HYDROGEN SYSTEM

Launch Phase – 26-11-2010

This report covers the Launch phase elements for the Hydrogen subproject carried out by Team 4.

This project is a part of the Energy Hub Project.

The project is a mandatory part of the 3rd semester at the Electronic Design Engineer education at AU-IBT.

The Project has been supervised by Klaus Kolle and Morten Jakobsen both teachers at the Electronic Design Engineering program.

Lasse Lykkegaard

Dennis Thomsen

Knud Baastrup

Anna Zueva

Content

Preface

Lasse Lykkegaard

This report covers the launch phase of a hydrogen system project. The launch phase is a specified part of the EUDP-method.

It is based on the EUDP Pre-project of the hydrogen system, see enclosure A.

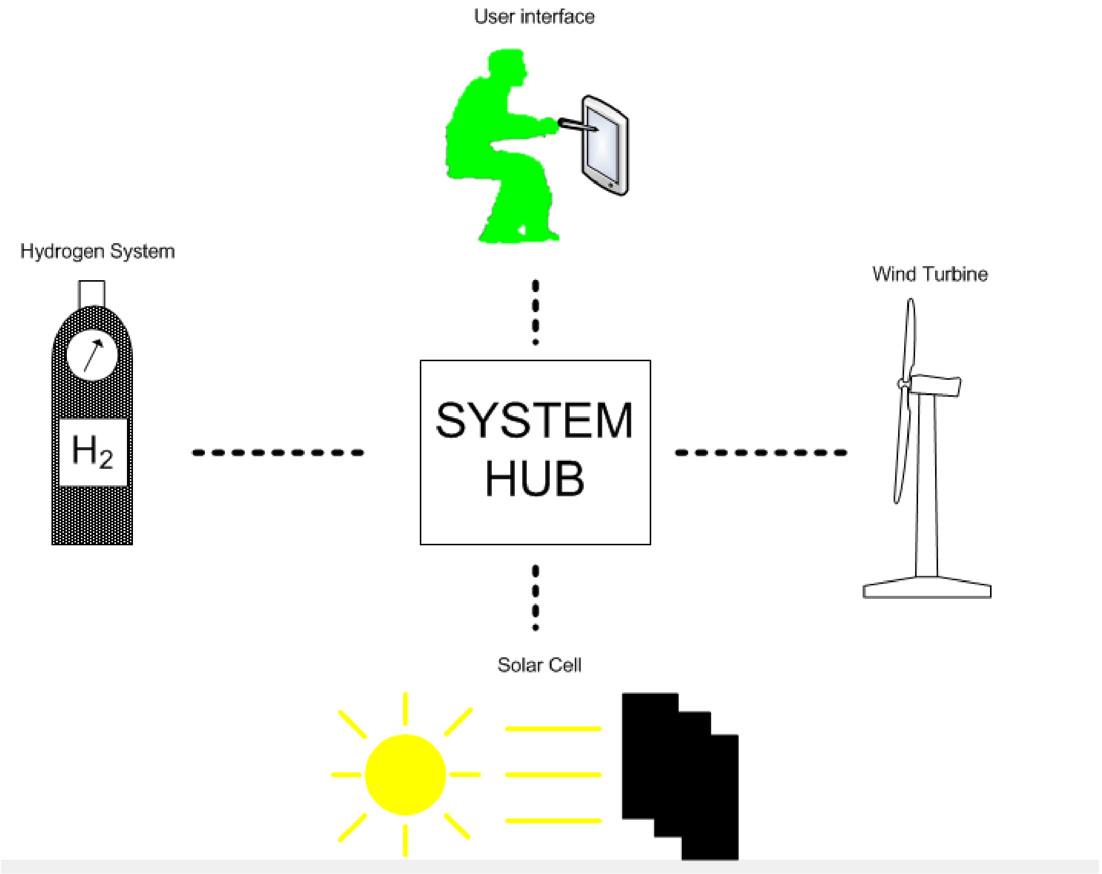
The content of the pre project will be further analyzed and a system model is being defined. Eventually this launch phase will be followed by the realization phase where the system-to-be are to be built.

The main goal is to deliver a project which meet customer demands, and also are implementable in the overall *Energy Hub project.* In which this is a subproject.

Basically we are asking ourselves the question "what?" and avoid thinking of "how?", sometimes it would be too cumbersome not saying "how", but in general we save the "how" for the very end of this phase.

This report is result of the 3rd semester project and the foundation for the 4th semester project of the EDE education at AU-IBT.

The hydrogen system project is a part of the energy hub project where energy producing or energy storing devices can connect and contribute to the system.

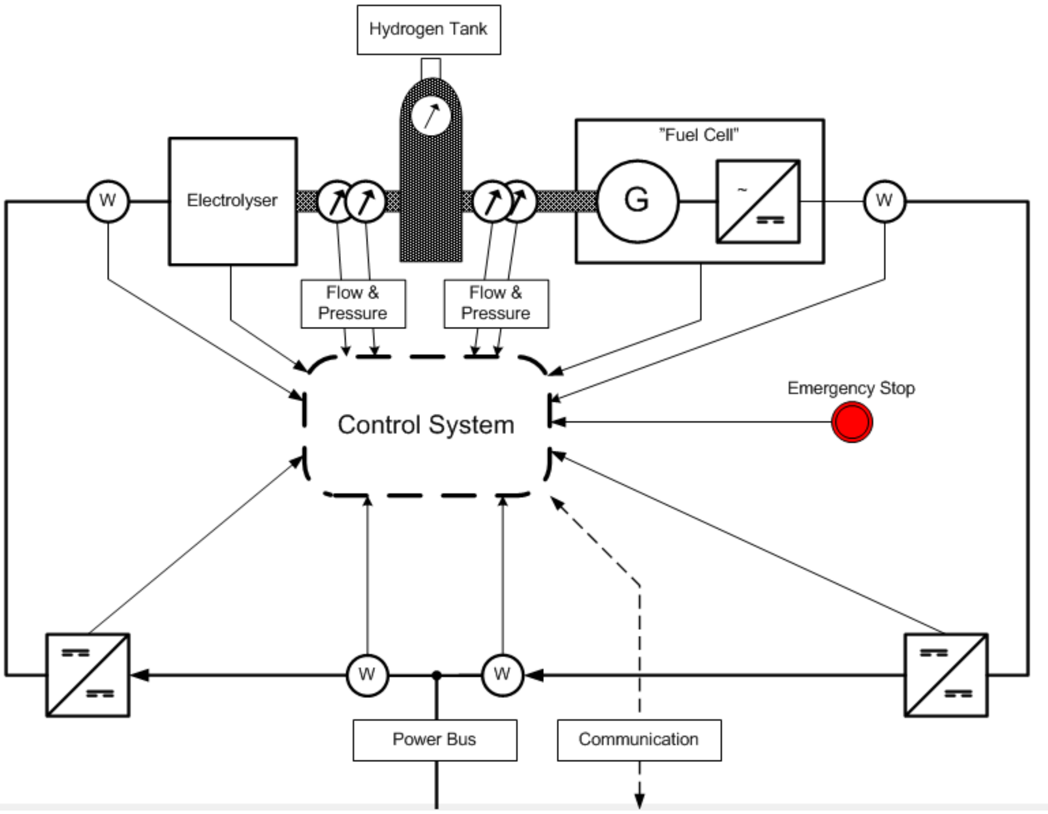


System Overview Diagram

Lasse Lykkegaard

The Figure below shows a System Overview Diagram that identifies the building blocks of the Hydrogen system.

The Hydrogen system basically is an energy storage system where surplus energy is converted to hydrogen in an electrolyzer, and stored. When in need of the stored energy, the system will transfer the hydrogen back to energy in a Fuel Cell. The subsystem is connected to other devices through a Power Bus and a communication bus.



CLASS ANALYSIS

Knud Baastrup

The Class and Event candidates has been explored and combined into a Class Event Table, which together with the System Diagram have served as input for the Class Diagram. The more complex classes have furthermore been described in terms of internal states in a State Machine Diagram.

Class Event Table

Knud Baastrup

The Class Event Table below combines the identified classes with the identified events. The table shows, which events that is expected to be handled by which classes and give in this way an overview of the responsibility and complexity of the selected classes.

Class / Event	Electrolyzer	Fuelcell	PowerBusToElectrolyzerConverter	FuelcellToPowerBusConverter	PowerSensor	FlowSensor	PressureSensor
startProduction	X	X					
stopProductionStop	X	X					
enablePower			X	X			
disablePower			X	X			
getConverterStatus			X	X			
setSystemData	X	X					
getSystemData	X	X					
getEfficiencyData	X	X					
getEfficiencyStatistics	X	X					
subscribeProductionStatus	X	X					
unsubscribeProductionStatus	X	X					
productionStatusNotification	X	X					
subscribeSensorData					X	X	X
unsubscribeSensorData					X	X	X
sensorDataNotification					X	X	X

Class Responsibilities

Knud Baastrup

We can from the Class Event Table identify some of the responsibilities to be assigned each of the classes as listed below.

Electrolyzer

- Starting and stopping the production of hydrogen
- Setting and getting of system properties, which include expected power consumption, green score, priority and some delays to ensure a minimum time between start and stop as well as stop and start.
- Option to send out notifications on production status changes in case of emergency stop or a manual stop required for maintenance or test purpose.
- Calculate the efficiency of the hydrogen production and provide on request either the current efficiency or some efficiency statistics measured for some duration of time.

Fuelcell

- Starting and stopping the production of electrical power
- Setting and getting of system properties, which include expected power consumption, green score, priority and some delays to ensure a minimum time between start and stop as well as stop and start.
- Option to send out notifications on production status changes in case of emergency stop or a manual stop required for maintenance or test purpose.
- Calculate the efficiency of the power production and provide on request either the current efficiency or some efficiency statistics measured for some duration of time.

PowerBusToElectrolyzerConverter

- Convert voltage from power bus into the required voltage for electrolyzer
- Enable and disable the incoming power to the electrolyzer
- Keep track of whether the power is currently enabled or disabled

FuelcellToPowerBusConverter

- Convert voltage from fuel cell into the required voltage for the power bus
- Enable and disable the outgoing power from the fuel cell
- Keep track of whether the power is currently enabled or disabled

PowerSensor

- Monitor current and voltage and provide the data on request
- Option to send out notifications on current or voltage changes

FlowSensor

- Monitor the flow of hydrogen and provide the data on request
- Option to send out notifications on flow changes

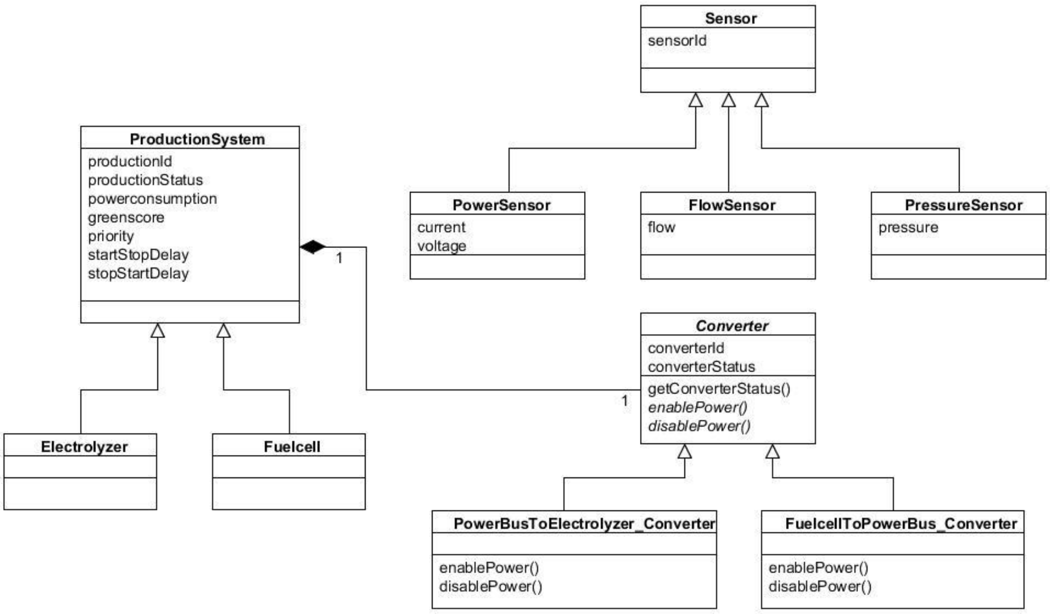
PressureSensor

- Monitor the pressure of hydrogen and provide the data on request
- Option to send out notifications on pressure changes

Class Diagram for Data Model

Knud Baastrup

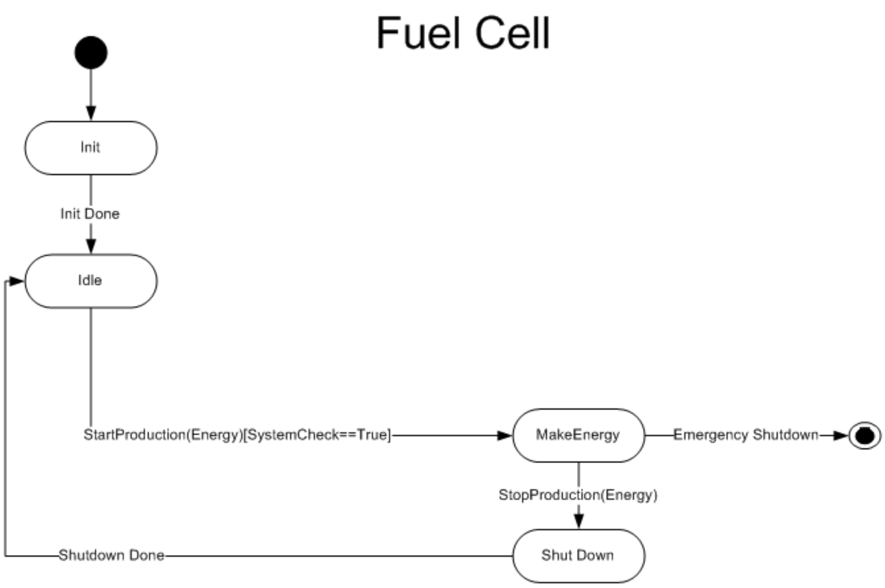
The classes have been included in below Class Diagram that now represents the Data Model. The sensor classes have been generalized into a super class named Sensor. The converter classes have been generalized into a super class named Converter with abstract operations to enable and disable power. Finally the electrolyzer and fuel cell have been generalized into a super class named ProductionSystem. An aggregation relationship has been defined between the ProductionSystem class and the Converter class due to the need for power bus access in order to produce hydrogen and deliver electrical power.

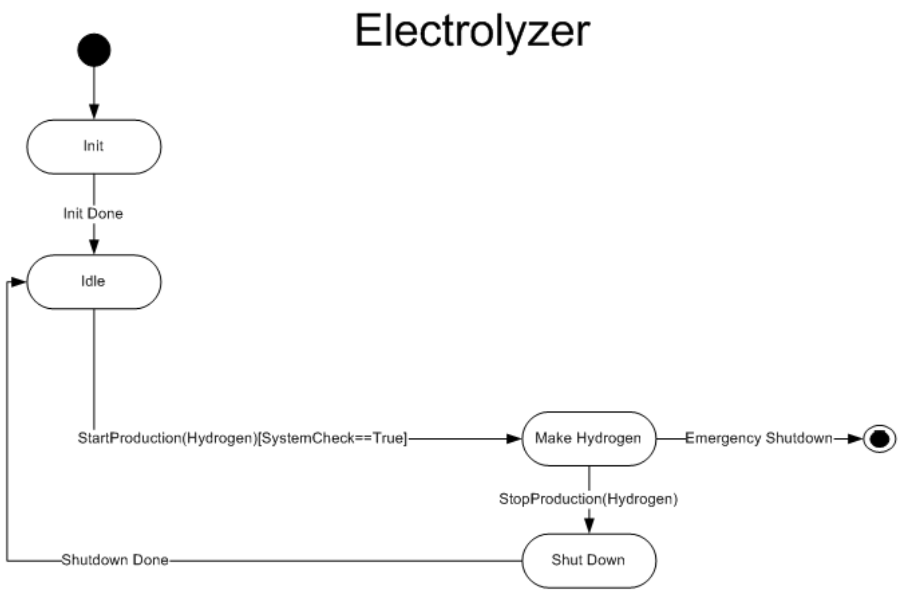


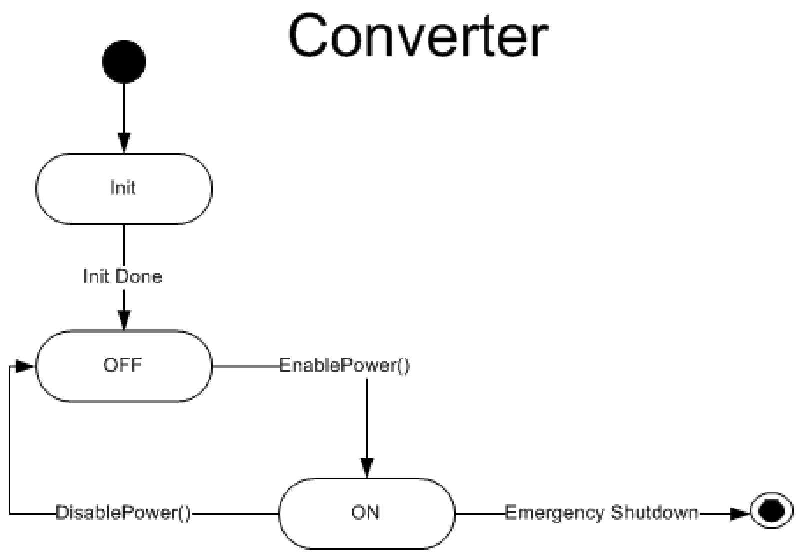
State Machine Diagram

Lasse Lykkegaard

A State Machine Diagram gives us an overview of how the system shall work.
And of cause which states the classes electrolyzer, fuel cell and converters can be in.





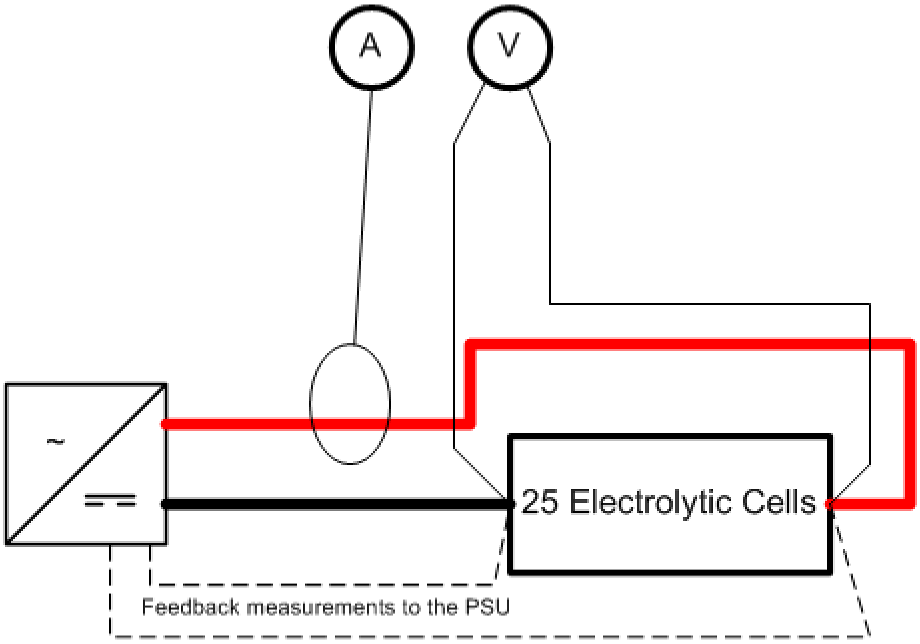


Electrolyzer Efficiency

Dennis Thomsen

Below measurements were carried out in order to find the power usage giving the best efficiency for the hydrogen production as well as the required input voltage.

In order to find this we measured the Flow rate of the Hydrogen coming out of the Hydrolyser and then calculated the Power used based on reading taken of Voltage and Ampere, and using the heating values of hydrogen to find how much Energy we stored in the form of the hydrogen pr. Sec, Last the Efficiency is calculated based on the input Power and the output Energy.



The flow of the Hydrogen is also measured in order to find the efficiency,

Input			Output			
Volt [V]	Ampere [A]	Power [W]	Flow [s/500ml]	Flow [mL/s]	Energy [W]	Efficiency [%]
48	6	288	83	6,02	70,04	24,32
50	7	350	42	11,90	138,42	39,55
52	9,7	504	34	14,71	170,99	33,90
54	12,6	680	19	26,32	305,97	44,97
56	16,5	924	14	35,71	415,25	44,94
58	20,7	1201	9	55,56	645,94	53,80
60	25	1500	7	71,43	830,50	55,37

From this table it is seen that the efficiency is improved when higher voltage and thereby higher power is added to the system. The power supply was rated to max 60V/max 100A so the efficiency might improve with higher voltage, but according to Hans Henrik the 25 cells in the electrolyzer are rated to not more than 2.4 V pr cell. With no idea of what will happen and when dealing with hydrogen and oxygen, we agreed that 60V was enough.

The PSU was corrected for voltage drop, so the measured voltage was in fact over the cells.

Calculations for finding the energy stored in the Hydrogen

The way of determinate how much energy is stored in Hydrogen or other flammable gasses is to determine the calorific value or heating value, when that is known we can calculate the energy loss in the converting process. The electrolyzer does not compress the hydrogen. The pressure is therefore 1 ATM or ≈ 1 Bar.

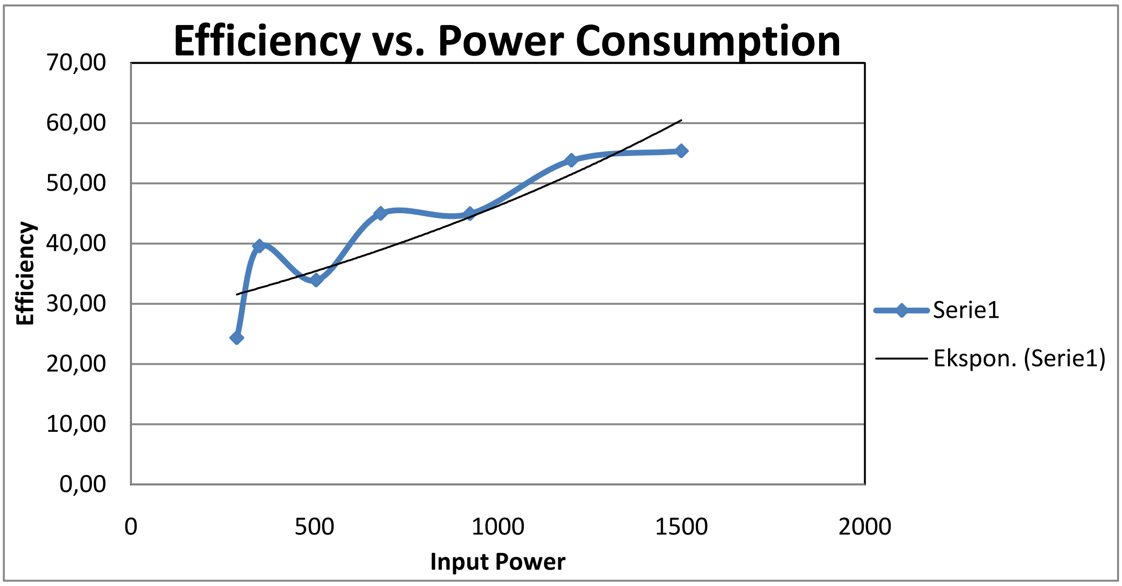
As we measure the produced Hydrogen by its flow, we measured this by how long it took to produce 500ml of hydrogen, so we could find the flow in mL/s, but in order to make the Calculations for finding the energy stored in the Hydrogen easier, we change the units for the energy value from MJ/kg to J/L using the Density of Hydrogen gas that is the weight of 1L in gram.

Energy content of Hydrogen pr. kilo: 141.8 MJ/kg (see References)

Density: 0,082 g/L (see References)

Energy content of Hydrogen pr. Liter (Calculated): 141.8 MJ/kg * 0,082 g/L = 11627 J/L

Graph based on our Data



User Interface Analysis

Dennis Thomsen

The user will only directly interact with our system via the Emergency Button, as the web-server that is going to be in system, is only a GUI representation of the Data and Status in our system, but the user won't be able to change anything in the system via it

System Interface Analysis

Dennis Thomsen

Communication with external systems (Hub, User interface) is essential for our system-to-be to do so we are going to be using a set of standard interfaces and protocols agreed upon between the different teams.

The system also need to connect to a Bus volt from which we can draw power to the Hydrolyser and deliver power from the Fuel cell, This Bus voltage is going to be agreed upon by the device teams (i.e. Our system and the windmill team) as they deal with the highest power levels.

POWER BUS

Lasse Lykkegaard

The bus voltage should fit for all participants of the system

Since several voltage sources and "consuming" products have different demands, not all would be happy with the choice.

Since we (the hydrogen group) is the far most energy consuming group. The electrolysis of the potassium hydrate, uses in the area of 1500W and this process demands a voltage of 60 V over the cells, and approximately 25 A.

We do therefore advocate for a higher voltage, thereby lower current and less energy loss and voltage drop in the supply cables.

A standardized voltage of for example 48 volts would minimize the costs of converters for other groups

It is possible to find DC to DC converter in the specified range?:

http://dk.farnell.com/synqor/nq60w60qgc20nrc-g/niqor-dc-dc-converters/dp/1817994

http://www.enatel.net/Telecom/DC-DC_Converters/CM1760-48/

Thereby it might be possible to avoid the PSU_XPR. Alternatively, we could build our own, but building a PWM switching power circuit in that size might challenge us too much.

We haven't been able to find any 12/24/48 VDC to 3x400 V inverter… a solution for this setup could be a DC to 230V AC inverter and then a frequency converter which could make the three phases and at last a transformer which transforms the voltage to the desired 400VAC. But seen from an economic point of this is not desirable, nor if you think of energy loss.

Eventually it was up to Group 2 and Group 4 to decide the voltage since they were the only ones left to interact with the bus.

The end decision was 48 VDC. More specifications can be seen in enclosure B

NETWORK TOPOLOGY

Lasse Lykkegaard

We do not have any time critical network communication processes running in our system. The latency on the network does not affect our system.

However if the system hub ask us to shutdown, the time for the message to arrive and the protocol to decode it is to be added to the response time. If the system hub needs a very fast response time, the network shall be fast.

The bandwidth of the network must be large enough the handle the necessary data, web pages, and all the logged data which are to be used elsewhere.

We have designed our system so far without any network protocol demands. All functions can be implemented with an adapter piece – a driver.

Packet order does not do anything – as far as the log-data, we have no buffed data. Like sound or video.

The priority could come in handy with start/stop commands from hub

Seen from our point of view an easy to use network would be preferable,

The groups which have most requirements to the network have gotten the decision power to make a specification of the network which is to be approved.

The final specification can be seen in enclosure C.

USE CASE ANALYSIS

Dennis Thomsen

Based on analysis of our use case candidates, and actor candidates we found the following use cases, these look at the system interactions, is going to be for users and other systems. Meaning the focus is on how the system is going to be used.

Use Cases

Emergency Shut-Down

Description: total system shut-down of both hydrogen production and energy production

Actors: User

Prerequisites: None

Detailed Use Case:

Number	Actor	System
1	Press Emergency shut-down bottom	
2		Shuts down Hydrogen production and Power Generator
3		Inform Hub that Emergency shut-down was activated and withdraw permission for energy/hydrogen production

Start Hydrogen Production

Description: For start up of hydrogen production, permission is need from the Hub

Actors: Hub

Prerequisites: None

Detailed Use Case:

Number	Actor	System
1	Enable Hydrogen Production	
2		Check if conditions is fulfilled and start production
3		Inform Hub that production have started

Stop Hydrogen Production

Description: For stop of power production, permission is need from the Hub

Actors: Hub

Prerequisites: None

Detailed Use Case:

Number	Actor	System
1	disable Hydrogen Production	
2		Check if conditions is fulfilled and stop production
3		Inform Hub that production have stopped

Start Power Production

Description: For start up of power production, permission is need from the Hub

Actors: Hub

Prerequisites: None

Detailed Use Case:

Number	Actor	System
1	Enable Power Production	
2		Check if conditions is fulfilled and start production
3		Inform Hub that production have started

Stop Power Production

Description: For stop of power production, permission is need from the Hub

Actors: Hub

Prerequisites: None

Detailed Use Case:

Number	Actor	System
1	Disable Power Production	
2		Check if conditions is fulfilled and stop production
3		Inform Hub that production have stopped

Read Efficiency Data

Description: The getting of data from sensor and transferring it to Hub

Actors: Hub, User interface

Prerequisites: None

Detailed Use Case:

Number	Actor	System
1	Actor requests Data	
2		Collect Data from sensors
3		Calculate Efficiency
4		Send Data to Actor

FUNCTION ANALYSIS

Dennis Thomsen

With function analysis the focus is on what rather than how, the functions determine how the data can be assessed and what can be with it, they can be viewed as different "handles" that is available for the system, our functions where found based on analysis of the function candidates, which where the potential "handles.

Functions

getEfficiencyData(productionId)

Description: Calculate the efficiency of either the Hydrolysis or Generator using the heating value of hydrogen, only able to do so if part is turned on

Type: Calculating

Complexity: Simple

getEfficiencyStatistics(productionId, duration)

Description: Transmit the efficiency data of either the Hydrolysis or Generator or the whole system

Type: Signaling

Complexity: Simple

StartProduction(productionId)

Description: Check if system is ready, if it is the Start and notify the system of it, only one system can be active at a time that is the Hydrolysis or Generator

Type: Updating/ Signaling

Complexity: Medium

StopProduction(productionId)

Description: Stop Hydrolysis or Generator and notify Hub it has been stopped.

Type: Updating/ Signaling

Complexity: Medium

getSensorData(productionId, sensorId)

Description: Reads out Measured Data for the sensor

Type: Reading

Complexity: Simple

getProductionStatus(productionId)

Description: Reads current status from a production system

Type: Reading

Complexity: Simple

subscribeProductionStatus(productionId)
Description: Set to continues read the current status from a production system

Type: Reading

Complexity: Simple

unsubscribeProductionStatus(productionId)
Description: Stop reading the current status from a production system

Type: Updating

Complexity: Simple

productionStatusNotification()
Description: Handles sending the Status of the production systems to those subscribed

Type: Signaling

Complexity: Simple

subscribeSensorData(productionId, sensorId)
Description: Set to continues read the current data from a sensor

Type: Reading

Complexity: Simple

SensorDataNotification()
Description: Handles sending the data from sensor's to those subscribe to it

Type: Signaling

Complexity: Simple

unsubscribeSensorData(productionId, sensorId)
Description: Stop reading the current data from the sensor

Type: Updating

Complexity: Simple

GetSystemData(productionId, Data parameter)
Description: Reads out the previously stored settings for the parameter.

Type: Reading

Parameters: EstPower, Greenscore, Priority, StartStopDelay, StopStartDelay, Status

Complexity: Medium

SetSystemData(productionId, Data parameter, value)
Description: Update the Parameter with the new value.

Type: Updating

Parameters: EstPower, Greenscore, Priority, StartStopDelay, StopStartDelay, Status

Complexity: Medium

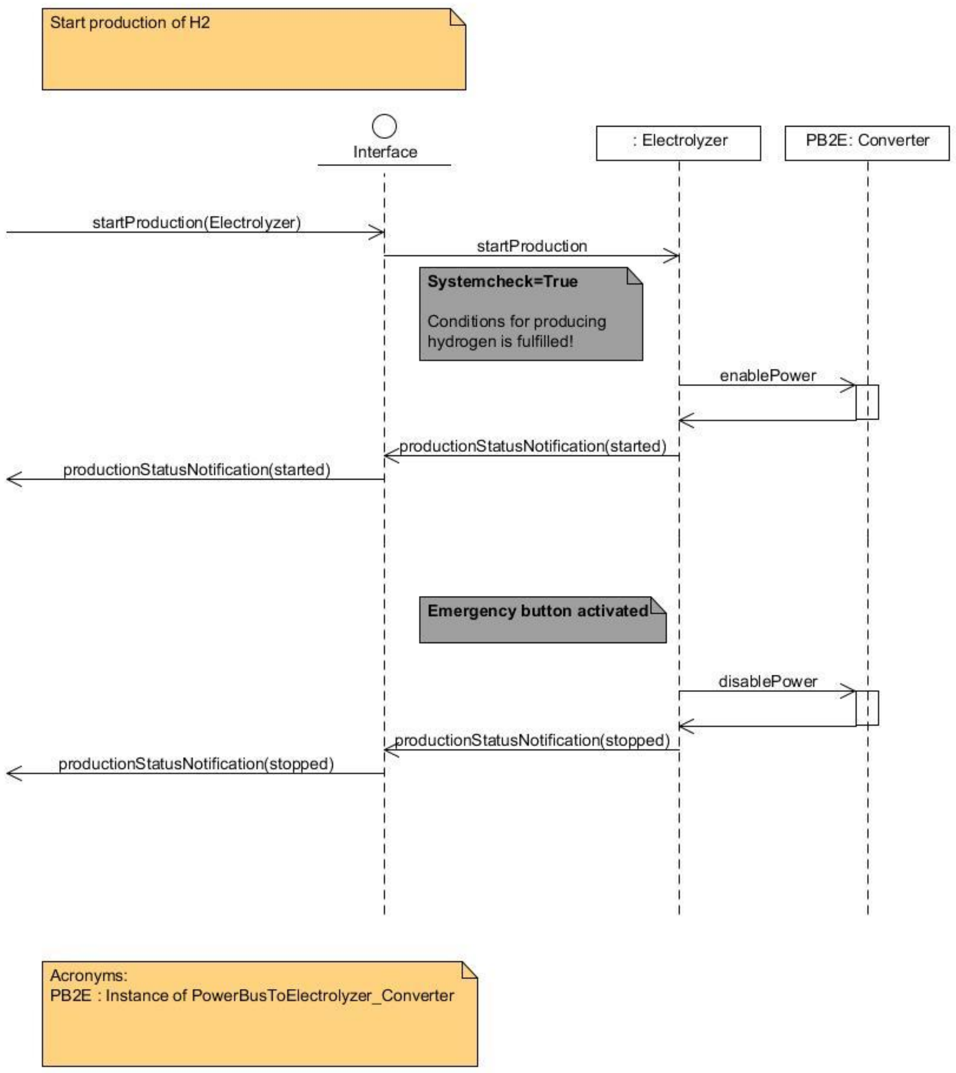
SEQUENCE DIAGRAM

Knud Baastrup

The sequence diagrams sketch how some of the Use Cases can be implemented. The sequence diagrams on this level will just cover the intended scenarios while the different failure scenarios will be further explored during realization.

Start Production

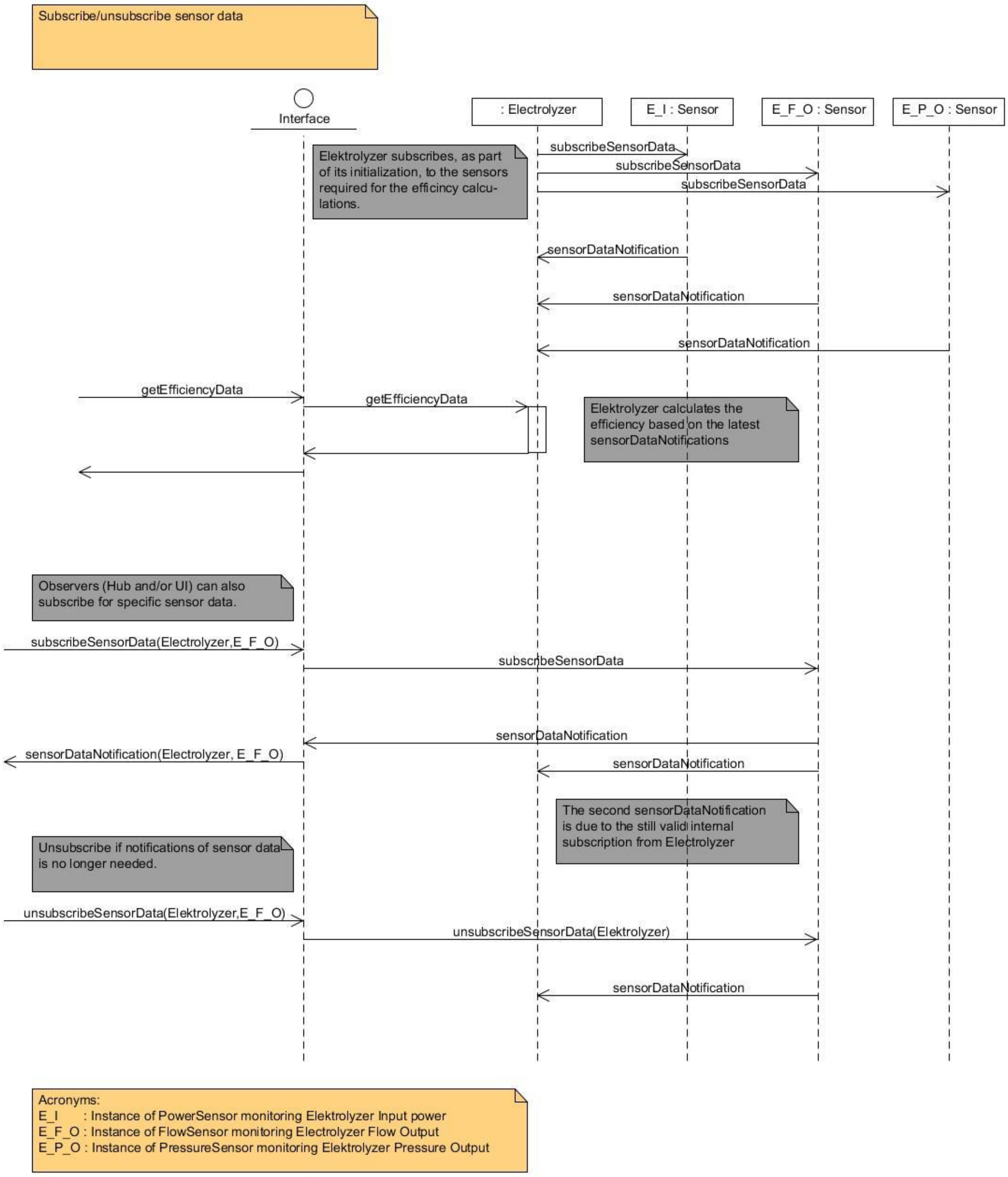
A production of either hydrogen using electrolyzer or power using fuel cell is initiated with the StartProduction event. A productionStatusNotification will be returned each time the status of the production system is changed. Below sequence diagram shows the start-up of a hydrogen production and how it once again is stopped due to the emergency button being pressed.



Subscribe and deliver sensor/efficiency data

Sensor Data can be subscribed and delivered via notifications. The data required for the efficiency calculations are subscribed from the relevant sensors. Electrolyzer will doing initialization subscribe sensor data from the relevant sensors, so efficiency calculations can be performed and delivered on request based on latest received sensor data.

Below sequence diagram show s a request for efficiency data based on internal subscriptions to sensor data and as well an external subscription for a specific sensor followed with notifications of sensor data from that specific sensor.



Customer Needs

Lasse Lykkegaard

Our main customer Jan Møller Nielsen has supplied us with some needs of the whole system see enclosure D.

Further to that he has added that the system must withstand the weather conditions in a shed outside.

Mr. Nielsen focuses much on the visual view of the system. It must be intuitive for the High School students to see and understand the system. But he did not have any special requirements regarding the function of the system and the interaction with the Hub.

Requirements

Knud Baastrup

The H2 subsystem is defined by below set of requirements. The requirements are split into General requirements (Gx.x) that defines overall requirements and requirements applying for both electrolyzer and Fuel cell and specific requirements for respectively electrolyzer (Ex.x) and Fuel cell (Fx.x). The requirements have been aligned and reviewed by customer Jan Møller Nielsen.

Once the requirements are frozen, the unique requirements numbers must NOT be changed in order to secure traceability.

G1.1 The H2 subsystem shall be able to produce hydrogen from electrical power using electrolysis and should as well store it in a hydrogen tank.

G1.2 The H2 subsystem shall be able to produce energy as electrical power using hydrogen fuel cell or any other device that can produce electrical power from hydrogen.

G1.3 The H2 subsystem shall be physical connected to a power-bus with a nominal voltage of 48 VDC. The voltage should be within 48 ±2 VDC with a maximum superimposed AC voltage of 2 V_{pp} in accordance with the Bus Voltage Specification. The power-bus will both deliver the power to be stored as hydrogen and consume the power produced using hydrogen fuel cell.

G1.4 The electrolyzer and Fuel cell shall not consume or deliver more than 3 KW or 62.5 A.

G1.5 The H2 subsystem shall monitor input/output power-bus voltage and input/output power-bus current and notify the Hub and other subscribed observers on changes in voltage or current level.

G1.6 The H2 subsystem shall be able to deliver current efficiency data to other systems on request.

G1.7 The H2 subsystem should be able to deliver efficiency data measured over certain duration of time that at least should cover up to 24 hours.

E1.1 It shall at any time be possible to start H2 production on request from Hub when all of the following conditions are fulfilled:

- Defined delay between stop and start has passed.
- Electrolyzer has not been manually stopped.
- No power production ongoing.
- Other (the system must be in ready state)

Hub shall be notified once H2 production has started.

E1.2 It shall at any time be possible to stop H2 production on request from Hub either immediately or when defined delay between start and stop has passed. Hub shall be notified once H2 production has stopped.

E1.3 The H2 subsystem shall be able to stop H2 production and notify Hub if one of the following conditions takes place:

- Sufficient power is no longer available for efficient H2 production.
- electrolyzer has been manually stopped due to malfunction

E1.4 It shall at any time be possible to manually stop H2 production immediately and notify Hub in case of emergency or for maintenance/test purpose.

E1.5 The H2 subsystem shall be able to produce hydrogen when sufficient power in terms of 1500W is available for the Electrolyzer.

E1.6 The H2 subsystem must be able to convert the power-bus voltage into the required input voltage for the given Electrolyzer. Alternatively the Electrolyzer should use the voltage given by the power bus despite an expected lower efficiency.

E1.7 Delay between start and stop of H2 production as well as delay between stop and start of H2 production should be configurable via local configuration interface/web interface to H2 subsystem.

E1.8 The H2 subsystem should monitor the input voltage and input current to the Electrolyzer to allow calculation of the converter efficiency for the converter required between power-bus and Electrolyzer.

E1.9 The H2 subsystem shall monitor the hydrogen flow and hydrogen pressure delivered by the Electrolyzer to allow calculation of the Electrolyzer efficiency.

F1.1 It shall at any time be possible to start power production on request from Hub when all of the following conditions are fulfilled:

- Defined delay between stop and start has passed.
- Fuel cell has not been manually stopped.
- No hydrogen production ongoing.

Hub shall be notified once power production has started.

F1.2 It shall at any time be possible to stop power production on request from Hub either immediately or when defined delay between start and stop has passed. Hub shall be notified once power production has stopped.

F1.3 The H2 subsystem shall be able to stop power production and notify Hub if one of the following conditions takes place:

- Sufficient hydrogen is no longer available for efficient H2 production.
- Fuel cell has been manually stopped.

F1.4 It shall at any time be possible to manually stop power production immediately and notify Hub in case of emergency or for maintenance/test purpose.

F1.5 The H2 subsystem shall be able to produce power when sufficient hydrogen can be delivered from hydrogen storage.

F1.6 The H2 subsystem shall be able to convert the output voltage from the given Fuel cell into the required input voltage for the power-bus.

F1.7 Delay between start and stop of power production as well as delay between stop and start of power production should be configurable via local configuration interface/web interface to H2 subsystem.

F1.8 The H2 subsystem shall monitor the input flow and input pressure to the Fuel cell to allow calculation of the Fuel cell efficiency

F1.9 The H2 subsystem should monitor the output current and output voltage delivered by the Fuel cell to allow calculation of the efficiency for the converter required between Fuel-cell and power-bus.

F1.10 The H2 subsystem shall be able to deliver a Green-score on request from Hub.

DESIGN CRITERIA

Lasse Lykkegaard

Performance

The electrolysis will produce less hydrogen, with a lower voltage and current, therefore it should be kept stabile – but no there is no hazard risk.
The delivered voltage should be stable in respect for other participants in the network.

The system shall perform the required but there is no need for adding extra power.

Price

The product is not in its current form mend to be mass produced – one copy only. If Working hours was taken into consideration, it would be better to build the system of premade blocks, but since that's not an issue ☺ the price is to be kept at small as possible and with that as much as possible designed, customized and made by ourselves.

Stability /Reliability

The system will not be used without any supervision; therefore it is not absolutely necessary that a fatal error never can occur. Never the less, the electrolysis shall be carried out in a safely way, and since hydrogen is flammable, precautions shall be made.

Size/outer requirements

There is no requirement of the physical system-size. Though is shall be installed outside in a shed where temperature fluctuation will happen.

User Interface (The ease of communication with the system)

The communication with a real user is one-way through a webpage interface where stats should be showed.

Communication remote start /stop is done through the communication protocol with the system hub.

Maintenance shall be performed local. (E.g. console based)

Upgrade/expansion

The system shall not be expanded; smaller modifications and/or software updates should be expected.

TECHNICAL PLATFORM

Lasse Lykkegaard

From the system overview diagram on page 3 we pulled out the main components of our subsystem.

Component list

- Electrolyzer
- Fuel Cell
- Control System
- Sensors
    - Pressure sensors
    - Flow sensors
    - Watt-”sensor’s”
- DC/DC-Converter (48VDC-60VDC)
- AC/DC-Converter (230VAC-48VDC) or DC/DC (12VDC-48VDC)
- Emergency stop

HW/SW specifications

The electrolyzer

is HW. One of the customer need is to build the project over this electrolyzer.
It’s a 25 Cell electrolyzer – which delivers hydrogen at 1 ATM pressure.

The fuel cell

is normally HW controlled by on/off. Our customer however has an imitation of a Fuel Cell – a rebuild gasoline-engine with a generator mounted. The generator has 12 VDC or 230VAC outlets. This engine is started with a manual string-starter know from lawnmowers. This will be a challenge. Also the fact that the generator needs compressed hydrogen in order to run. The current electrolyzer cannot compress hydrogen

Control System

The control shall handle all communication from the bus, and handle outputs, this is the heart of the system. For easy implementation and code writing processors (ARM, CORTEX etc.) are preferred instead of FPGA-chips. The board must handle all the sensor data.

Sensors

All analog sensor signals will be run through an A/D converter at some time since the HUB and other equipment on the bus should be able to get the measurement data. Therefore the choice will be a matter of accessibility, resolution and price of whether to go analog or digital. If all sensors are to be analog, 8 A/D converters must be able on the control system board

Pressure sensors

At this level, our costumer has not determined how in details to storage the hydrogen.

The current equipment cannot put the hydrogen under pressure. Therefore we may need to clear this matter in some other way – maybe not to store any hydrogen, and by using bottled hydrogen for the fuel cell

Flow sensors

Flow sensors could be implemented mechanically with a digital counter that counted every time a certain amount of hydrogen was run through. Or it could be done with an analog signal that gave the real time value.

Watt-"sensors"

Since the bus is DC, these could be implemented as an Ampere meter and a Voltmeter, but we should then have in mind that it then requires the double amount of A/D converters on the control system –board as well

Converters

DC/DC (48VDC-60VDC):

This product is examined, due to the complexity of finding equipment for a special bus voltage, in the Power Bus section at page 10.

http://www.enatel.net/Telecom/DC-DC_Converters/CM1760-48/ would be a possibility.

AC/DC (230VAC-48VDC) or DC/DC (12VDC-48VDC)

Since the generator produces an AC, which then is converted to 12VDC, the least loss will be to convert the 230VAC to 48V, and with these standard voltages is should be possible to get PSU within a reasonable price range. The 12 to 48VDC should be avoided.

Emergency Stop

according to the Danish regulative and machineries EN 204-1 it is not allowed use other than HW for this task. Special exceptions are however allowed (special emergency PLC's etc.)

Dangerous machineries must be stopped physically with this stop – the control system may continue to run, but all peripheral components shall halt immediately.

HW/SW diagram

CLASS	INTERFACE	HW	SW	MW
Electrolyzer	NONE		X	X
Fuel Cell	NONE		X	X
Control System				
Sensors	ANA/DIG			
• Pressure	ANA/DIG	X	X	
• Flow	ANA/DIG	X	X	
• Watt	ANA/DIG	X	X	
Converter		X		
• DC/DC	ON/OFF	X		
• DC/AC	ON/OFF	X		
Emergency Stop	ON/OFF			X

SUBSYSTEM DESIGN

Knud Baastrup

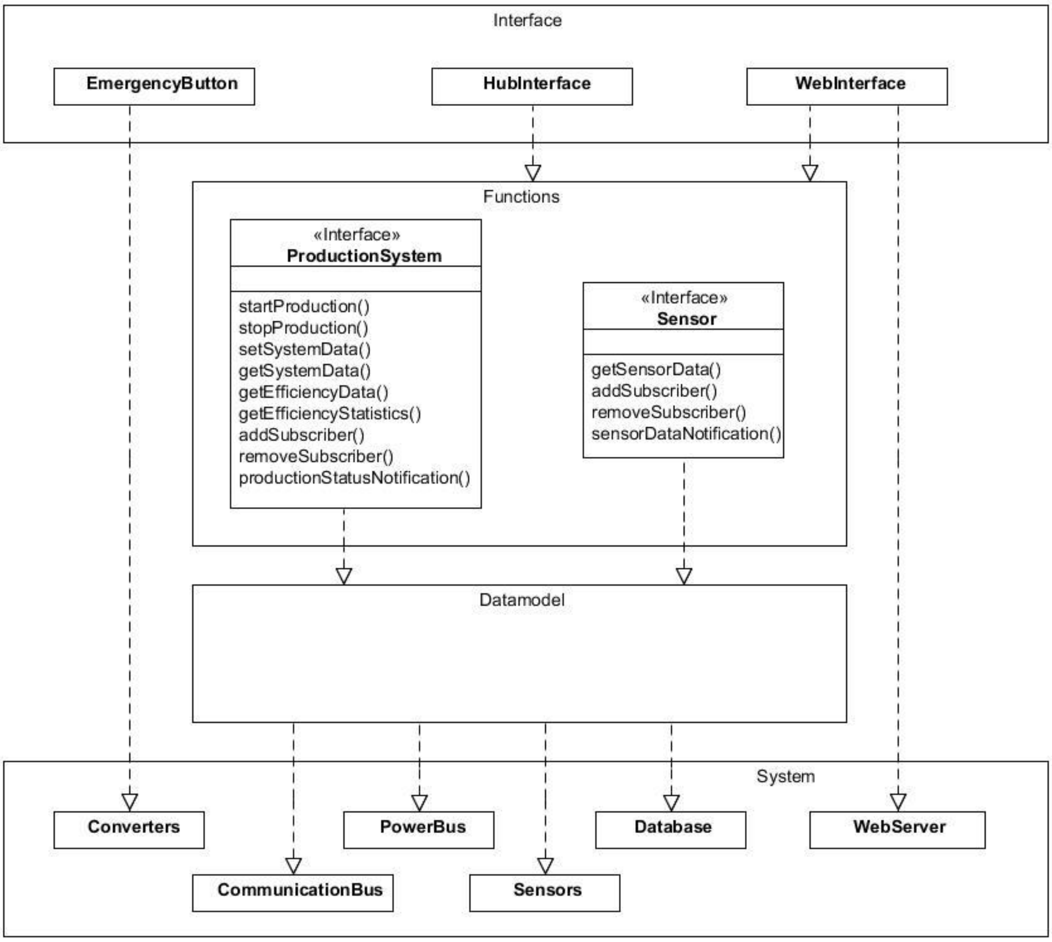
The subsystem design extends the data model previously defined (see page 6) and considers how the data model should interact with its surroundings. Below subsystem diagram shows how the data model have been extended with a Function subsystem, Interface subsystem and a System subsystem.

The Function subsystem defines the functions derived from the Functions Analysis, which are the functions required to fulfill the need from the Interface subsystem.

The Interface subsystem is derived from the Use Case and Interface Analysis and includes a user interface in terms of an emergency button, an interface to the Hub system and a web based user interface for initial configurations and basic read-outs.

The System subsystem provides access to the hardware interfaces, the communication and power bus and finally some storage in terms of a database.

The dependency arrow indicates that changes can be done in the upper layer/component without affecting the layer/component below.


Interface
EmergencyButton
HubInterface
WebInterface
Functions
«Interface»
ProductionSystem
startProduction()
stopProduction()
setSystemData()
getSystemData()
getEfficiencyData()
getEfficiencyStatistics()
addSubscriber()
removeSubscriber()
productionStatusNotification()
«Interface»
Sensor
getSensorData()
addSubscriber()
removeSubscriber()
sensorDataNotification()
Datamodel
System
Converters
PowerBus
Database
WebServer
CommunicationBus
Sensors

Development Plan

Dennis Thomsen

The development plan is used to map our expectations regarding the use our resources in the realization phase.

Name	Estimated Weeks
Hardware	
Emergency Stop	2
Converters	1.5
Sensors	1
EMC test	0.5
Printlayout	1
Software	
Embedded computer platform - configuration	2
Interface to sensors	1.5
Interface to Generator	1.5
Interface to Hydrolyser	1.5
Interface to converters	1.5
Interface to Hub	2
Webserver	2
Webserver Interface	1
Database	1
Data model	2
Verification (Product acceptance test)	1.5
Deployment	1.5
Project Management	1.5

Timebox length: *2 weeks.*

Resources:

Staff: Anna, Knud, Lasse, Dennis

Project Time: 17 weeks.

The X's indicate where the main focus of the week will be placed

At the end of each timebox iteration in the realization phase, we will go over the plan and revise according to the current status if necessary.

Timebox Goals

Project Week 2: Basic configuration of platform

Project Week 4: Able to Start/stop production of Hydrogen

Project Week 6: Get hole though to the Sensors

Project Week 8: Get Generator running

Project Week 10: Emergency stop + finished with Hardware/print layout

Project Week 12: EMC test done + Able to communicate with Hub

Project Week 14: Get Web-server up and running

Project Week 16: Web- server interface

Project Week 17: Post project + finish up report

		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17
Name	Estimated Weeks																	
Hardware																		
Emergency Stop	2									XXXXXX	XXXXXX							
Converters	1.5	XXXXXX				XXXXXX												
Sensors	1				XXXXXX													
EMC test	0.5												XXX					
Printlayout	1								XX	XX	XX							
Software																		
Embedded computer platform - configuration	2	XXXXXX	XXXXXX															
Interface to sensors	1.5					XXXXXX	XXXXXX											
Interface to Generator	1.5							XX	XXXXXX									
Interface to Hydrolyser	1.5			XXXXXX	XXXXX													
Interface to converters	1.5			XXX	XXX													
Interface to Hub	2											XXXXXX	XXXXXX					
Webserver	2													XXXXXX	XXXXXX			
Webserver Interface	1															XXXXXX		
Database	1							XXXXXX										
Data model	2			XXXX				XXX										
Verification (Product acceptance test)	1.5		XX		XX		XX		XX		XX		XX		XX		XXXX	XXXX
Deployment	1.5		XX		XX		XX		XX		XX		XX		XX		XXXX	XXXX
Project Management	1.5		XX		XX		XX		XX		XX		XX		XX		XXXX	XXXX

Product Acceptance

Anna Zueva

Product acceptance testing involves running a set of tests on the system. Each individual test, performs a particular operating condition that is expected of the system, and will result in a pass or fail outcome.

The test environment should be designed to be as close as possible to the systems normal operating environment.

The following is the description of the test cases that can be performed in order to ensure that the exact requirements of the system have been met. The following test cases were designed with accordance to the Exact Requirements, the outcome of each test-cases is Boolean, either pass or fail.

Each Test Case was designed in accordance with the Exact Requirements[1].

Test Case G1.1

The test can be performed using the procedure described below:

1. Start the hydrogen production
2. Read the flow and pressure sensors
3. Alternating/increasing value insures ongoing hydrogen production.
4. Increasing pressure in hydrogen tank confirms the process of hydrogen storage.

Test Case G1.2

The test can be performed using the procedure described below:

1. Start the energy production
2. Read the power sensors.
3. Alternating/increasing value insures ongoing power production.

Test Case G1.3

The test can be performed using the procedure described below:

1. This test can be performed by simply measuring voltage on the input and the output of the Power-Bus.
2. The measurements taken can be compared to the values of power sensors, to insure that power sensors are working correctly.
3. If the measurements are equal to the specified power-bus voltage the requirement is fulfilled.

Test Case G1.4

The test can be performed using the procedure described below:

1. Measure current and voltage on output/input of the fuel cell/electrolyzer while the system is at work.
2. If the measurements are not larger than the required 3KW or 62.5 A, the requirements are fulfilled.

[1] See, Requirements specifications, p. 18

Test Case-G1.5

The test can be performed using the procedure described below:

1. Start the system
2. Make manual readings of the power
3. Compare the readings to those from the system. If measurements are equal to the data- system monitors input/output power-bus voltage and input/output power-bus current correctly
4. Insure that the Hub and subscribers received notification

Test Case-G1.6

The test can be performed using the procedure described below:

1. Request data from H2 system from the other device
2. Note down measurements manually from the power sensors and H2 systems UI
3. If the data received by the other device is equal to data that was previously noted down and sent the requirement is fulfilled.

Test Case-G1.7

The test can be performed using the procedure described below:

1. Monitor system manually by reading power sensors at random time.
2. Check if the efficiency data is equal to the manually measured data.

Test Case-E1.1

The test can be performed using the procedure described below:

1. Insure that electrolyzer hasn't been manually shut.
2. Insure that there is no ongoing power production, by measuring the current/voltage at the output.
3. Request from the Hub to start the hydrogen production
4. Read the measurements from the pressure and flow sensors. The changing measurements insure that the hydrogen production is ongoing.
5. Insure that the Hub received notification once the hydrogen production has started.
6. Test must be repeated at multiple times with different time delay, to insure that system can produce hydrogen on a request at anytime.

Test Case-E1.2

The test can be performed using the procedure described below:

1. Request to stop hydrogen production from the Hub.
2. Insure that hydrogen production is stopped by reading the measurements from the pressure sensor. Once the value is stable – the hydrogen production is stopped.
3. Insure that Hub is notified with the message that the hydrogen production has been stopped.
4. Repeat test multiple times with different time delay in between the tests.

Test Case-E1.3.1

The test can be performed using the procedure described below:

1. Measure and note down a fixed value of what is assumed to be the sufficient amount of power, for hydrogen production, by measuring the power sensors. Any values below the measured fixed value must be considered as insufficient values for production of hydrogen.
2. Let the system run as it produces hydrogen from power, while taking the readings from the power sensors.
3. Insure that the system has stopped producing hydrogen once the power has dropped to the fixed value (below sufficient amount of power) by making readings from the pressure and flow sensors.
4. Insure that the Hub received notification.

Test Case-E1.3.2

This test can be performed to recreate the environment where the hydrogen production was stopped manually, using the procedure described below:

1. Let the system run as it produces hydrogen from power, while taking the readings from the flow and pressure sensors, to insure the production.
2. Manually shut down the Electrolyzer.
3. Insure that the system has stopped producing hydrogen, once the Electrolyzer has been shutdown, by reading measurements from the pressure and flow sensors, once the value is stable- the hydrogen production is stopped.
4. Insure that the Hub received notification.

Test Case-E1.4

The test can be performed using the procedure described below:

1. Let the system run as it produces hydrogen from power, while taking the readings from flow and pressure sensors.
2. Manually shut down the system.
3. Insure that the system has stopped hydrogen energy, once it's been shutdown, by making readings of the flow and pressure sensors, once the values are stable- the hydrogen production is stopped.
4. Insure that the Hub received notification.

Test Case-E1.5

The test can be performed using the procedure described below:

1. Insure that sufficient power in terms of 1500W can be delivered from power-bus, by measuring the current/voltage on the input.
2. Make readings from the flow and pressure sensors, if the values alternate/increase – the hydrogen production is started.

Test Case-E1.6

The test can be performed using the procedure described below:

1. Perform multiple conversance tests in the lab environment in order to insure the both stability and efficiency of the PowerBusToElectrolyzerConverter.
2. Once the lab test is performed, the system can be started. Measurements of voltage must be taken from Power-bus output, as well as measurements of the input of the electrolyzer.
3. The measurements from power-bus output must meet the required input value of the electrolyzer.

Test Case-E1.7

The test can be performed using the procedure described below:

1. Configure the time delay via local configuration interface/web interface to H2 subsystem.
2. Start making readings of the flow and pressure sensors before the preconfigured start-time.
3. Once the values of flow and pressure sensors began to alternate, note down the time.
4. Secure that the time of production started matches to the preconfigured time.
5. Perform the test several times with different preconfigured time delay.

Test Case-E1.8

The test can be performed using the procedure described below:

1. Start hydrogen production
2. Note down the measurements of the input current and voltage of the Electrolyzer from power sensor.
3. Check if the power sensor measurements are equal to the data stored in data-log(/UI)

Test Case-E1.9

The test can be performed using the procedure described below:

1. Make readings from the actual power and flow sensors
2. Compare readings to the system readings.
3. Repeat multiple times.

Test Case-F1.1

The test can be performed using the procedure described below:

1. Pressure in hydrogen tank should be checked, in order to confirm that the sufficient amount of hydrogen is available for the power production.
2. Insure that no hydrogen production is ongoing by measuring the flow and pressure. If the pressure is stable and there are no changes in the flow, there is no ongoing hydrogen production.
3. Request power production from the Hub
4. Measure the energy production, by measuring current/voltage
5. The test must be repeated multiple times, with different time delay.

Test Case-F1.2

The test can be performed using the procedure described below:

1. Request to stop power production from the Hub
2. Insure that power production is stopped by measuring the output voltage/current.
3. Insure that Hub is notified with the message that the power production has been stopped.
4. Repeat test multiple times with different time delay in between the tests.

Test Case-F1.3.1

The test can be performed using the procedure described below:

1. Measure and note down a fixed value of what is sufficient amount of hydrogen in the tank, for power production, using pressure sensors. Any values below the measured fixed value must be considered as insufficient values for production of hydrogen.
2. Let the system run as it produces power from hydrogen, while taking the readings from the pressure sensors.
3. Insure that the system has stopped producing energy once the pressure in the tank dropped to the fixed value (below sufficient amount of hydrogen) by measuring the voltage/current of the output.
4. Insure that the Hub received notification.

Test Case-F1.3.2

This test can be performed to recreate the environment where the hydrogen production was stopped manually, using the procedure described below:

1. Let the system run as it produces power from hydrogen, while taking the voltage/current readings from the output.
2. Manually shut down the Fuel Cell
3. Insure that the system has stopped producing energy, once the Fuel Cell has been shutdown, by measuring the voltage/current of the output.
4. Insure that the Hub received notification.

Test Case-F1.4

The test can be performed using the procedure described below:

1. Let the system run as it produces power from hydrogen, while taking the voltage/current readings from the output.
2. Manually shut down the system
3. Insure that the system has stopped producing energy, once it's been shutdown, by measuring the voltage/current of the output.
4. Insure that the Hub received notification.

Test Case-F1.5

The test can be performed using the procedure described below:

1. Measure and noted down a fixed value of what is sufficient amount of hydrogen in the tank, for power production, using pressure sensors. Any values below the measured fixed value must be considered as insufficient values for production of hydrogen.
2. Request power production from the Hub.
3. Insure that the system started producing energy, by measuring the voltage/current of the output.

Test Case-F1.6

The test can be performed using the procedure described below:

1. Perform multiple conversance tests in the lab environment in order to insure the both stability and efficiency of the PowerBusToFuelCellConverter.
2. Once the lab test is performed, the system can be started. Measurements of voltage must be taken from Power-bus output, as well as measurements of the input of the Fuel Cell.
3. The measurements from Power-bus output must meet the required input value of the Fuel Cell.

Test Case-F1.7

The test can be performed using the procedure described below:

1. Configure the time delay via local configuration interface/web interface to H2 subsystem.
2. Start making readings of the power sensors before the preconfigured start-time.
3. Once the values of power sensors began to alternate, note down the time.
4. Secure that the time of production started matches to the preconfigured time.
5. Perform the test several times with different preconfigured time delay.

Test Case-F1.8

The test can be performed using the procedure described below:

1. Start the power production
2. Note down the measurements of the input flow and pressure to the Fuel Cell from flow and pressure sensors.
3. Check if the power sensor measurements are equal to the data stored in data-log(/UI)

Test Case-F1.9

The test can be performed using the procedure described below:

1. Measure input and output voltage of the Fuel Cell
2. Compare readings to the system readings.
3. Repeat multiple times.

Test Case-F1.10

The test can be performed using the procedure described below:

1. Make a request from the Hub to send Green Score data
2. Note down values from all of the sensors
3. Compare to sent/received data with values from the sensors.

Test case	Approved	√	Date	Signature
G1.1				
G1.2				
G1.3				
G1.4				
G1.5				
G1.6				
G1.7				
E1.1				
E1.2				
E1.3.1				
E1.3.2				
E1.4				
E1.5				
E1.6				
E1.7				
E1.8				
E1.9				
F1.1				
F1.2				
F1.3.1				
F1.3.2				
F1.4				
F1.5				
F1.6				
F1.7				
F1.8				
F1.9				
F1.10				

SUMMARY

Knud Baastrup

The launch phase has now been finalized and the H2 subsystem-to-be has been sufficiently analyzed, scoped and planned for realization in EDE09 4th Semester.

The building blocks of the H2 subsystem were initially identified in a System Overview that served as base for a more detailed analysis of the problem domain and eventually a data model depicted in a Class Diagram. The usage domain was analyzed in parallel and it was possible to settle a number of Use Cases during some talks with the end customer and some test performed on already existing prototype systems. The Use Cases were compiled into a number of functions that as well could serve the need from other subsystems like the Hub and User Interface subsystem. The study of the problem domain and especially the usage domain resulted eventually in a list of exact and unambiguous requirements.

A subsystem design diagram was created with a basic architecture model that allowed a split into a system, model, function and interface layer. This split allowed us to make changes in upper layers with no or limited impact on layers below.

Knowing what to be implemented some more studies were carried out to get some understanding on how to realize. This included some HW and SW specifications where each building block were briefly analyzed to figure out if it were best suited to be implemented in HW, SW or any combination. The study highlighted among other things the challenge in realizing a Fuel Cell based on a string-starter generator and as well the challenge in storing hydrogen without having any H2 tank available.

The last part of the launch phase included the construction of a development plan and a Product Acceptance test. The development plan split the tasks into a number of value adding iterations with the aim to gradually build up a complete system with more and more functionality. The product acceptance test were developed in order to confirm that the H2 subsystem fulfill the given requirements.

REFERENCES

- http://www.eudp.net
- Conversations with Jan Møller
- Conversations with Hans Henrik Hansen
- CRC Handbook of chemistry and physics 91st Edition
  - 5 – 69 table: Energy content of Fuels
  - 4 – 66 table: physical constants of inorganic compounds
- UML Distilled (Third Edition) by Martin Fowler

ENCLOSURE

A. Pre Project
B. Power Bus Specifications
C. Communication Bus Specifications
D. Document from Jan Møller