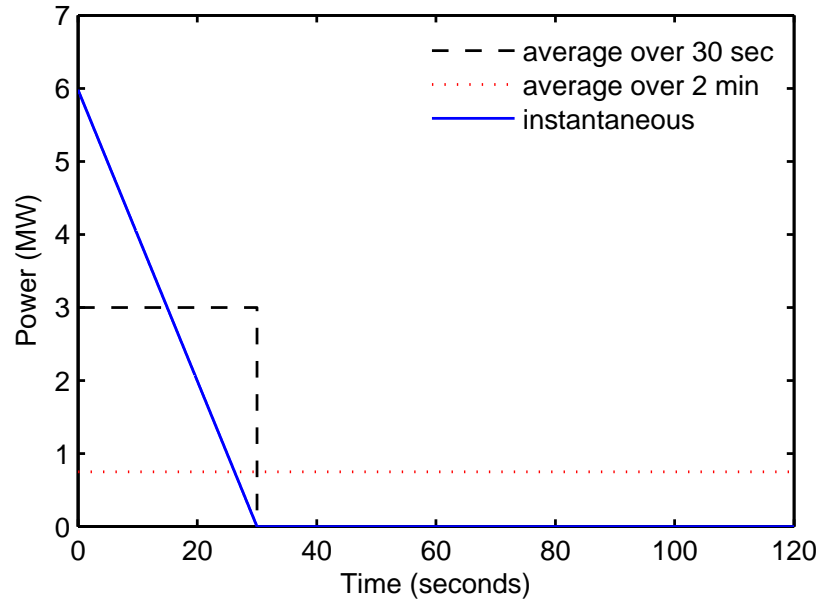
It consists of a rectifier, a DC-DC converter, a temporary energy storage system, and a DC-AC converter that interfaces with the power grid.



At the taxiing mode, the coils are energised so that the aircraft can be moved forward or backward. This involves running the machine as a motor in both directions and is implemented via a drive device. It is possible to combine the drive and the power conditioning device together by using a converter that could be operated in four quadrants.



Power profile



$$p = -F_e \cdot v = -ma \cdot (v_0 + at) \quad p = -ma_0t(v_0 + \frac{1}{2}a_0t^2).$$


(a) Constant deceleration

(b) Linearly increasing deceleration

Simulation results

Some simulation results are given to show the system behaviour, using the data and the model given above. In addition, assume the following:

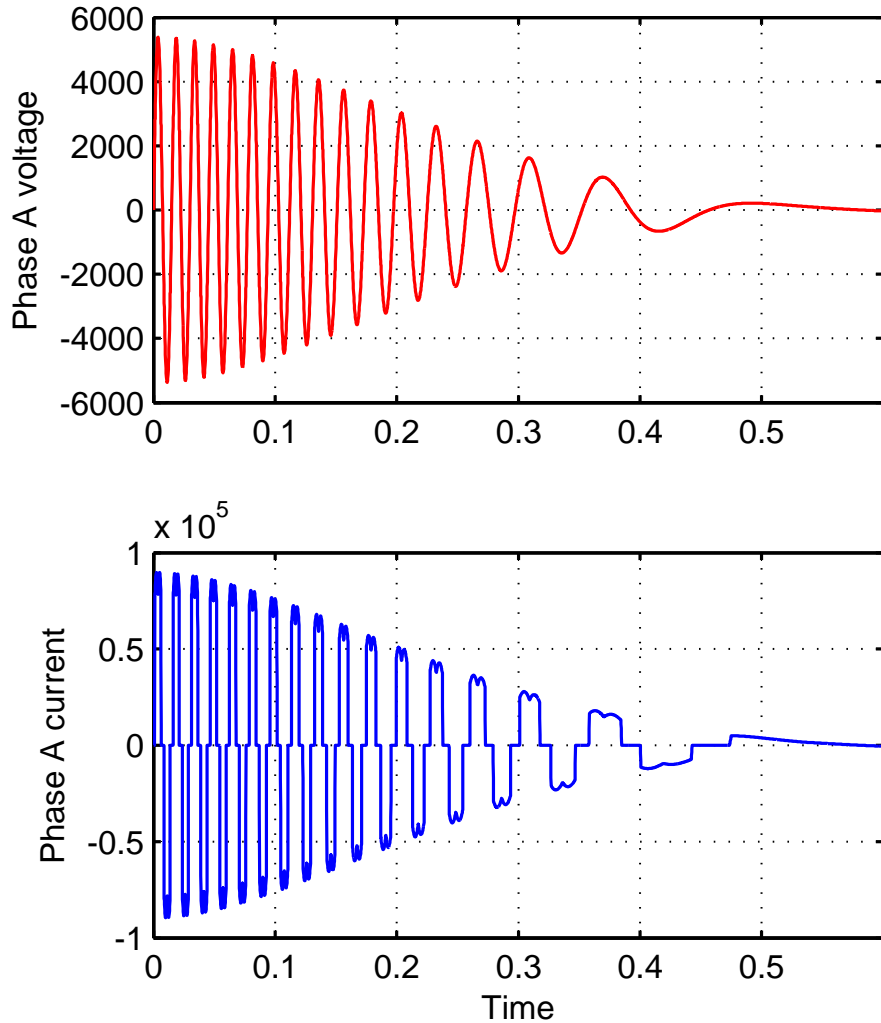
- The linear synchronous machine has a series resistance $R_s = 0.001\Omega$ and a low-pass filter $\frac{1}{0.1s+1}$ added to remove the ripples in the currents (and hence in the electromagnetic force);
- $\beta = 1\text{m}$;
- The generated line-line voltage at landing speed $v_0 = 67\text{m/s}$ is 6600V (with a frequency $f = \frac{v_0}{\beta} = 67\text{Hz}$).
- The recovered energy is supplied to a resistive load via a three-phase diode rectifier.



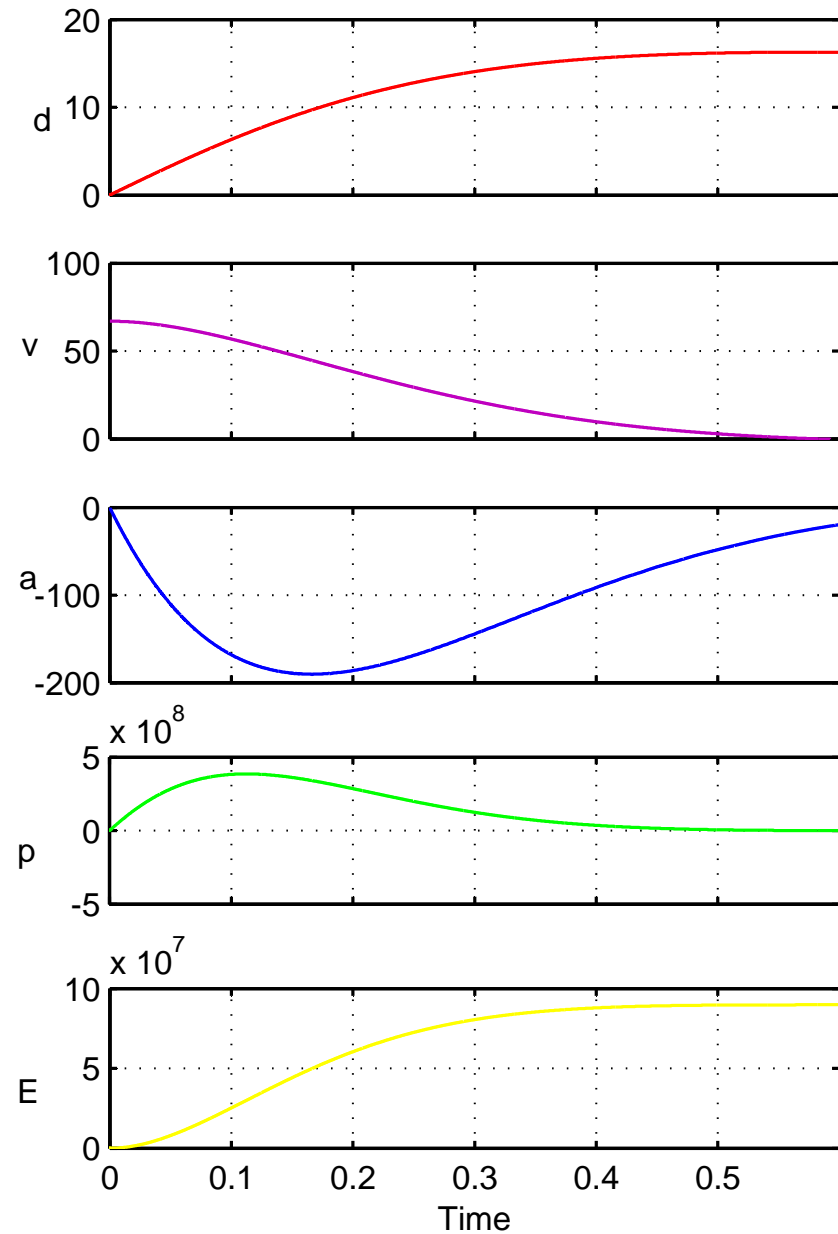
In order to understand how the system behaves, a very heavy load $R = 0.1\Omega$ was connected to the DC-bus of the rectifier.

One particular characteristics of the system is that the generated voltage has a varying voltage and a varying frequency, as the speed of the aircraft changes. This makes the use of a PWM-controlled rectifier very difficult. The amplitude of the current also varies as well. In this simulation, the aircraft was decelerated heavily and stopped in less than a second. All the kinetic energy was recovered. In reality, the recovery efficiency will be much lower because of various losses that are not modelled in the model.

System behaviour: $R = 0.1\Omega$

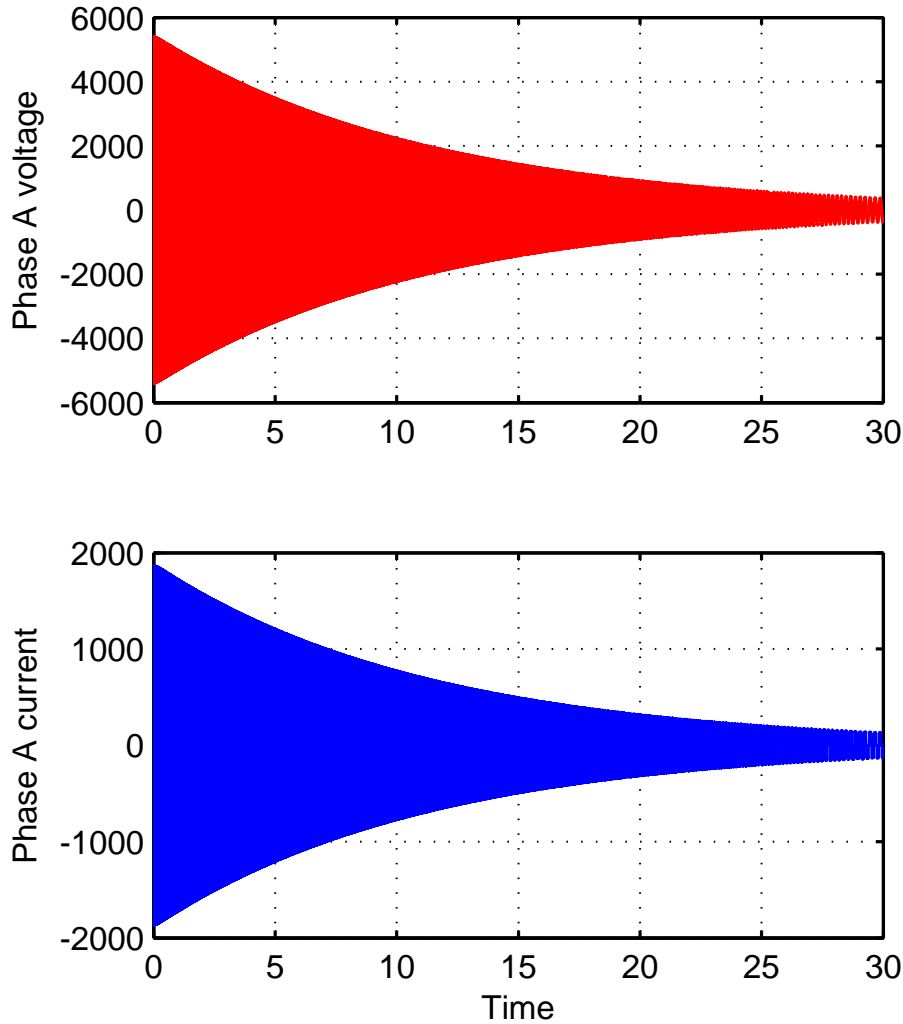


(a) Phase current and the generated voltage (phase)

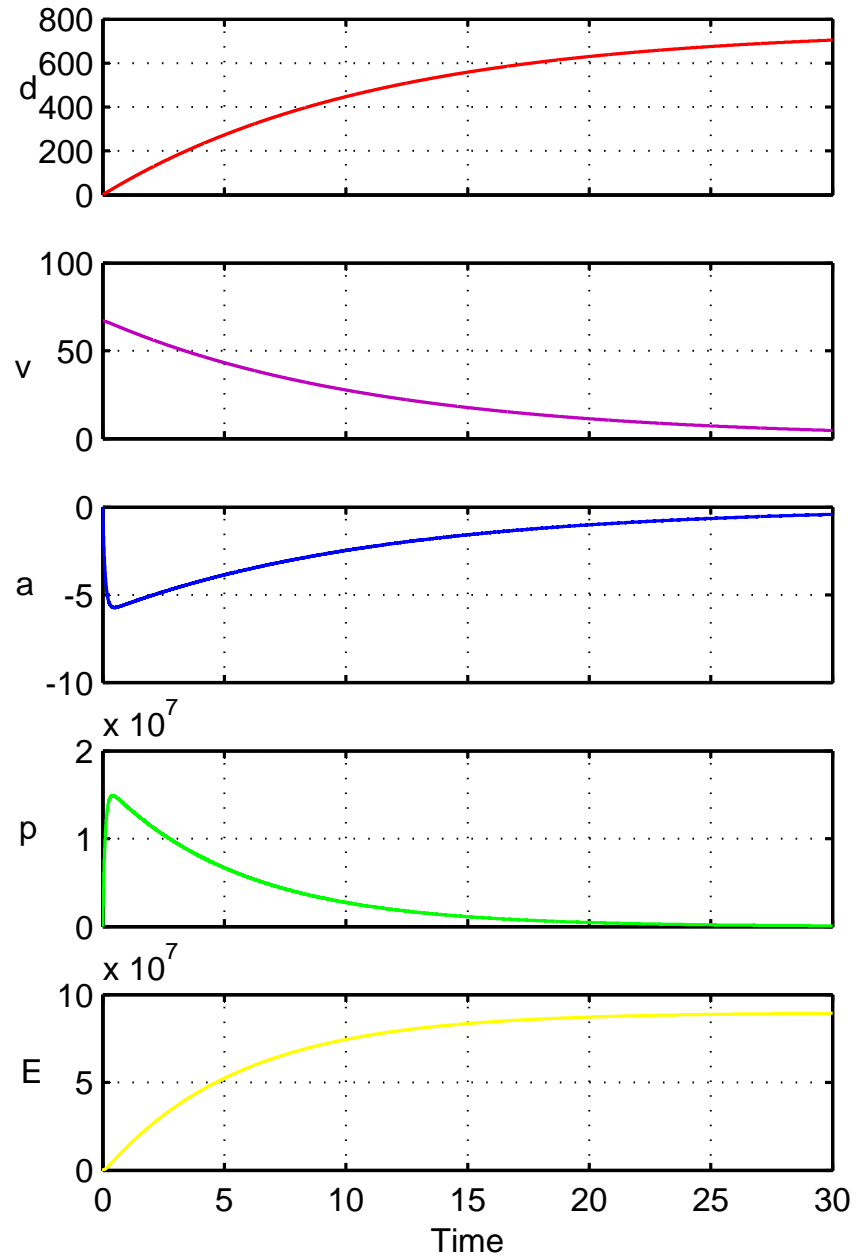


(b) Distance, speed, deceleration, power and energy

A realistic scenario: $R = 5\Omega$



(a) Phase current and the generated voltage (phase)



(b) Distance, speed, deceleration, power and energy

Future works

This is a completely new concept. There are many issues to be addressed. Some of them are listed below:

- To identify an optimal topology of the electric machine
- To investigate the mechanical impact of the energy recovery system on the aircraft
- To identify a solution for processing impulsive transient power, including a fast-responding energy storage system, to minimise the impact on the connected public grid
- To develop a complete control system for safe operation
- To identify an optimal deceleration profile without compromising passenger comfort and causing extra difficulty for power conditioning