Final Report

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1 Introduction

Energy storage is getting more and more interesting now a days. As part of the energy system transformation, the power generation in the European Union is to be completely decarbonized by 2050 (Website). This requires a massive of renewable energy sources. Renewable energy have the great disadvantage of being highly fluctuating, due to their dependence on sun and wind. This means that the energy generated with renewable energy sources can't meet the energy demand at any given time, due to weather conditions and the shifting position of the sun throughout the day. To meet the demand of having electricity(energy) at any given moment of the day, it is important to store the surplus energy so it can be used when there is no energy generated.

1.1 European project semester (EPS)

Since 1994 European Project Semester (EPS), become a huge success. Within a EPS, students work in international and interdisciplinary teams of 3–6 students on a project. Beside the project the semester consist of short courses. The different courses are team building, project management, English academic writing and local language Swedish

The project is commissioned by Novia university of applied science, a multi-professional university of applied sciences (UAS) with campuses located in five cities in Finland. They offer high quality practice-oriented higher education at both Bachelor's and Master's levels as well as further education in Swedish and English. (website)

The stakeholder of the project is the energy research group of a collaboration of different universities in Vaasa, named: Energy Storage in Our Future Low Carbon Stociety (Energilagring!). They have a collaboration with the following companies: Wärtsilä, Vaasan Sähkö, Danfoss, Gigafactory and the Regional Council of Ostrabothnia.

1.2 Team dynamics

The project group exist out of 5 members. With three different nationalities and three different study backgrounds. The members are:

- Carles Perrez, Spain, Mechanical Engineering
- Eeke de Jong, The Netherlands, Applied Physics
- Felix Pogats, Austria, Urban Renewable Energy technologies
- Leon Verberne, The Netherlands, Mechanical Engineering
- Renier Looijen, The Netherlands, Mechanical Engineering

There is a different in the amount of working hours every member can contribute in the group. Because four will earn 22 ECTS for the project, that equals to 32 hours per week. The fifth person will earn 15 ECTS credits for the project, that equals to 22 hours per week.

1.2.1 Study background

Everyone will bring his own experience and knowledge to the project. There are three different study backgrounds.

Three project mates have a mechanical engineering background. Mechanical engineering is the discipline that applies the principles of engineering into the design, analysis, manufacturing, and maintenance of machines and mechanical production techniques.

One studies Urban renewable energy technologies. Within this discipline they learn at the interface between energy technology, building services engineering and plant engineering. Students receive a technical-engineering education with a focus on our increasingly renewable energy system (especially in urban areas). The course of studies imparts knowledge about the functionality and operating behaviour of renewable energy technologies, the dimension of technological components and their integration into the overall system.

The last one has a background in applied physics. Within physics even complex systems can be described and understood with just some simple and basic universal key concepts. In a structured and applied research a physicist digs up new knowledge and information. The activities are aimed to answer the research question or to solve a problem.

1.2.2 Belbin team roles

Dr Meredith Belbin and his team discovered that there are nine clusters of behaviour these were called team roles. To have a high preforming team you need all the different team roles. However, this doesn't mean that every team requires nine people! Most people will have two or three Team Roles that they are most comfortable with, and this can change over time. Each Team Role has its strengths and weaknesses, and each has equal importance. As stated on the Belbin website.

All members of the project made a Belbin test. With the results of the test we can see where are strength lie and what will be risky for our group. First the different team roles will be explained, as they are stated on the Belbin website. After that the results of every team member will be analysed. Finally there is a summary made with how the dynamics of our group would be.

- Coordinator = needed to focus on the team objectives, draw out team members and delegate work appropriately
- Shaper = provides the necessary drive to ensure that the team keeps moving and does not lose focus or momentum
- Plant = tend to be highly creative and good at solving problems in unconventional ways
- Monitor = provides a logical eye, making impartial judgements where required and weights up the team's options in a dispassionate way
- Implanter = needed to plan a workable strategy and carry it out as efficiently as possible
- Resource investigator = uses their inquisitive nature to find ideas to bring back to the team
- Team worker = helps the team to gel, using their versatility to identify work required and complete it on behalf of the team
- Finisher = most effectively used at the end of tasks to polish and scrutinise the work for errors, subjecting it to the highest standers of quality control
- Specialist = brings in-depth knowledge of a key area to the team

1.2.3 Team members

For all the team members a graph is made with the results see figure 1 until 5. Out of this graph the top two of team roles of every member is mention, whit his/her strengths and weakness.

	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	1	0	3	2	0	0	2	2
2	0	1	3	1	0	2	2	1
3	0	0	2	0	1	3	3	1
4	1	2	2	2	1	2	0	0
5	0	1	2	2	1	3	0	2
6	0	0	2	2	2	2	2	0
7	3	0	0	0	0	3	2	2
Tot	5	4	14	9	5	15	11	8

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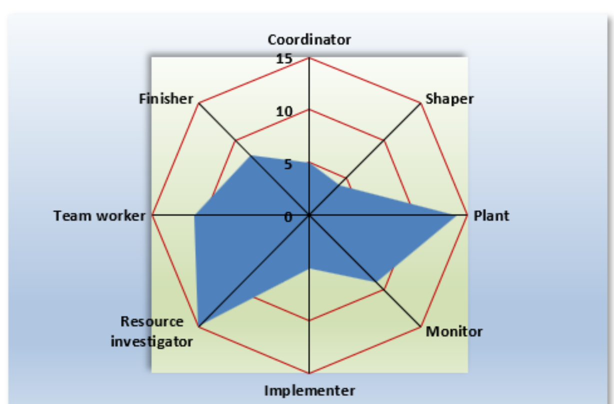


Figure 1: Belbin test Carles

As shown in the figure 1 the two key team roles for Carles are plant and resource investigator. The following strengths and weakness will come with this team roles.

STRENGTHS	WEAKNESS
Creative Imaginative Free thinking Solves difficult problems Outgoing Develops contacts	Might ignore incidentals Too preoccupied to communicate Forgetful over-optimistic can lose interest

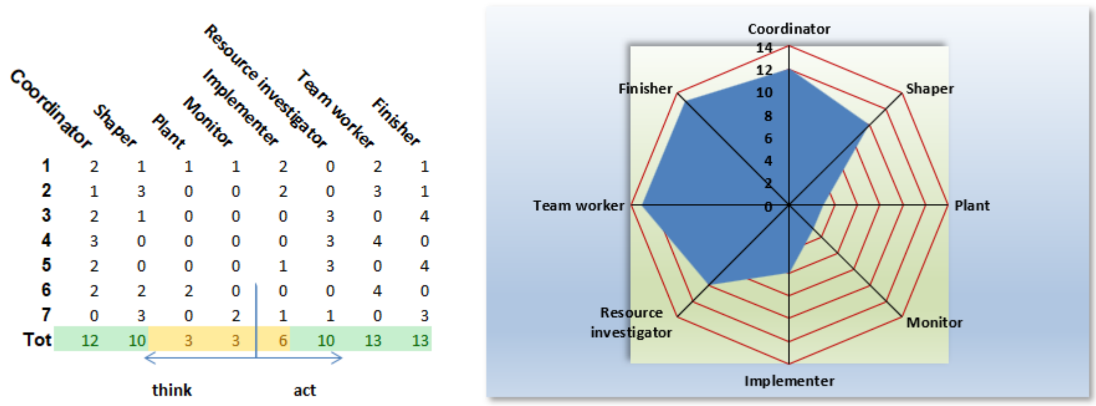


Figure 2: Belbin test Eeke

As shown in the figure 2 the two key team roles for Eeke are team worker and finisher. The following strengths and weakness will come with this team roles.

STRENGTHS	WEAKNESS
Co-operative	Avoiding confrontation
Perceptive	Indecisive in crunch situations
Diplomatic	Worry unduly
Painstaking	Reluctant to delegate
Conscientious	Extreme perfectionism
Polish and perfects	

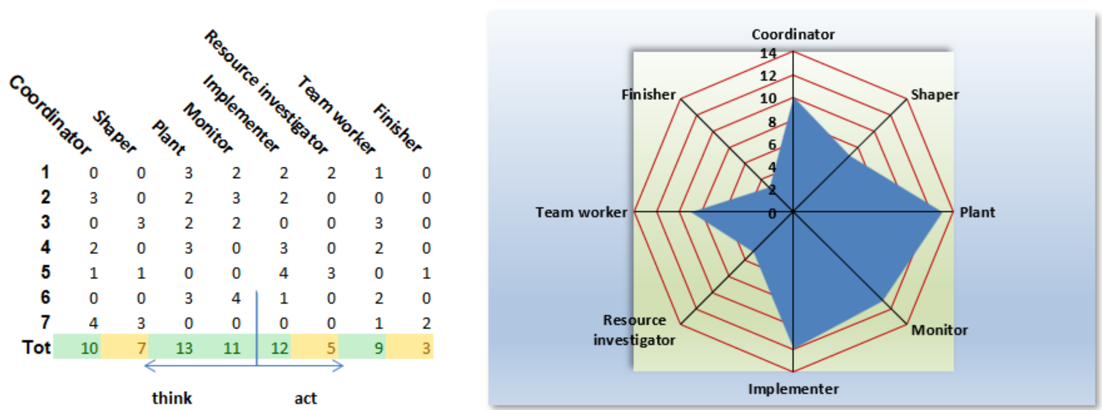
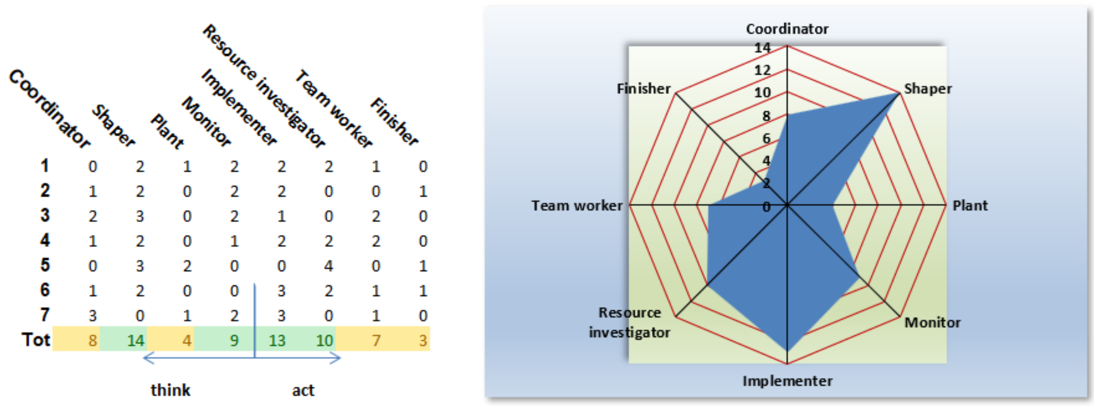


Figure 3: Belbin test Felix

As shown in the figure 3 the two key team roles for Felix are plant and implementer. The following strengths and weakness will come with this team roles.

STRENGTHS	WEAKNESS
Creative	Might ignore incidentals
Imaginative	Too preoccupied to communicate
Free thinking	Forgetful
Solves difficult problems	Inflexible
Practical	Slow with new possibilities
Reliable	
Efficient	

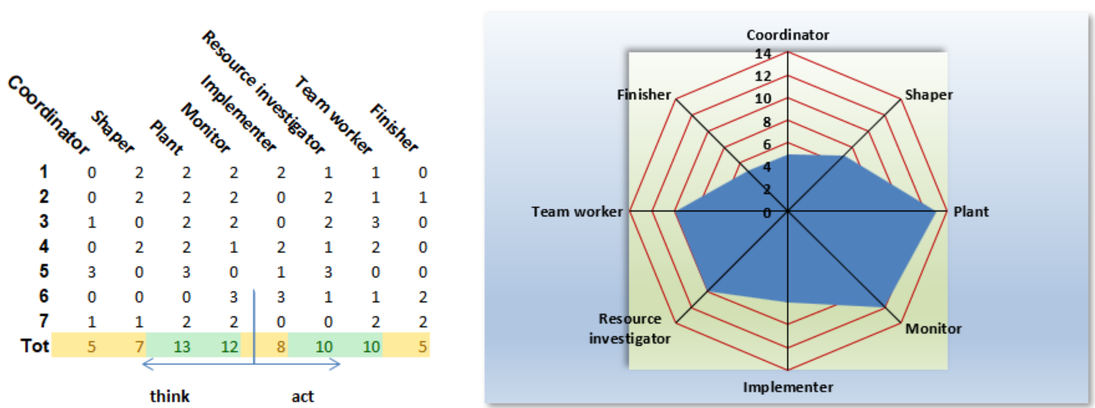


	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	0	2	1	2	2	2	1	0
2	1	2	0	2	2	0	0	1
3	2	3	0	2	1	0	2	0
4	1	2	0	1	2	2	2	0
5	0	3	2	0	0	4	0	1
6	1	2	0	0	3	2	1	1
7	3	0	1	2	3	0	1	0
Tot	8	14	4	9	13	10	7	3

Figure 4: Belbin test Leon

As shown in the figure 4 the two key team roles for Leon are shaper and implementer. The following strengths and weakness will come with this team roles.

STRENGTHS	WEAKNESS
Challenging	Provocation
Dynamic	Offend people's feelings
Thrives on pressure	inflexible
Practical	Slow with new possibilities
Reliable	
Efficient	



	Coordinator	Shaper	Plant	Monitor	Implementer	Resource investigator	Team worker	Finisher
1	0	2	2	2	2	1	1	0
2	0	2	2	2	0	2	1	1
3	1	0	2	2	0	2	3	0
4	0	2	2	1	2	1	2	0
5	3	0	3	0	1	3	0	0
6	0	0	0	3	3	1	1	2
7	1	1	2	2	0	0	2	2
Tot	5	7	13	12	8	10	10	5

Figure 5: Belbin test Renier

As shown in the figure 5 the two key team roles for Renier are plant and monitor. The following strengths and weakness will come with this team roles.

STRENGTHS	WEAKNESS
Creative	Might ignore incidentals
Imaginative	Too preoccupied to communicate
Free thinking	Forgetful
Solves difficult problems	Lacks the drive and ability to inspire others
Strategic	Overly critical
Sees all options and judges accurately	

1.2.4 Overall Team

In our team we have the following team roles: Team worker, finisher, plant, implementer, shaper, monitor resource investigator. The missing team role are coordinator. According to the description on the Belbin website, it can be that people have to act according to three team roles. If that is the case all the team roles are present in our group. Eeke had a score of 12 out 14 on coordinator as well, so that one is present in the team as well.

2 Plan of action

This section is dedicated to the organizational structure of the project, the methodology of the project.

The supervisor is Cynthia Söderbacka, a member of 'Energy Storage in Our Future Low Carbon Stociety (Energilagring!)'. There will be a weekly meeting with the project group and Cynthia. The project group will meet every Wednesday with the five of them. Everyone who is available at 9:30 on workdays (Monday until Friday) will have a coffee meeting. In this coffee meetings the plans for that day will be announced and small problems will be discussed. The project members will work in the EPS room in Technobothnia or in the library Tritonia. The guideline for the working hours is to work between 9:00 until 17:00.

2.1 Problem analyse

In this section the problem of this EPS project will be described, the requirements and the beneficial organisation will be mentioned.

In Technobothnia the Energy Storage in Our Future Low Carbon Stociety (Energilagring!)-group has an energy lab. In this lab different experiment set-ups are located. Technobothnia is a wide ranged laboratory unit co-owned by three universities, the University of Vaasa, Vaasa University of Applied Sciences and Novia Univeristy of Applied Science The laboratory unit serves to the educational need of the approximately 2400 technical students of the three schools, and also functions as a platform for research and close interaction with the local industries. All to ensure the regions position as one of the leading technology hubs of Finland. (Website)

The Energy Storage in Our Future Low Carbon Stociety (Energilagring!)-group would like to give students more insight about energy storage. To get a real understanding about different energy storage systems, the energy research group wants to have a demo in Technobothnia.

The goal of this EPS-project will be to build a energy storage demo in Technobothnia. The following requirements and conditions needs to be considered. The demo has to be suitable for learning purpose. So there has to be a manual so students can work independently with the experiment set-up. The system should have some changeable parameters, so students can research the influence of this variables. The experiment with the demo has to be finished within 3 hours. Safety of the students is priority one. The amount of energy storage has to be enough to light a bulb. The demo can not make to much noise, because other students have to work in the same lab. For the same reason the set-up has to work independent from other projects. The set-up can not by higher then 4,5 meters and has to be compact, so it fits in the energy lab of Technobothnia. The budget for the project is 6.000,-.

The project will start at 9-9-2019 and ends at 18-12-2019. The focus of this project will lay on building the demo and not on the use of the student.

2.2 Objectives

This chapter is dedicated to define the objectives that will be delivered at the end of the project.

As stated in the problem analyse, the EPS project group will build a energy storage demo in the energy lab in Technobothnia. The objectives that will be delivered on 18-12-2019 are a energy storage demo, a manual how to use the demo and a final report. The final report contains: decision making process, project management, a research about energy storage, designing and the building process.

2.3 Methods and measurement equipment

This section is dedicated to the working methods and the different phases the project will pass through. The phases will be:

1. Research
2. Design
3. Build
4. Test
5. Improve

2.3.1 Research

First more background information about what The Energy Storage in Our Future Low Carbon Stociety (Energilagring!)-group wants and already had done will be collected. Next general research about different energy storage's principles will be done. This in combination with the list of requirements a decision for what kind of energy storage there will be build, will be made. After the sort of principle is decided a more in depth research about that subject will be done.

2.3.2 Design

In the design phase there are different steps that has to be taken. Step one will be creating a morphologic chart. A morphological chart is a table based on the function analysis. On the left side of the chart the functions are listed, while on the right side, different mechanisms which can be used to perform the functions listed are drawn. It is a visual aid used to come up with different ideas.

The most promising ideas from the morphologic chart are going to be investigated with a proof of principle. A proof of principle is a realization of a certain method or idea in order to demonstrate its feasibility, or a demonstration in principle with the aim of verifying that some concept or theory has practical potential.

The last two steps will be make a conclusion about what solution we will go for. When a decision is made about what solution there will be worked with, a component list can be made.

2.3.3 Build

When the component list is made, the needed materials and components can be ordered. To be sure there is a working demo at the end, the system will cut up in pieces. A basic set-up of the demo will be build and if the time allows the system will be expanded. The basic system will exist out of standardized components, so the only thing that has to be done is connecting all the parts with each other and make it work. When there is a working demo, measurement equipment will be added. If the times allows it, some self made parts will be added to the system.

2.3.4 Test and improve

When there is a working system, the system will be tested. With the different test results, there can be concluded how well the demo is working. Whit that knowledge the system will be improved where possible.

2.4 Feasibility and risks

This chapter is dedicated to whether this research project if utile and what risks may appear.

There are different risks for the project. One is an under estimated delivery time of the different components. Also making wrong assumptions for the components that are needed, is something to be aware of. The wrong assumptions can come from miss calculations and fault in the created date sheet. That's the reason the building phase exist out of a basic system and the expanded version.

Within the team there are also some risks to take in account. The team exist out five completely different kind of people. That's why it is important to have a good communication going on, to avoid conflict. That's the reason the project team will have every morning a coffee meeting, as discussed in chapter 2 Stakeholders and organization.

3 Research

This chapter is dedicated to the research phase of the project. As described in chapter 2.3.2 first some global research about energy storage will be done. The global research combined with the background information from the Energy Storage in Our Future Low Carbon Stociety (Energilagring!)-group and the list of requirements, will be the base for the decision making.

3.1 Energy storage

In storage technologies, a distinction is made according to their application between short-term, shifting and long-term storage. Short-term storage units can absorb and release energy several times within one day. As a rule, they offer only a limited capacity. In contrast, long-term storage systems must be able to store electrical energy for several days or weeks, for example to bridge phases of a long wind calm in which the sun hardly shines. In between there are shifting storages, which are able to save energy for around 24 hours. Another distinction can be made by the physical principle on which the technology is based.

3.1.1 Electrochemical

Liquid electrolytes are used and flow to electrodes in two independent circuits in a cell. An exchange of ions takes place at the membrane. Graphite felts serve as the base, which is intended to rule out a chemically unwanted reaction. The electrolyte pairs zinc-bromine, polysulfide-bromide and vanadium-vanadium are examples of redox pairs that have already been successfully tested and applied. The REDOX flow battery was tested very successfully with two identical liquids, namely the redox vanadium vanadium pair. Since vanadium can be used at will, a surprisingly high efficiency could be calculated. The electrolytes are characterized by an efficiency of 75-80 percent. The technology of the REDOX flow principle has been around for quite some time and is often used more or less successfully. Redox flow energy storage systems create a high number of cycles and can therefore be reused for a long time.

3.1.2 Electrical (Supercapacitors)

Supercapacitors work according to a different principle of charge storage than rechargeable batteries. Supercapacitors consist of electrochemical double layers on electrodes moistened with an electrolyte. When a voltage is applied, ions of opposite charge accumulate at both electrodes and form thin zones of immobile charge carriers. In contrast to rechargeable batteries, only a charge shift occurs, but no chemical change.

3.1.3 Chemical

Power-to-Chemicals refers to a process in which excess electrical energy from renewable energies is used to produce chemical raw materials via water electrolysis and other downstream steps. Power-to-Chemicals is therefore a Power-to-X technology that can be used for sector coupling as part of the energy turnaround. Power-to-Chemicals is based on the power-to-gas process with which it is closely related. However, the products produced are not used for direct energy storage, but are intended for material used in order to decarbonize the basic material production of the chemical industry.

There are several methods of storing energy within chemical energy storages:

- Power-to-Gas (e.g. hydrogen, methane)
- Power-to-Liquid (e.g. ethanol)
- Power-to-Chemicals (e.g. ammoniac)

3.1.4 Thermal

Thermal storages are mainly used to store heat within a storing mass with a high thermal capacity (usually water or concrete). The higher the thermal capacity of the storage, the more inert the system reacts to changes. This means that depending on the quality of the insulation of the storage, they are more often used as shift storages (eg warm water tanks in buildings) or even seasonal storages (e.g. seasonal thermal energy storage in Norway)

3.1.5 Mechanical storage

An effective way of storing energy is mechanical storage, hereby three principles are mainly used; translation, pressure and elevation differences. Depending on the characteristics of the systems the ability to react to changes in demand can vary a lot.

1. Pumped hydro

   In pumped hydro storage plants, the energy is stored in the form of potential energy from water that is pumped into a higher basin and then converted back into electricity by flowing off via a turbine with a connected generator. Pumped storage power plants are technically mature and currently the only storage technology in Europe that can be used to any appreciable extent.

2. Flywheel

   A flywheel accumulator consists of a flywheel and an electric motor/generator combination. The flywheel is located in a vacuum and is usually equipped with sliding or magnetic bearings to keep the frictional resistance as low as possible. The surplus energy drives the electric motor, which accelerates the flywheel to a high speed. If energy is needed in the grid, the flywheel drives the electric motor, which then functions as a generator and converts back mechanical energy into electrical energy.

3. Gravitational storage

   Gravitational storages are based on the same principle as pumped hydro systems. When surplus electricity is available in the grid electric motors raise up blocks of concrete or stone to a certain hight, when the energy demand increases again the electric motors, which now function as generators, produce electricity driven by the weights.

4. Compressed Air Energy Storage (CAES)

   Excess electricity is used to press air into underground salt domes or former gas caverns (compression). When electricity is needed, the compressed air flows through a turbine and generates electricity again. The heat generated during compression can be used to improve efficiency (adiabatic compressed air storage).

3.2 Decision making

This section is dedicated to how the project group made the decision about the sort of principle the energy storage demo will be about. As stated in the beginning of this chapter for the decision making three different things are needed:

- Basic research about energy storage
- The list of requirements
- Background information from The Energy Storage in Our Future Low Carbon Stociety (Energilagring!)-group

The list of requirements is described in 2.1 and listed as follows:

1. The complete test cycle takes maximum 3 hours.
2. The system cost maximum 9000,- euro's.
3. The lifespan of the system is minimum 5 years.
4. The system can have an maximum dimension of 2x2x2 meter.
5. The system stays under 85 db.
6. The system has at least two adjustments settings.
7. The system has at least four values what are able to read out.
8. The system has at least an efficiency of 2% of returning its energy.

The Energy Storage in Our Future Low Carbon Stociety (Energilagring!)-group looked into three different kind of energy storage principles; hydro pump, compressed air energy storage and liquid air storage. There all a form of mechanical energy storage. Liquid air storage was not within the budget. So the decision had to be made between the hydro pump and the compressed air energy storage. To show the principle of the hydro pump a high height is needed. As stated in the list of requirement, number 7, the demo can not be higher then 4,5 meters. So the hydro pump is not an option. This project will focus on the principle of compressed air energy storage (CAES).

3.3 Compressed air energy storage (CAES)

The way energy is stored in this system is by compressing air and storing that compressed air in tanks. When the energy is needed again it can be retrieved by release the air out the tank and let it expand within a turbine. The turbine will drive a generator that will convert mechanical energy into electrical energy.

To make the air expanded even more the air could to be heated. But still a lot of energy gets lost with the CAES system. See figure 6 one with the steps and what kind of energy gets lost.

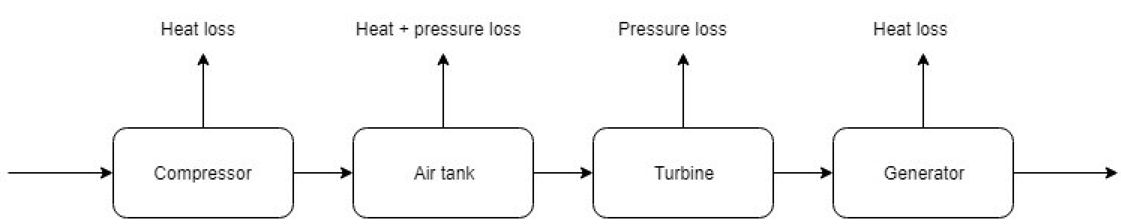


Figure 6: Schematic energy lost

There are three different main theoretical systems developed. At the moment there are two large scale working Compressed Air Energy Storage (CAES) plants, one in Huntorf Germany and one in McIntosh, Alabama USA. A CAES plant mainly consists of (1) compressor train, (2) motor-generator unit, (3) gas turbine and (4) underground compressed air storage. In both plants the underground compressed air storage is stored in excavated salt domes.

3.3.1 Diabatic CAES system

Both plants are a Diabatic CAES system. A D-CAES System is not a pure energy storage system. To make the system more efficient the air need to expand, by heating the air, before entering the turbine. This is done with burning natural gas.

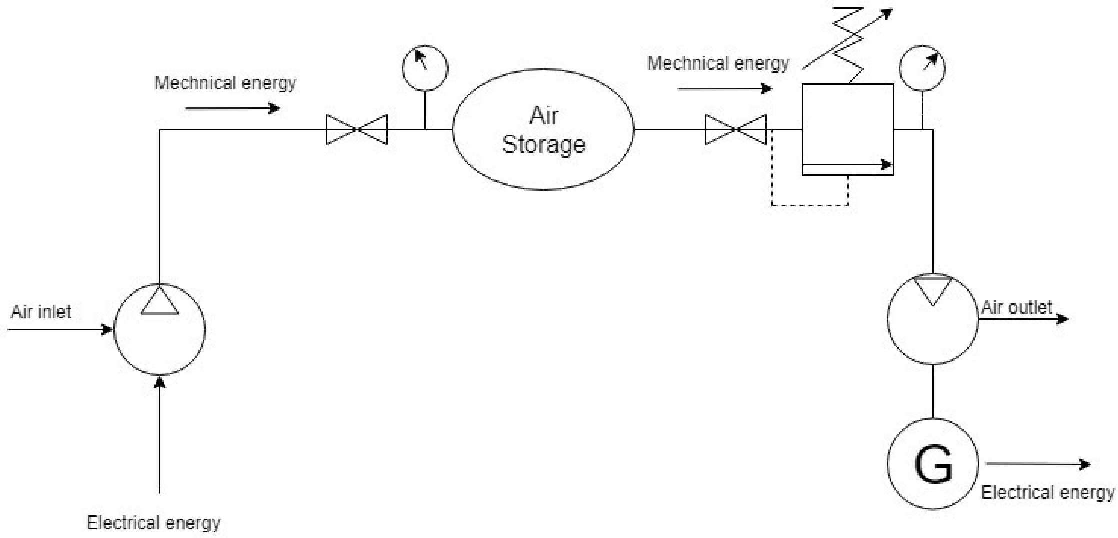


Figure 7: Schematic CAES

- Huntrof Germany

  CAES plant was built in 1978 and is world's first. During low-cost off-peak load periods (compressed) air will be stored in the underground salt domes. During peak load periods a reverse process takes place. The air will be released to the surface and is used to burn natural gas in the combustion chambers. The resulting combustion gas is expanded to spin the generator and produce electricity. The CEAS plant produces 321mW for 2 hours, the air compressing takes up 8 hours. Operating in a pressure range between 4.8 MPa and 6.6 MPa. The total cavern volume is 310.000 m3 and 600m below the ground. Two different caverns are used for this CEAS plant because:

  - Redundancy cavern shut-down
  - Easier cavern refilling after drawing down the pressure in a cavern to atmospheric pressure.
  - Start-up procedure for plant compressor requires a minimum pressure

  It has been reported that the plant has run in good condition and consistently shown excellent performance with 90% availability and also 99% starting reliability respectively.

- McIntosh Alabama USA

  McIntosh CAES was built in 1991 and produces 190mW for 26 hours. Recharging is partially done during weekday nights and is fully recharged at weekends. The storage capacity is about 560,000 m3, 450m underground. And the operating pressure range is 4.5 MPa to 7.4 MPa. The design of this CAES is almost the same as Huntorf. One major improvement is a heat recuperator to reuse part of the heat energy from the exhaust of the gas turbine section. This way it is tried to create a pure energy storage system and makes it more a adiabatic CAES system. Unfortunately in practical this is not the case. Still the fuel consumption is reduces by 22-25% and improves the cycle efficiency from 42% to 54%, in comparison with the Huntorf plant. The reliability between the year 1998 and 2008 has been between 91.2% and 92.1%.

3.3.2 Adiabatic CAES system

When air is being compressed it will produce heat, normally this heat is a waste product of the compression. A solution that already is used, would be to store this thermal energy of the compressor and use it to heat the air before the turbine. The air will expands and will take up closer to the amount of energy it took to produced compressed air.

For the storing of the thermal energy, it first needs to be transferred from the compressor to a move able medium. When this medium is heated up it needs to be moved away from the compressor to an insulated storage vat. The most used medium is water. If you use water there should be enough cooling water to keep the compressor from overheating and the water from boiling. When the time comes to produce electricity, the water needs to be pumped to heat up the air before entering the turbine or air motor. In this way it's made sure the air doesn't shrink in the turbine due to cooling, which will lead to power loss.

Figure 8 shows the schematics of the system with a heat storage.

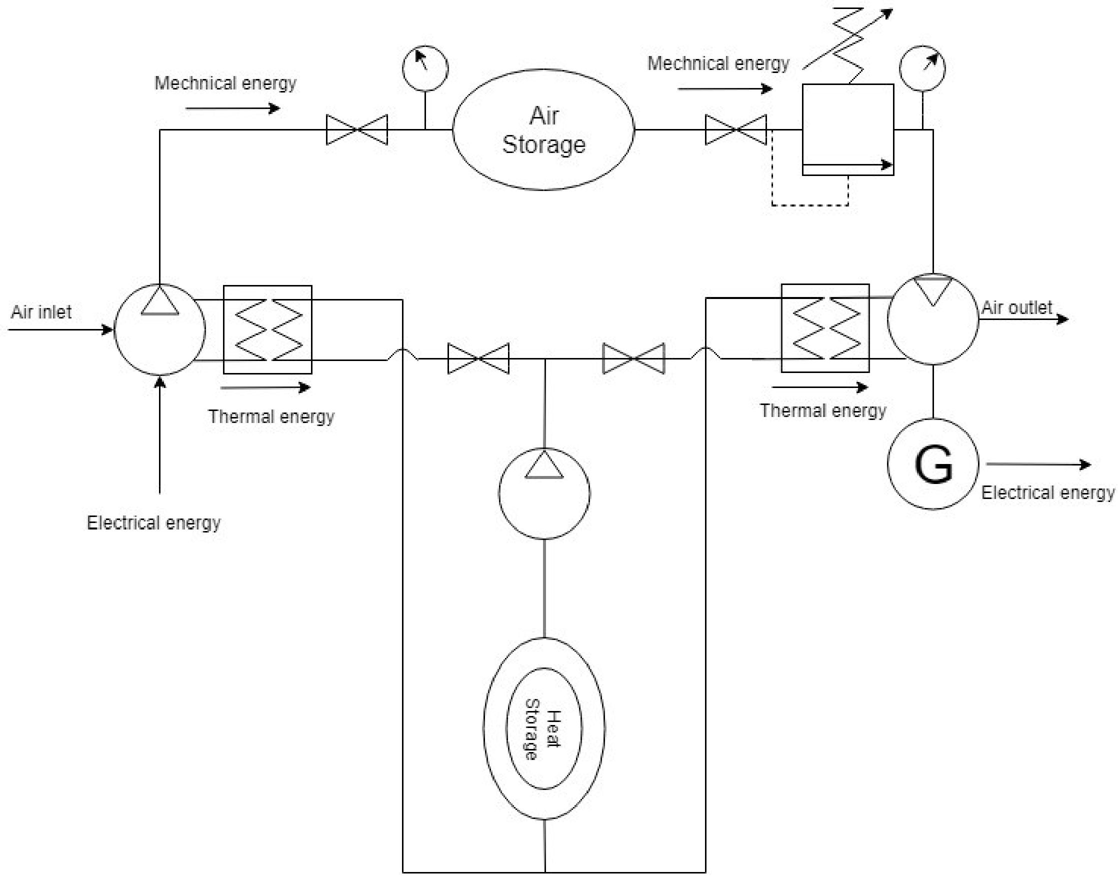


Figure 8: Schematic Adiabatic CAES

3.3.3 Isothermal CAES system

The Isothermal CAES makes also use of a heat storage. But to cool down the heat during the compression process water is sprayed into the airstream to cool the air, in order to achieve an isothermal compression of the air. This leads to a reduction of work for the compressor during this stage. The thermal energy, stored in the water, is then captured in and stored in an heat storage, similar to the adiabatic CAES system. When the energy is needed again the hot water is released during the expansion process, by spraying water into the airstream. The heat water will increase the air what leads to expansion. This procedure is supposed to be the most efficient CAES system.

3.3.4 Variables

It's also important to know which variables are adjustable and what could influence the efficiency of the system. If the student adjust those variables he could see the effect on the efficiency of the system. The following adjustable variables apply for the CAES system.

- The temperature of the cooling water

  The temperature can be influenced by how much cooling water is put into the system, there is a minimum of how much cooling water should be in the system. The minimum is dictated by how much heat the compressor produces. The water temperature in the system should always remain within safe values, those values will be determined later.

- The pressure in the storage tank

  The pressure can be regulated with a pressure valve. The compressor will most likely have a best efficiency area. The area where the least electricity is used to compress the most air with the highest pressure.

- Pressure inlet of the air turbine

  The inlet pressure can be regulated with the same kind of valve as the pressure in the storage tank. Instead now the pressure running through the turbine is changed. In search for the most efficiency area of the turbine.

- With or without use of a heat exchanger

  In the case of not using a heat exchanger the water pump is still needed to cooldown the compressor. The electricity use of the pump should not be included within the efficiency calculation also, the water should be cooled down before the next run. All of this in prevention of making inaccurate measurements.

3.3.5 Measurements

If you want to control and measure certain values in the system the system needs an computer. To control and measured the system you need different sensors and valves/regulators. The following sensors could be used in the system:

1. Power usage of the compressor
2. Pressure sensor
3. Temperature in + out of the heat storage system
4. Power usage of the pump
5. RPM of turbine
6. Generate energy by the generator
7. Temperature and pressure outside system

The outcome values of the sensors makes it possible for the student to calculate efficiency of the system. And how big of an effect an adjustments has on the efficiency of the CAES system.

The power usage of the compressor and the pump are important to measure. Otherwise you couldn't calculate how much energy the system used for the energy storages. With the measured value of generated energy of the generator it's possible to calculate the efficiently of the system.

The sensors what are required for the system are probably compatible with PLC's, Arduino system or Raspberry Pi. The Raspberry Pi and Arduino system are cheap but work only on 5 volt. That could make it more of a challenge to make it work with different types of sensors. PLC's work on 12volt or 24 volt but they are very expensive. Also a good thing is that they are very reliably. Which system will be used for the project will be decided on the budget and the type of the sensors.

4 Design

5 Building

6 Conclusion

7 Appendix