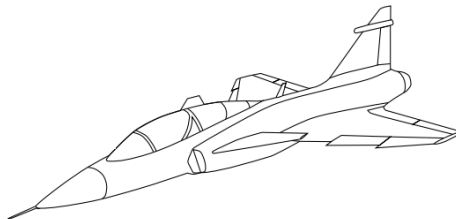


# Design Specification Future Aircraft Energy Management Systems

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# 1 Introduction

This document is the design specification for the project *Future Aircraft Energy Management Systems* in the Automatic Control - Project Course (TSRT10) at Linköping University autumn term of 2021.

This is a new project at Linköping university, supported by Saab Aeronautics who is the main stakeholder and customer. The project is a bilateral collaboration between the departments IEI/Flumes and ISY/Vehicular Systems. Two projects, one from each department, will work together to deliver the final demonstration. The IEI-project will focus on the development and implementation of the aircrafts electric consumers while this project (the ISY-project) will focus on the electric supply system and energy management. The purpose of this document is to specify the design specification for the project.

## 1.1 Background and purpose

The aircraft industry is trending towards electrification, also known as More Electric Aircraft, MEA. Electrification is expected to help the industry reach future objectives such as reduced aircraft weight, increased efficiency, lower maintenance and higher safety. In practice this means the development and implementation of a more efficient electric power distribution, more efficient and electric driven components and intelligent control of available power. Energy management will be important when more high power electric consumers, such as actuation system and sensors, are integrated in the aircraft.

The scope of this project is to develop a Digital Twin of the power generation system, streamline the energy consumption of the Iron Bird and to ensure that the tactical system gets the desired power, with help of a control system. To reach the objective, the Iron Bird needs to be prepared with the development and implementation of the electric power distribution system, power consumers and control strategies.

## 1.2 Definition of terms

- **AC** - Alternating current.
- **BAT** - Battery.
- **DC** - Direct current.
- **Digital Twin / D.T** - Virtual representation of a physical object or system.
- **EHA** - Electro Hydraulic Actuator
- **EMA** - Electro Mechanical Actuator
- **FAEM** - Future Aircraft Energy Management Systems.
- **ICD** - Interface Control.
- **Iron Bird** - The test rig used in the project.
- **ME** - Main Engine.
- **MEA** - More Electric Aircraft.
- **MGEN** - Main Generator.



- **SHA** - Servo Hydraulic Actuator
- **SSPC** - Solid-State Power Controllers.
- **VDC** - Voltage of direct current.
- **PSU** - Power supply unit.
- **PCU** - Power consumption unit.

## 2 System overview

This project can be divided into two separate parts. The first part consists of control and modelling of the aircraft energy management system. The purpose here is to develop a Digital twin of the power generation system. The Digital twin will consist of models for each component as well as control strategies for the power system.

The second part consists of setting up the hardware. The hardware consists of a PC, real time computer (speedgoat), PSU, PCU and Iron bird. The purpose here is to connect everything so that it's possible to simulate the Digital twin both digitally and with real hardware.

These systems are developed side by side but the idea is that these systems should be integrated and work together. Both systems shall also work together with an aircraft simulator called JSBSim. The simulator takes in values such as rudder angles from the actuators and outputs information about the aircraft that can be used in the models.

The complete system is illustrated in Figure 1, which also denotes the power systems Digital Twin that shall be developed during the project.

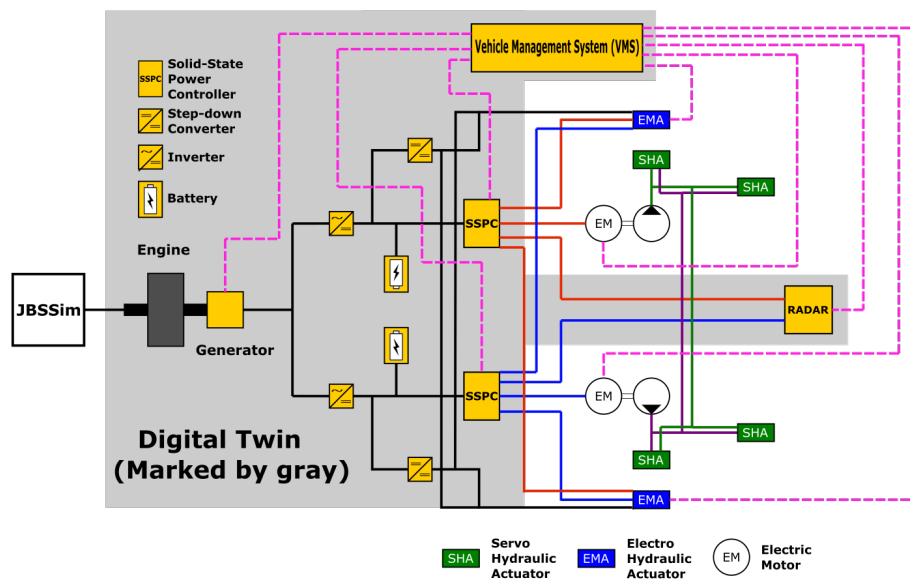


Figure 1: System overview



### 3 Models and modelling structure

At this stage in the project, a brief design for every model of the system has been made. These are presented below in the sections Energy producing components, Vehicle management system, Physical components and Energy consuming components.

#### 3.1 Subsystem 1 - Energy producing components

##### 3.1.1 Main engine

The main engine is the first model for the system, that dictates how much power the generator can produce. One way to model the engine is to have an RPM speed as output that can be used in the generator. However, the JSBSim flight simulator has not got this output value. Therefore, the first model will instead use the throttle angle as input to calculate the available power.

A more complex model for the main engine could be designed to include the thrust used to move the aircraft forward. This can be used to determine how much power can be used to produce electric power and how much is needed for propulsion. The model created now uses a lookup table between throttle angle and power from the engine. A throttle angle of  $\pi/2$  rad generates maximum specified power, and an angle of zero rad generates the specified idle power.

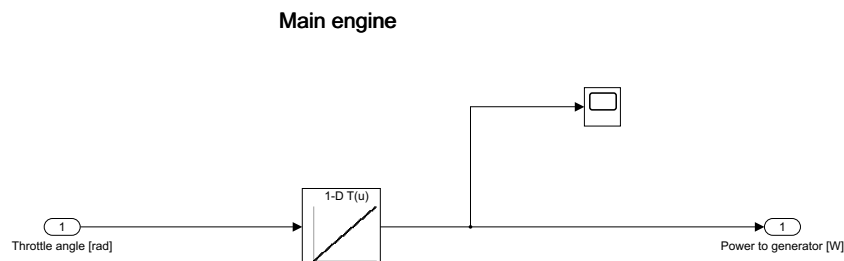


Figure 2: Main engine



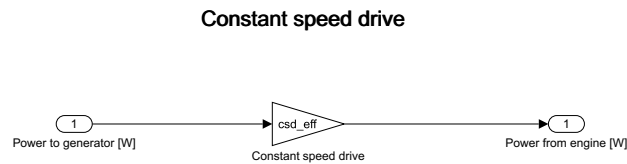


Figure 3: Constant speed drive

### 3.1.2 A/C Gearbox

The A/C gearbox is directly linked to the main engine and transfers power of the engine axle and reduces the RPM to a suitable range for the CSD to work with. This component is not modeled in this project. The needed inputs would be the engine rpm and available torque (re-calculated from thrust).

### 3.1.3 Constant Speed Drive (CSD)

A constant speed drive (CSD) is a type of transmission which takes an varying rotating shaft as input, delivering the power to an output shaft that rotates at a constant speed.

The idea is that the CSD is placed between A/C gearbox and generator providing the generator with a constant speed even though the shaft from A/C gearbox varies. Since the main engine is modeled only with throttle angle as input and mechanical power as output, the CSD is also simplified.

To make the CSD model as simple as possible, the CSD is modeled as a loss of power. This can then be further developed in the future to include RPM speed and more realistically model a CSD.

### 3.1.4 Main Generator (MGEN)

The generator model one of the more complex models in this project. It has four different input, Power from engine [W], Desired power  $P_d$  [W], previously generated electrical power  $P_{e\_old}$  [W] and Consumed current  $I_c$  [W]. These four inputs are used to model

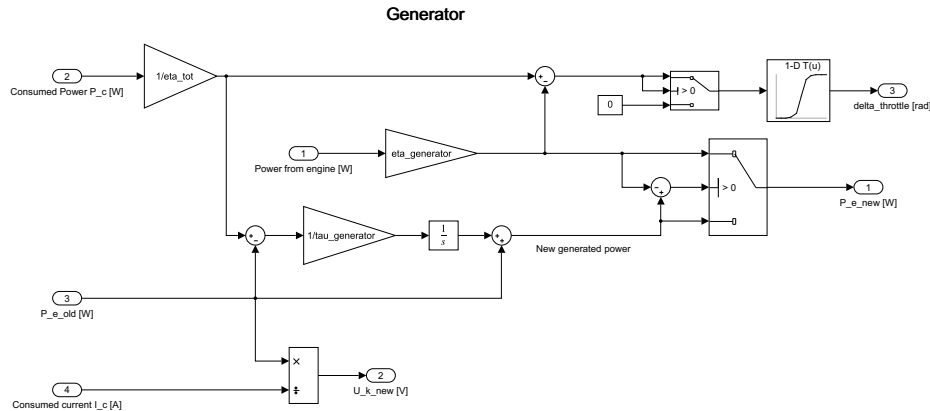


Figure 4: Generator

three outputs, generated electrical power  $P_{e\_new}$  [W], voltage to Keysight  $U_{k\_new}$  [V] and change in throttle angle  $\text{delta\_throttle}$  [rad].

The previously generated electrical power and the consumed current are used to determine what voltage the generator is producing. This information is sent to the Keysight. This part of the model will be extended to include the reference voltage of 270V.

The variable Desired power  $P_d$  is the value that the IEI group calculates as their desired power that the actuators and radar consume. If this value is higher than the previously generated electrical power, the generator should increase its power generation. This is done based in the variable  $\tau_{generator}$ , the time constant for the generator, that models how fast the power generation can change. At the end this value is compared to the available power from the engine and the lowest value is chosen as  $P_{e\_new}$ .

The change in throttle angle is calculated as the difference between desired power and the power from the engine. If the desired power is higher an increase in throttle angle is sent to JSBsim.

### 3.1.5 Rectifier

The main task of a rectifier is to convert the alternating current to direct current, which simply means that input to the rectifier is AC and output is DC. The simplest model of



this is with an ideal single-phase full-wave rectifier, which output is

$$\begin{aligned}V_{DC} &= \frac{2 \cdot V_{PEAK}}{\pi} \\P_{DC} &= \frac{2 \cdot V_{PEAK}}{\pi} \cdot \frac{2 \cdot I_{PEAK}}{\pi} \\P_{AC} &= \frac{V_{PEAK}}{\sqrt{2}} \cdot \frac{I_{PEAK}}{\sqrt{2}} \\ \eta &= \frac{P_{DC}}{P_{AC}} \approx 81\%\end{aligned}$$

where  $V_{PEAK}$  is the AC input voltage,  $I_{PEAK}$  is the AC input current. Single-phase is used as an initial model to keep it simple, but a three-phase network would represent the true system better and may be modeled if time allows.

### 3.1.6 Battery

The battery will act as an energy storage component in the system. In the case of engine-or generator failure, the battery shall supply the system with power. Important parameters include:

- State of charge (SoC): The level of charge relative to the electric battery's capacity. The units of SoC are measured in percentage points where 0% = empty and 100% = full.
- The voltage when the battery is fully loaded at no charge ( $V_0$ ): Will be defined by the nominal voltage.
- The constant  $\beta$ :  $\beta$  is calculated so that the battery voltage is  $V_1$  when the charge is  $AH_1$ . The ampere-hour rating  $AH_1$  is the charge when the no-load voltage is  $V_1$ , and  $V_1$  is less than the nominal voltage  $V_0$ .

The voltage will be a function of the charge and will have the following relationship:

$$V = V_0 \left( \frac{SoC}{1 - \beta(1 - SoC)} \right) \quad (1)$$

Later on, charge dynamics, thermal effects and battery aging may be included in the model.

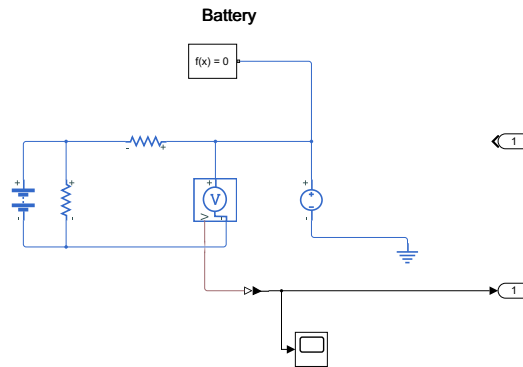


Figure 5: Battery

### 3.1.7 SSPC

Solid state power controller (SSPC) is semiconductor device that controls the power supplied to a load. The SSPC monitors the electric system, protecting it from overload conditions or prevent short circuits.

The main purpose for the SSPC is protecting the power consuming components of the aircraft. E.g. If an actuator suddenly demands a higher power this will lead to a rapid increase in current. To protect the electronic circuit the SSPC will limit the maximum flow of current.

The SSPC will be modelled as simply as possible. The SSPC model has multiple inputs which many can be lumped together. In summary all power that is intended for the 270 V system will pass the SSPC. It will also have inputs from the VMS, specifying the operating voltage and current for the electric system.



### 3.2 Subsystem 2 - Vehicle management system

The vehicle management system will be used to control different inputs to certain models. It takes in information about the current state of the power generation system.

The VMS controls the power generation in the generator. It takes in information about desired power and the previously generated power and sends this information to the generator model. The difference between these is used to model an increase or decrease in magnetizing current in the generator. It also calculates a change in the throttle angle based on the difference in desired power and available power from the engine and sends this to JSBSim.

The VMS controls when to use the battery to supply the components. Different control strategies can be used for this. The simplest one is to only use the battery when no power is supplied from the generator, for example if the engine dies. A more complex strategy is to use the battery to balance the loads from the actuators and radar. Then the battery can be discharged and charged to help stabilize the voltage from the generator.

The SSPC's maximum allowed current and voltage for each component is set by the VMS. This is calculated using available power and voltage from the generator. If, for example, the radar is activated and the actuators need more power the SSPC should limit the voltage and current flowing to the radar to ensure the control of the aircraft.



### 3.3 Subsystem 3 - Physical components

Subsystem 3, Physical components, consists of hardware in the system related to the power supply and the communication between components. This section will explain how the system is built up in form of hardware and the connections that has to be made for a complete system. There are four main connections which has to be established to get a complete system. All connections are established with help of Ethernet communication. When established a Ethernet connection communication occurs both way. This means that there is no need of two cables for communication back and forth but rather all communication goes through one Ethernet cable.

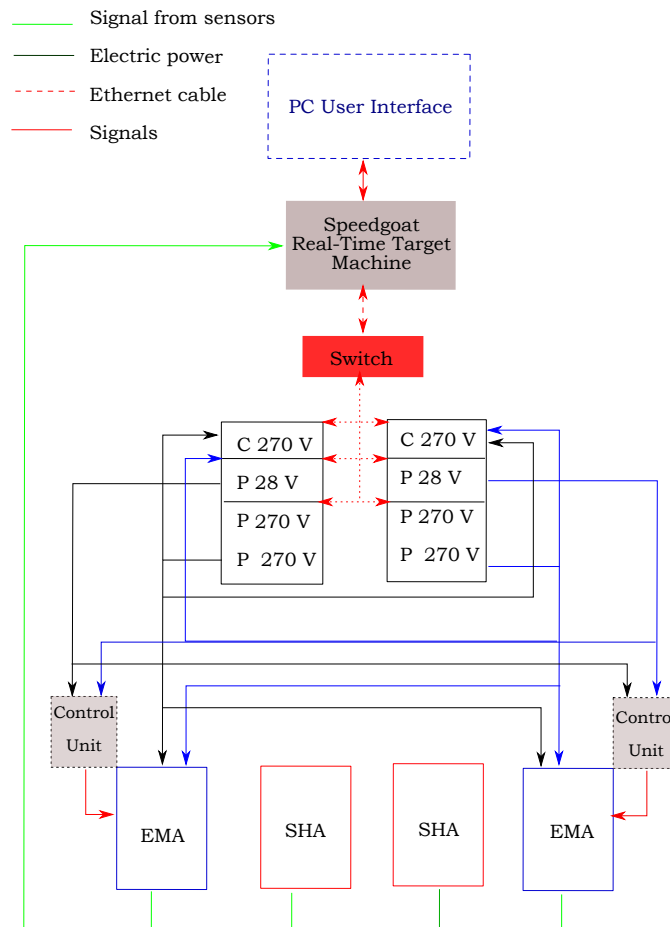


Figure 6: Visualization of hardware setup.

#### 3.3.1 PC↔ Speedgoat

PC, here is where all simulink/matlab files can be executed. The PC is connected to the speedgoat. The connection is established via an Ethernet connection. With the speedgoat comes software as in MATLAB libraries. These libraries are developed by speedgoat and helps set up the connection between the PC and the speedgoat.

The purpose with this connection is to compile and send the information located on the PC to the speedgoat.

### 3.3.2 Speedgoat↔Keysight

This connection is set up to enable communication between speedgoat and keysight products, PSU and PCU. In the beginning of the project, the goal is too establish connection and being able to communicate between speedgoat and one PSU. But as the project progresses, communication between speedgoat and more than one PSU should be made.

In the latter option that communication takes place between more than one PSU and speedgoat a switch has to be implemented to enable communication. In that case the connections will be created as in Figure 6, **Speedgoat↔Switch** and **Switch↔Keysight**. Here the switch will act as a form of distributor and enable multipath communication.

Broadly speaking, it can be said that the challenges lies in sending information back and forth between speedgoat and PSU. Since the idea is to connect these two devices with an Ethernet cable and send information back and forth, one has to establish something which makes this communication possible. By setting up a TCP client one allows connecting, sending and receiving data over a network.

An example of how to establish TCP client and how it can be implemented can be seen in figure 7.

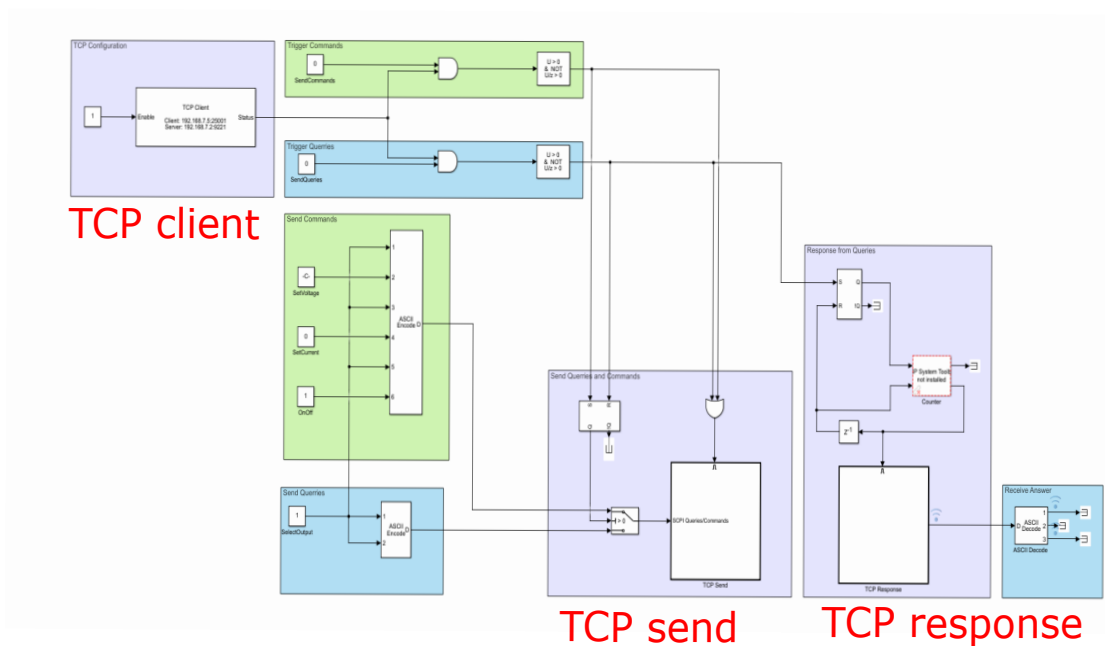


Figure 7: TCP setup

The TCP client consists of three main blocks. **TCP client** which establish a server and enables for transfer of data between speedgoat and PSU. This block takes in IP addresses



from each of the devices that should be connected. It also consists of **TCP send** and **TCP response**, which are blocks necessary to send and receive messages between the two devices.

### 3.3.3 Keysight↔Control Unit

The Keysight PSUs will supply the actuators with electronic power, at 28V and 270V. The 28V PSUs will supply the actuator sensors. While the 270V PSUs will supply the power to move the EMAs.





### 3.4 Subsystem 4 - Energy consuming components

Subsystem 4 consists of models for the energy consuming components which creates the IEI group's digital twin. Figure 8 shows how the D.T consumer is modeled.

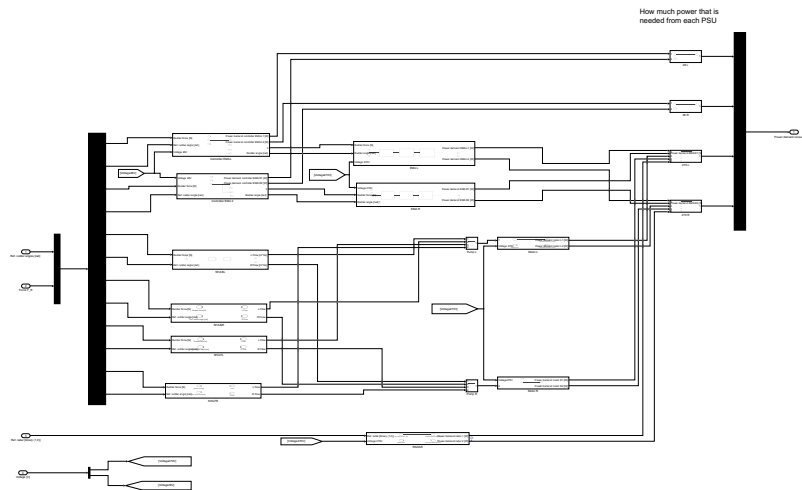


Figure 8: An overview of D.T consumer

The components include 2 EMAs and their corresponding controller. The EMAs are supplied with 270V while the controllers are supplied with 28V. There are also 4 SHAs, that run on pumps driven by motors. The motors are supplied with 270V. The voltage that the components are supplied with is the voltage that the power generation system can supply. The consumed power by the components is then fed back to the power generation system.



## 4 Interface and simulation

The idea is that the complete system should be possible to simulate in one simulink file. The simulink file should be possible to run by a PC computer. But for the simulation to be executed in real-time, the simulink must be ran by the real time computer (speedgoat). However, by connecting the PC with the Speedgoat it should be possible to compile the simulink file and run it from the Speedgoat. By using built in matlab libraries, which is supplied by speedgoat this connection is already established. The supplied libraries enables to create a simulink real time file, which then is compiled and able to be ran via the Speedgoat. The simulink real time file will consist of three main parts, *JSBsim*, *Digital twins* and *communication with keysights*.

### 4.1 JSBsim

JSBsim is a open-source Flight dynamic model (FDM) software which models the flight dynamics of an aerospace vehicle. This block will take in actions and information for a given flight mission that is to be performed. These actions includes parameters as, height, throttle angle, different aircraft rudder angles etc.

The Simulink block of JSBsim will act in between the two Digital twins (D.T). For a given flight mission there will be actions that the pilot wants to execute. These actions go into the D.T consumer. The D.T will in turn provide JSBsim with input signals. For example, if the pilot wants to turn left there will be a change of rudder angles. Models in the digital twin will then calculate an actual rudder angle e.g., how much were the aircraft able to move its rudder angles. This information then goes into JSBsim which output flight dynamics e.g., forces acting on the aircraft. This information can then be used by the D.T consumer to compute how much power is used, which in turn becomes input for D.T producing.

### 4.2 Digital twins

There will be two separate digital twin blocks which will work together but have been developed by the two different groups, IEI and ISY. One consisting of the producing components of an aircraft, included with a overall control system. The other digital twin will consist of the consuming components. For a complete system these two digital twins will have to be implemented so that they work together.

### 4.3 Communication with keysight

To create a system where hardware can be simulated the main simulink file must contain a block which sets up communication between where the simulation takes place (speedgoat) and the hardware in form of keysight. This block will setup communication in form of a TCP client. The TCP client makes sure that communication can occur between speedgoat and keysights.



## 5 Tests and verification

To fulfill the requirement specifications some tests will have to be performed. These tests will be performed by connecting a simulink model to the Keysight PSUs via a speedgoat and thereafter send and receive signals to the simulink model. By doing these tests, the set requirements for function and performance of the models can be checked and fulfilled. The test plan includes more information on how exactly each and every test will be executed.