Hybrid HVDC transformer for multi-terminal networks

Project Plan

Industrial Doctoral Centre for Offshore Renewable Energy

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02-August-2013

Academic Supervisors
Lead Supervisor: Jonathan Shek, *The University of Edinburgh*
Co Supervisor: Gerasimos Theotokatos, *The University of Strathclyde*
Co Supervisor: Mohammad Abusara, *The University of Exeter*

Industrial Supervisors
Chong Ng, Head of Validation Narec
Paul Mckeever, Head of Research and Development, Narec

Background

As subsidies for offshore wind decreases, energy costs will need to become comparable to traditional sources of energy generation and onshore wind. There is therefore a push to move further offshore and increase development capacities to maximise revenues. As distances from shore and farm sizes increase, energy exportation and reliability issues will become increasingly important.

All fully operational offshore wind projects utilise either High or Low Voltage Alternating Current (HVAC or LVAC) cables for power transportation. While AC overhead lines work well on land, the increased parasitic capacitances present in cables greatly reduce overall efficiency and power quality. Since the parasitics are proportional to cable length, there are practical and financial limitations on the distance wind farms can be located from shore.

An option is to get around this using High Voltage Direct Current (HVDC) cables. As the current is no longer oscillating, parasitic losses associated with inductance and capacitance are negated. Voltages can therefore be increased from around 132kV to 400kV thereby also reducing resistive losses. The cable costs also reduce with DC as for a given amount of power 1/3 less copper is required. Additionally power factor correction at the grid connection point is no longer required offering significant cost savings. High semiconductor prices used in the converters have made HVDC links unattractive in the past; however, now that these costs are falling and copper prices rising [1], the breakeven point for HVDC vs. AC is around 50km. There is therefore, a trend for wind farms under construction off the coast of Germany and many of the UK round 3 projects, to use HVDC cables.

Current HVDC designs have been brought over from systems used to link AC grids together. As such, they are designed for bulk energy transfers emanating from a central hub. LVAC (33kV) cables are used to link the turbines to the central converting station reducing efficiency. The large central converting station requires considerable capital expenditure and offers very little redundancy.

Project Aim

This joint Narec-IDCORE project aims to overcome these problems through the design of a new modularised HVDC transformer for use within an offshore DC network. The first section of the project involves the investigation of the transformers' interactions within this network. This includes identification of the device failure modes and their impact on the network, fault protection, methods of controlling power flow within the network and the potential removal of the offshore substation.

To enable the creation of the inter-array DC network to maximise efficiency, a novel transformer will be designed to fit within the turbine's nacelle or tower, increasing redundancy. The transformer will therefore have a power rating at least equal to that of the turbine itself. To accomplish this, Narec has created a new converter topology. This project will investigate the merits of the new topology and, if necessary, improve it. Switching and control algorithms will be written for the converter and a novel transformer core designed, with consideration to the switching frequency, to minimise size, while maintaining high efficiencies. The transformer will be modelled in Matlab Simulink and the results verified through the construction and testing of a prototype device. This will occur either as an additional component of this project or as a separate project run by Narec.

Previous Works

There are several commercially available HVDC transformers by Siemens, Alstom and ABB. As mentioned previously however, these designs are focused around large bulk energy transfers emanating from a single point and as such are less suited for wind farm integration. There has been much research in the academic world to improve transformer and DC network designs. Research at Strathclyde has examined the possibility of utilising a DC/DC transformer in conjunction with clusters of wind turbines [2], [3].

Narec currently owns a patent for the Hybrid HVDC transformer [4] on which this project is based. The patent details an initial converter topology, which will be assessed and if necessary improved upon as part of the research project, and suggestions as to how it maybe incorporated into a network. An early stage feasibility study was also performed which lead to the creation of this joint Narec-IDCORE research project [5].

Objectives

Background

- Existing offshore wind farm specifications
  - Literature investigation
- Investigate the three main HVDC converter topologies; Cascade H-Bridge, Diode Clamp and Modular Multilevel Converter
  - Literature review to identify topologies, switching combinations and pros and cons.
  - Simulink to model converters and determine current flows for various loading conditions, switching stresses and number of devices
- Topologies currently in use
  - Literature review to investigate commercial topologies and limitations
- Converter Research
  - Extensive literature review to identify next generation converter designs and concepts as well as mitigation methods for converter limitations

Network

- Pros and cons of topology
  - Previous literature reviews will be combined with results of a Simulink model of the proposed HVDC converter to identify its strengths and weaknesses
- Failure modes
  - The converter model will be used to simulate various network scenarios to identify the failure modes of the converter.
- Fault protection
  - A literature review will be conducted to identify fault protection equipment for HVDC
  - Assessment of fault protection required in the network
  - Assessment of the impact that faults have on the network and how their effects can be minimised
- Substation
  - Investigate methods of combining the inter-array cables into a single export cable.
- High-level control algorithm
  - Identify method of controlling power flow in network

- Write algorithm to utilise this method and maximise energy yield from wind farm
- Network analysis
  - Develop simulation model
  - Use model to perform detailed analysis of HVDC network

Device

- Identification of space
  - Literature review of current and proposed wind turbines
  - Identify anticipated space within nacelle
  - Use this to define a reasonable final size for transformer
- Topology
  - Assess topology suitability for high efficiency, low cost and high availability
  - Use outcomes of current research into converters and pros and cons of topology to suggest possible amendments
  - If necessary make amendments to device
- Switching devices
  - Literature review of semiconductor devices
  - Identify optimal device to meet transformer specifications
- Frequency
  - Use device model to select optimal switching frequency to create a compact but efficient device.
- Switching algorithm
  - Review of switching algorithm theory
  - Use Simulink to write a switching algorithm which minimises device losses
- Transformer
  - Literature review of transformer core materials and designs
  - Design a transformer core which will minimise losses and size
  - Some iteration is expected between the switching frequency & algorithm and the transformer design sections to achieve the desired specifications
- Gating system
  - System which will ensure switch arrays are switched simultaneously
- Control Algorithm
- Full transformer model
  - Model of the full system will be developed in Simulink
  - Device performance tested/optimised
  - Detailed analysis of device under various conditions
- Prototype
  - A small scale prototype will be built at Narec for model verification

Agreements

Industrial Supervision

Weekly face to face meetings will be scheduled by the research engineer with additional meetings planned as necessary.

Academic Supervision

Video and Teleconferencing will be the principal form of contact between the academic supervisors and the research engineer, with email correspondents occurring as required. The research engineer will organise semi-monthly meetings, either face to face or teleconference, with the lead supervisor. Teleconferences between all supervisors and the research engineer will occur on a monthly basis.

Resources

The research engineer will have access to online journals, through the Universities of Edinburgh and Exeter. Electrical lab facilities will be provided either at The University of Edinburgh or Narec towards the end of the project.

Health and Safety

A health and safety induction has been attended by the research engineer after starting at Narec.

The following signatures imply agreement to supporting the project

Lead supervisor: Jonathan Shek

Co-Supervisor: Gerasimos Theotokatos

Co-Supervisor: Mohammad Abusara

Industrial Supervisor: Chong Ng

Industrial Supervisor: Paul Mckeever P. McKeever

Bibliography

[1] C. Ng & P. Mckeever. *Next generation HVDC network for offshore renerable energy industry.*

[2] D. W. Elliott, et. al. 2012. *Offshore wind farm clusters based on DC collection network-operation and design considerations.* ACDC2012 p1-6

[3] D. W. Elliott, et. al. Single converter interface for a cluster of offshore wind turbines. Available online at http://www.strath.ac.uk/

[4] C. Ng et. al "A power collection and distribution system" Patent WO 2011/033308. March, 24, 2011.

[5] C. Ng. *Low loss HVDC transformer feasibility study report*

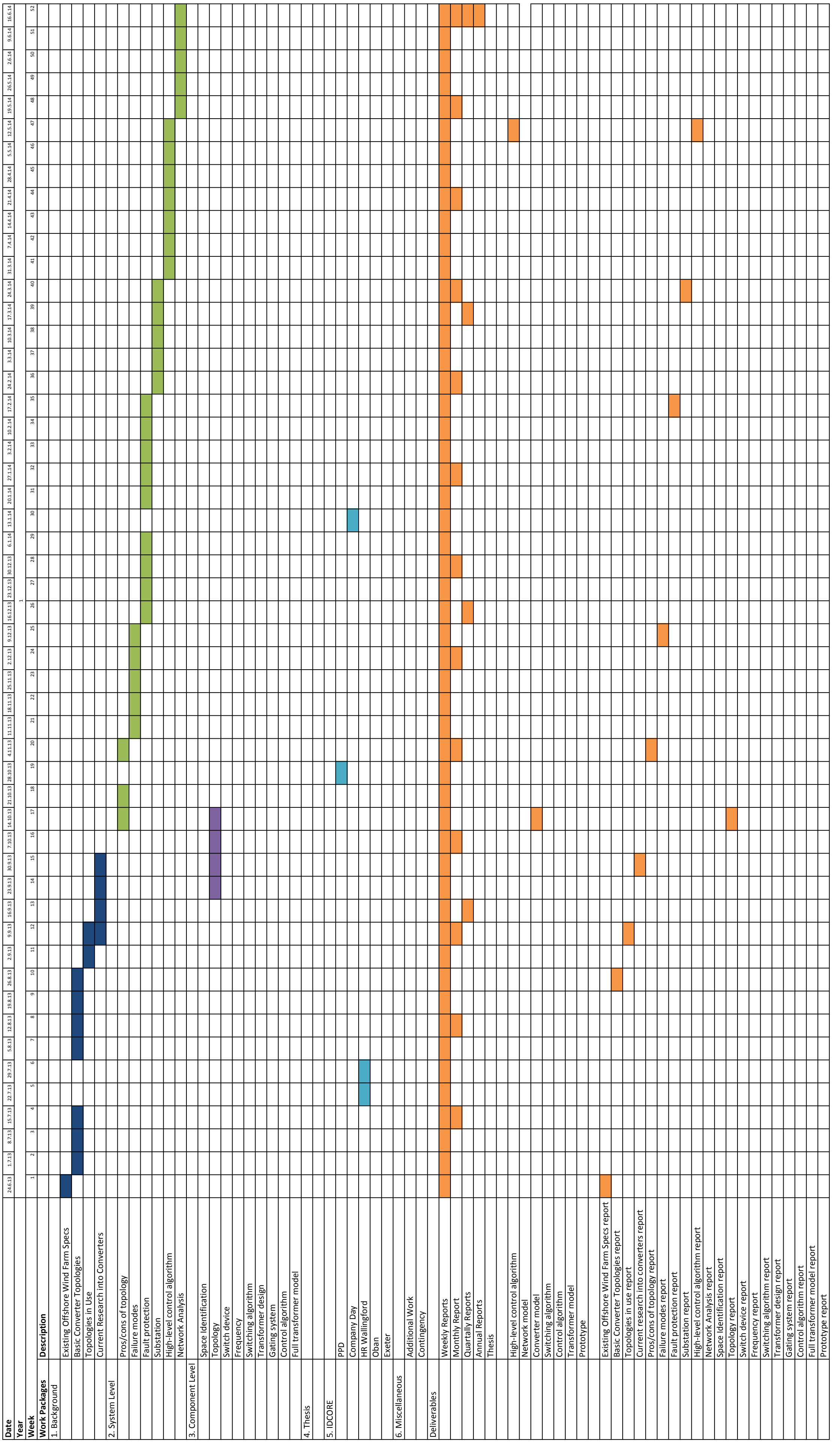

Figure 1. Year 1 Gantt Chart

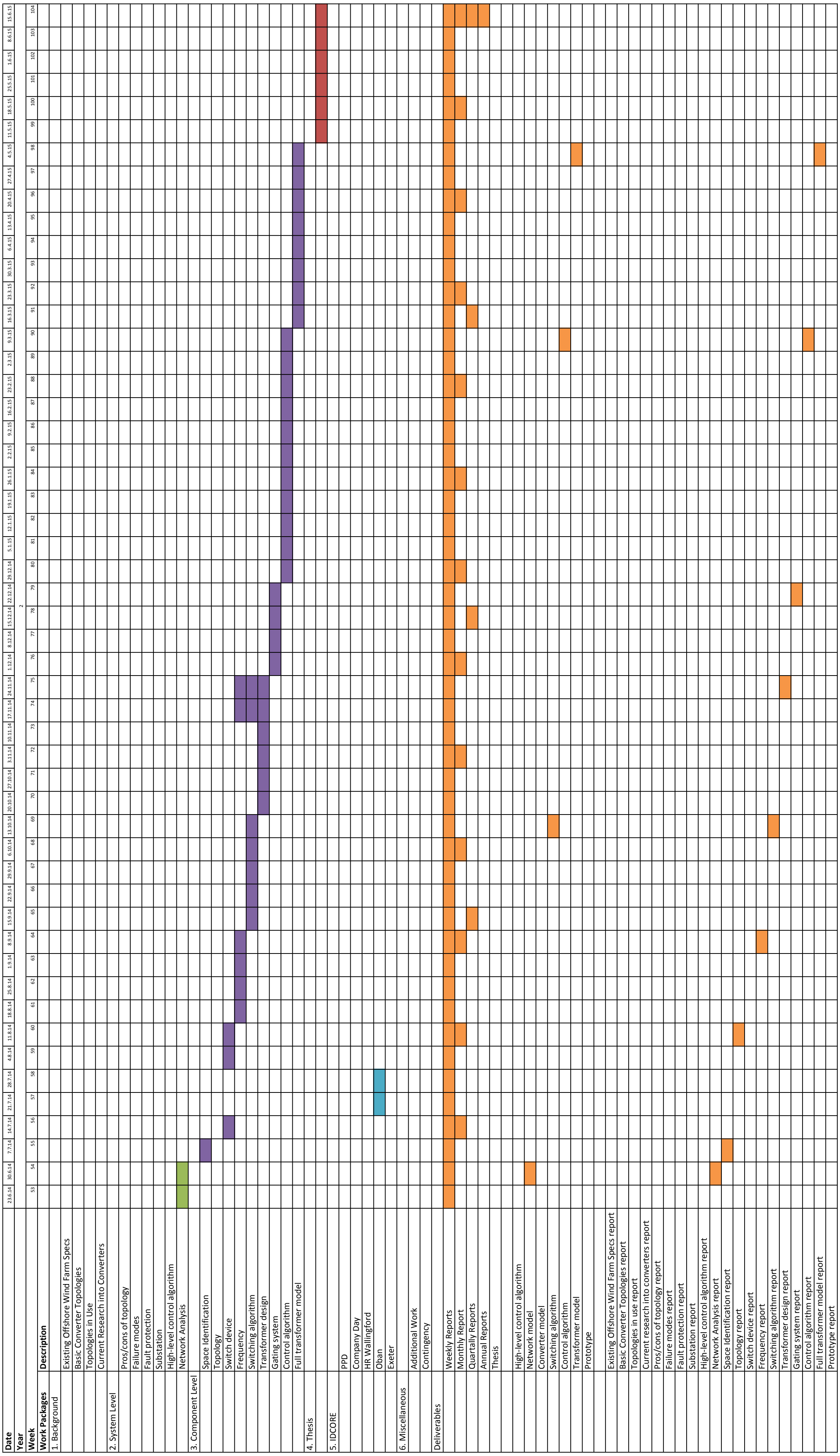

Figure 2. Year 2 Gantt Chart

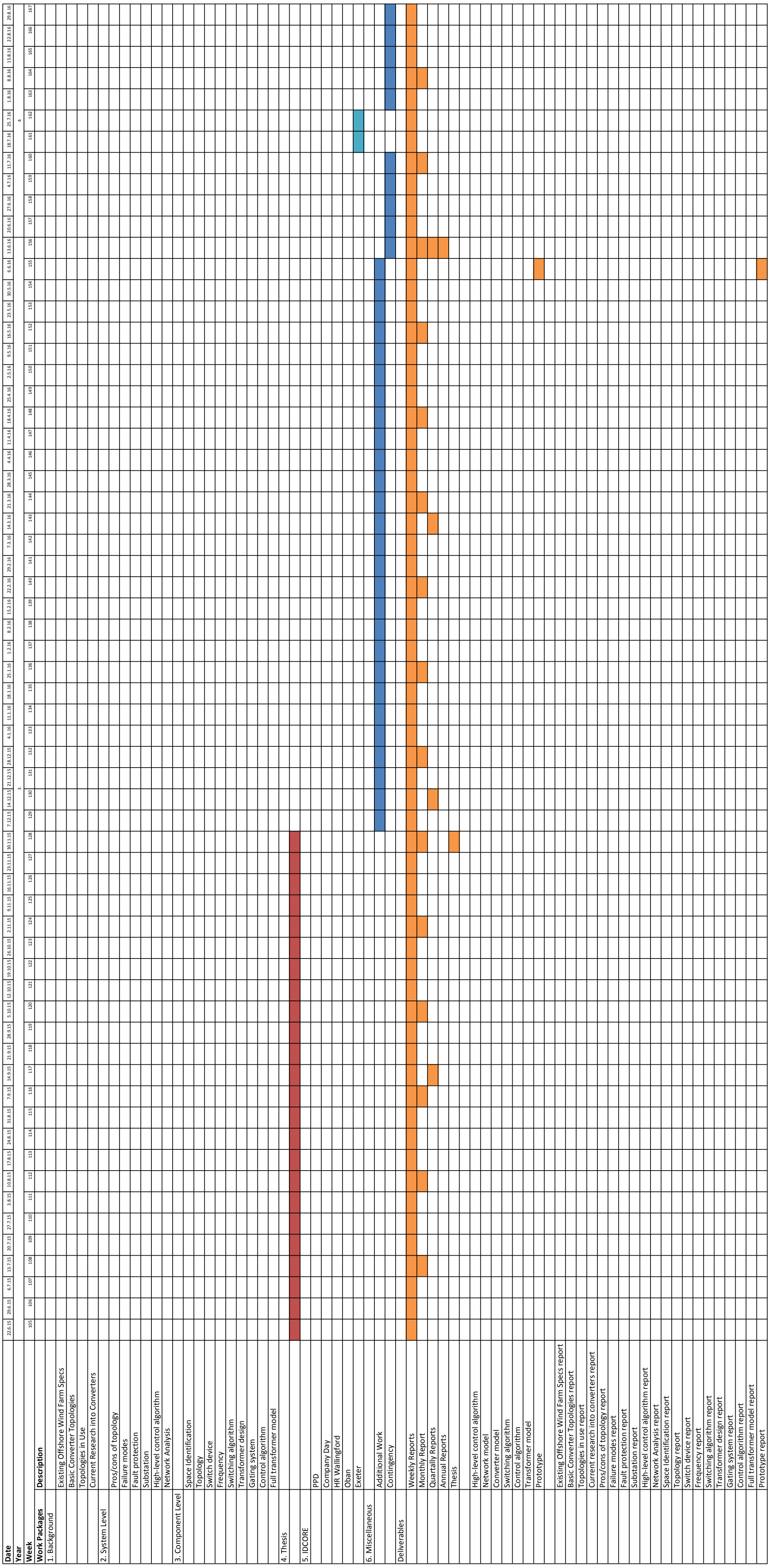

Figure 3. Gantt Chart Years 3&4