CHALMERS
UNIVERSITY OF TECHNOLOGY

Signal box optimisation at the Swedish railway

Master's Thesis within the Sustainable Energy Systems programme

PETRUS SIGVARDSSON

Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2014

MASTER'S THESIS

Signal box optimisation at the Swedish railway

Master's Thesis within the Sustainable Energy Systems programme

PETRUS SIGVARDSSON

Department of Energy and Environment
Division of Electric Power Engineering
UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden

Signal box optimisation at the Swedish railway
Master's Thesis within the Sustainable Energy Systems programme

Examensarbete / Institutionen för energi och miljö,
Chalmers tekniska högskola

Department of Energy and Environment
Division of Electric Power Engineering
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46(0)31 772 10 00

Cover:
Signal box 300. Photo: Petrus Sigvardsson.

Chalmers Reproservice
Göteborg, Sweden

Signal box optimisation at the Swedish railway
Master's Thesis within the Sustainable Energy Systems programme
PETRUS SIGVARDSSON
Department of Energy and Environment
Division of Electric Power Engineering
Chalmers University of Technology

ABSTRACT

The transport sector faces major challenges in meeting the increasing demands of energy efficiency. Work is carried out to optimize energy consumption in the railway signalling system. However, no studies have been made of what the actual power requirement is for the signal boxes along the railway. This thesis has investigated if an energy optimization can be done in three existing signal boxes of type 95 in Göteborg. Type 95 signal boxes are computer based and control e.g. signals and railway switches. Today, consultants relay on data sheets from suppliers during new design and reinvestment. The result in this thesis is a new proposed method for optimization that can be used on both existing signal boxes and signal boxes that will be build in the future.

The developed model used in the optimization method tells the user the actual power requirement for a certain setup of components in the signal box and has proven to give good results. This was determined by comparing the model to earlier proposed optimization results and by testing the model on different sizes of signal boxes. The model uses maximum values both from the in depth power consumption analysis of the railway switches, and the assumed values from output groups with no measurements on. Thus, the energy optimisation can be improved with further work in the future.

The conclusion of this thesis is that some of the signal boxes in Göteborg are dimensioned to handle much higher power consumption then the actual power consumption is in the signal boxes. Subscription rates can thus be lowered which results in a financial benefit. Cable dimensions can be reduced in planned new signal station and in that way reduce used material. The UPS could also, in some cases, be made smaller and take less space due to lower power peaks. This is both cheaper and reduces the resources needed to build the signal box.

Key words: Signal box type 95, Energy optimization, PSU 151, Railway switches, Diversity factor, Cable dimensioning.

Optimering av signalkiosker hos den Svenska järnvägen
Examensarbete inom Mastersprogrammet Sustainable Energy Systems
PETRUS SIGVARDSSON
Institutionen för Energi och Miljö
Avdelningen för Elteknik
Chalmers tekniska högskola

SAMMANFATTNING

Transportsektorn står inför stora utmaningar i att möta de ökande kraven på energieffektivitet. Arbete utförs för att optimera energiförbrukningen i järnvägens signalsystem. Dock har inga studier gjorts av hur stor den faktiska effektförbrukningen verkligen är i ställverk längs järnvägen. Detta examensarbete har undersökt om en energioptimering kan göras på tre befintliga ställverk av typ 95 i Göteborg. Typ 95 ställverk är databaserade och kontrollerar bland annat signaler och spårväxlar. Idag använder konsulterna datablad från leverantörer då ny design av ställverk skall göras eller vid återinvesteringar. Resultatet i detta examensarbete föreslår en ny metod för energioptimering som kan tillämpas på både befintliga ställverk och ställverk som planeras bli uppförda i framtiden.

Den utvecklade modellen som används i metoden för optimering talar om det faktiska effektbehovet för användaren, då en viss konfiguration av komponenter i ställverket. Modellen har visat sig ge goda resultat. Detta bestämdes genom att jämföra modellens värden med tidigare föreslagna optimeringsresultat och genom att testa modellen på olika storlekar av ställverk. Modellen använder maxeffekter både från den ingående analysen av järnvägsväxlarnas beteende och antar maxeffekter på de utgående effektgrupper i ställverket där inga mätningar utfördes. Således kan energioptimeringen förbättras med ytterligare utfört arbete i framtiden.

Slutsatsen i examensarbetet är att en del av ställverken i Göteborg är dimensionerade för en mycket högre effekt än den faktiska effekten verkligen är. Abonnemangskostnaderna kan således minskas vilket resulterar i en ekonomisk vinning. Kabeldimensionerna kan minskas i planerade ställverk och på så sätt minska använt material. UPS-enheten kan också, i vissa fall, göras mindre och ta mindre plats på grund av lägre effekttoppar. Detta är både billigare och minskar de resurser som krävs för att bygga upp signalboxen.

Nyckelord: Ställverk 95, Energioptimering, PSU 151, Järnvägsväxlar, Sammanlagringsfaktor, Kabeldimensionering.

Preface

This master thesis was carried out at former Vectura Consulting AB, current Sweco rail AB. The thesis work is the final part in my MSc in Sustainable Energy Systems at Chalmers University of Technology.

I would like to thank everyone that contributed and helped me with this thesis. Special thanks go out to following people:

- Christer Antonsson and Esko Svahn, my supervisors at Sweco rail AB for help with measurements and expert advice in the subject.

- Clas Larsson, technical director within electrical engineering at Sweco rail AB, for help with the creation of this thesis and the opportunity for me to work with it.

- Ivan Sare, signal engineer at Sweco rail AB, for help with finding various documents and drawings.

- Magnus Svahn, signal engineer at Sweco rail AB, for expertise regarding the operation of a railroad switch.

- Mats H Lundström, signal engineer at Sweco rail AB, for help with the search for old theses.

- Hannu Björkenskär, system engineer at Trafikverket, for help with log files for the railway switches.

- Jimmy Ehnberg, my supervisor at Chalmers for help with the technical design of the report

- Last but not least my family for the support during the thesis work.

Göteborg, June 2014

Petrus Sigvardsson

Contents

Glossary

Glossary with words related to this thesis with Swedish translation within brackets.

A/D converter	Device for converting analogue signal to digital signal. (A/D-omvandlare)
AC	Alternative current (växelström)
Ampacity	The maximum electrical current a device can carry without damaging the device. (Märkström)
Amperage	Strength of an electric current. (Strömstyrka)
ATC	Automatic train control. Protection system for the train operator. (ATC)
AXQJ	Electric cable (Swedish standard): aluminium conductor, polyethylene isolation, polyolefin cable jacket, installation in ground. (AXQJ)
Banverket	Swedish rail administration. Became “Trafikverket” after 2010. (Eng: Swedish rail administration)
BKE	Type of railway switch motor. (BKE)
Block section	A part of the track, when it is occupied by a train, blocks control operation of switches or derailer. (Blockeringssträcka)
Bombardier	Multinational railway equipment manufacturer. (Bombardier)
Caching point	Switch on refudge siding. (Skyddsväxel)
CCU	Communication control unit. Handles data transmission and reception between components and communication network. (Kommunikationsstyrenhet)
CTC	Centralized traffic control. Consists of train dispatchers that controls rail traffic flows. (Driftledningscentral)
DC	Direct current. (Likström)
Distribution board	Electrical component that divides electrical power into several circuits while providing protective fuse or circuit breaker for each circuit. (Gruppcentral)
Dranetz	Company within energy and power measurement. (Dranetz)
Dranview Professional	Measurement software reading data from PowerVisa. (Dranview Professional)
D-type fuse	Fuses with ceramic body ranging between 2A to 100A. (D-säkring)
Diversity factor	Sum of individual max power demand/max power demand for station. (Sammanlagringsfaktor)
Eaton	Company within power management solutions. (Eaton)
EL-Vis	Software for cable dimensioning. (EL-Vis)
EMC	Electromagnetic compatibility. Ensuring electronic devices don’t interfere with each other through EMI. (Elektromagnetisk kompatibilitet)
EMI filter	Device to decrease electromagnetic interference. (EMI-filter)
ERTMS	European rail traffic management system. Paneuropean train control system with purpose to get interoperability across national borders. (ERTMS)

ESTA1/ESTA2	ESTA1 means switch in left position. ESTA2 means switch in right position. (ESTA1/ESTA2)
ETRCS	European train control system. Paneuropean safety signalling system. (ERTCS)
EXQJ	Electric cable (Swedish standard): solid copper conductor, polyethylene isolation, polyolefin cable jacket, installation in ground. (EXQJ)
Facing point	Switches viewed in the direction where two tracks goes into one track. (Medväxel)
Favored power	Power that can experience power failure. (Favoriserad kraft)
Flange	Outmost protection on a train wheel acting against derailing. (Fläns)
Frog	Crossing point of two rails. (Korsningsspets)
Fuse	Electronic device that provides over current protection. (Säkring)
FXQJ	Electric cable (Swedish standard): stranded copper conductor, polyethylene isolation, polyolefin cable jacket, installation in ground. (FXQJ)
GSM-R	Global system for mobile communications-railway. Paneuropean mobile telephone system for railway use. (GSM-R)
Guard rail	Part of the rail that ensures that the wheels follow the right track. (Moträl)
Hall Effect	The phenomenon that current carrying conductors in a magnetic field exert a transverse force perpendicular to the current direction. (Halleffekt)
I^2t value	Value that should be greater than the surge current if the fuse should withstand the surge. (I^2t värde)
Interlocking	Term used for the control of locking and unlocking railway switches and signals. (Förreglingssystem)
Inverter	Electrical device that changes direct current to alternative current. (Inverterare)
JEA	JEA is a type of point machine. (JEA)
JZU840	Older version of the train object controller. (JZU840)
Line installation	Line installations ensure that two trains never comes to close to each other. (Linjeanläggningar)
NH fuses	Fuses used for high currents. (NH säkring)
OC subracks	Space in the train object controller locker for OCS950 circuit boards. (OC subracks)
OCS950	Train object controller used for the railway system. (OCS950)
PowerVisa	A/D converter used in this thesis work. (PowerVisa)
PSU	Power supply unit. A computer controlling trackside objects. (PSU)
PSU 151	Power supply unit 151. A computer controlling railway switches. (PSU 151)
Selectivity	When electrical components are connected in series in a system a good selectivity will ensure that they not melt simultaneously. (Selektivitet)

Signal box	Facility that controls the railway traffic within a station. (Ställverk)
Signal box 95	Computer based signal box used for control and monitoring of operation sites with conventional signalling and ERTMS. (Ställverk 95)
SJ	Swedish government owned passenger train operator. (Statens järnvägar)
Slip current	Maximum current that the motor operates within. (Slirström)
Standard fuse	Automatic fuses. (Normsäkring)
Station installation	Station installation controls signals, switches and possible barriers. (Stationsanläggningar)
Buffer stop	Physical object preventing trains from going past the end of a track. (Stoppbock)
Surge current	Maximum input current needed for an electric device when turned on. **(**Startström)
Switch/point	Section of the track with moving parts allowing trains to change track. (Växel)
Switching	Motion to move trains between tracks. (Växling)
Refuge siding	Part of the track leading to a buffer stop. (Säkerhetsspår)
TN-C system	Earthing system where PEN (protective earth and neutral) is combined. (4 ledarsystem)
TN-S system	Earthing system where PE and N (protective earth and neutral) are separated. (5 ledarsystem)
Track coil	Transponder that transmits information between the track and the train. (Balis)
Traffic planning system H	Traffic planning system based on the existence of signal cabin and block system on the line. (System H)
Traffic planning system M	Traffic planning system based on that the line is supervised by two movements inspectors. (System M)
Trafikverket	Swedish transport administration.
Trailing point	Switches viewed in the direction where a track branches of into two tracks. (Motväxel)
Train object controller	A part of the signal box where trackside objects such as switches and signalling objects are connected. (Utdel)
Trigger condition	Calculation that a fuse blows correctly**.** (Utlösningsvillkor)
Uninterruptible power	Power fed online from a battery pack **(**Avbrottsfri kraft)
UPS	Electrical device providing uninterruptible power if main power fails. (UPS)
Vectura	Technology consulting firm within transport infrastructure. Vectura is a part of Sweco since July 2013. (Vectura)
Västlänken	Planned railway tunnel under Gothenburg.

1 Introduction

This chapter will give an introduction to the thesis. A more in depth system background will be given in the next chapter. The introduction starts with a short background followed by aim and objective. Delimitations are thereafter stated. The introduction ends with an outline.

1.1 Background

The railway system has been a part of Sweden's transportation system since the middle of the 1800s. This was late compared to some other countries in Europe. In the beginning there were a lot of opponents that Sweden should have a railway system at all. The opponents were worried about the costs and that the expansion of the railway system would lead to an undesirable industrialization. Despite the opponents the railway system expanded until the year 1938 when people started to get cars. At the same time the Swedish state owned railways, SJ, started to take over the privately owned railways. The state owned railways were in the beginning small parts of the total railway network but will for now on become nearly exclusively state owned [1].

At the year 1988 the management of the railway system changed a lot when the task of managing and maintaining the tracks was moved to the newly formed state administration, Banverket. Banverket would later (2010) become a part of the state administration, Trafikverket [2].

Approximately 80 % of the 14700 km railway network Trafikverket administrate is electrified. This makes Swedish railway one of to the most electrified in Europe [3].

The transport sector faces major challenges in meeting the increasing demands of energy efficiency. Changes in the transport sector are needed in order for these requirements to get fulfilled. Transportation by train in Sweden is one of the best environmental options as the largest part of the Swedish railway system is electrified and the majority of the energy supply coming from sustainable sources, like hydro power. Work is carried out to optimize the energy consumption in the railway signalling system. Among other things by educate train drivers to drive more energy efficient. However, no studies have been made of what the actual power requirement is for the railway signalling system and whether it is possible to optimize it. Signalling boxes stands under large amount of regulations. This drives consultants to rely on data sheets from suppliers during new design and reinvestment. This often results in, at least what experienced consultants think, in oversized facilities. An earlier test measurement performed by Vectura indicates over dimensioned signalling boxes. All together this results in higher cost for investment, operation and maintenance. Only maintenance and reinvestment of signal installations cost 280 million SEK per year for the Swedish Transport Administration (Trafikverket) [4].

1.2 Aim

The aim of this thesis is to create a model for evaluating the actual power requirement in a signal box and use it for optimizing its component setup.

1.3 Objective

The objectives of this thesis are to

- Measure and record currents and voltages in some existing signaling control boxes for the railway system in Gothenburg in order to collect actual power patterns and peaks in the system.
- Create a model which easily evaluates the dimensioned uninterruptible and favorable power requirement, i.e. energy optimization[1], for a railway signal system.
- Use result from the model to propose how to optimize the component setup in the signal box that steers the railway signal system.

1.4 Delimitations

The measurements in this project are only performed in some selected signalling boxes in Gothenburg. The power supply studied is just to the Swedish transport Administration's signalling boxes. Thus this does not, for example, include power supply for heating of switches or power supply to the overhead line systems that operates the trains. Most of the components in an existing signal box cannot be replaced. However a better knowledge about the actual power use of the components could still be retrieved. The measurements took place in the spring and autumn in 2013. The change of the power demand due to seasonal variations is not included in this thesis due to limited time. The limited time will also affect the quantity and length of measurements. The project will only include existing signalling boxes, but the analysis and the resulting data can be used for future planning.

1.5 Outline

The report is divided into the main chapters; theory, method, results, discussion and conclusion. The theory chapter contains necessary theory needed to understand the rest of the report. The theory is quite in depth in order for the inexperienced reader could follow the rest of the report. The method begins with a data collection followed by measurements and analysis of measurements. The second part of the method consists of creating a model that describes the system and an attempt in energy optimisation. A more detail description of the methodology is found in chapter 4. The results from the method will thereafter be presented and discussed. A conclusion will summarize findings and recommendation of further investigations will be presented.

---

[1] The optimisation in this thesis is seen from a resources point of view. A better understanding of the actual power requirement in the signal box can lead to a component setup that is better adapted to the actual power requirement. Less use of resources leads indirectly to an energy optimisation as discussed in the discussion.

2 System description

The system described below is a simplified picture of the complex electrical schematic of the signal box type 95. For a schematic picture over the system see Figure 1. Worth to mention is that each signal box of type 95 looks a bit different depending on what it is supposed to control.

Signal box type 95 has, at least two different power supplies. One of the power supplies, Trafikverket’s own network is the standard supply when it is available as it is the cheapest. The other power supply works as a backup and only feeds when the standard supply fails, at a power blackout as an example. Standard supply can also be the local power network, when Trafikverket’s network is not available. As a backup network, Trafikverket’s network or the local network is used in first hand. If none of these are available, the backup supply can be performed by a fixed installed reserve power.

The standard power supply goes through a transformer that ensures that the three phase electrical power ends up at the right voltage and current level before it enters the function for automatic switch of electric mains.

The reserve supply have mid transformer, which task is to separate the different power networks from each other. This to get galvanic isolated electrical systems. It is not a demand from all power suppliers to a have a mid transformer, but from most of them. On the reserve feed there is also a subscription with a fixed cost. Regardless if the reserve network is used or not, this cost has to be paid to get access to the reserve supply in case the standard supply would fail. The subscription cost is determined by which main fuse that is used for the signal box. The higher the amperage on the fuse the higher is the subscription cost. The reserve power is only used if the standard supply would fail. This is because the standard supply is Trafikverket’s own network and cheaper [5].

The automatic switch of electric mains that are located between standard and reserve supply, has the function that it controls that the switch happens automatically at a under voltage or over voltage of 10%. This switch can also be performed manually on site by maintenance staff [6].

The power is then fed as uninterruptible power or favored power depending on properties. The uninterruptible power is fed online from a battery pack via a rectifier, inverter or UPS. The uninterruptible power is needed for components that are sensitive to power failure, as the batteries can continue power supply even if the standard network would be disconnected. The batteries should handle a power failure of at least 15 minutes. The rest of the supply happens via favored power, which will receive a power failure until the reserve network is connected. The point machines, interesting from the view of the report, are most often fed by favored power. This to reduce cost for larger UPS’s and battery backups, needed to cover the high effects of the point machines [6].

The favored and uninterruptible power is further fed through a train object controller. There are two types of train object controller systems, OCS950 and JZU840. OCS950 is the newest system and is used in sites installed after year-end 2010. In OCS950 there are a number of different power units that supplies power to components like receivers like signals, electronics and switches. The fed voltage goes to the power unit via cables mounted on sockets in the distribution board and converts in the power unit to AC/DC that are demanded from the receivers. The power units each have their own numbered socket in the distribution board [7]. The power units are delivered from Bombardier in both one phase and three phases. Three phases is the most common and occurs in four different models depending on use (point machines, signal light bulbs and LED units, OC sub-racks with internal logic voltage 24V, external logic system via OCS 950). For every power unit there is also an EMI filter installed to fulfil the demands on EMC for OCS950 [7]. The power units have one or more receivers consisting of a number computer boards mounted in a rack that feed the power further via object sockets to the objects. For one or more receivers there is a communication control unit installed. This takes care of data transfer and data reception in a ”duplex communication path”. The CCU is therefore an important part for the communication [8].

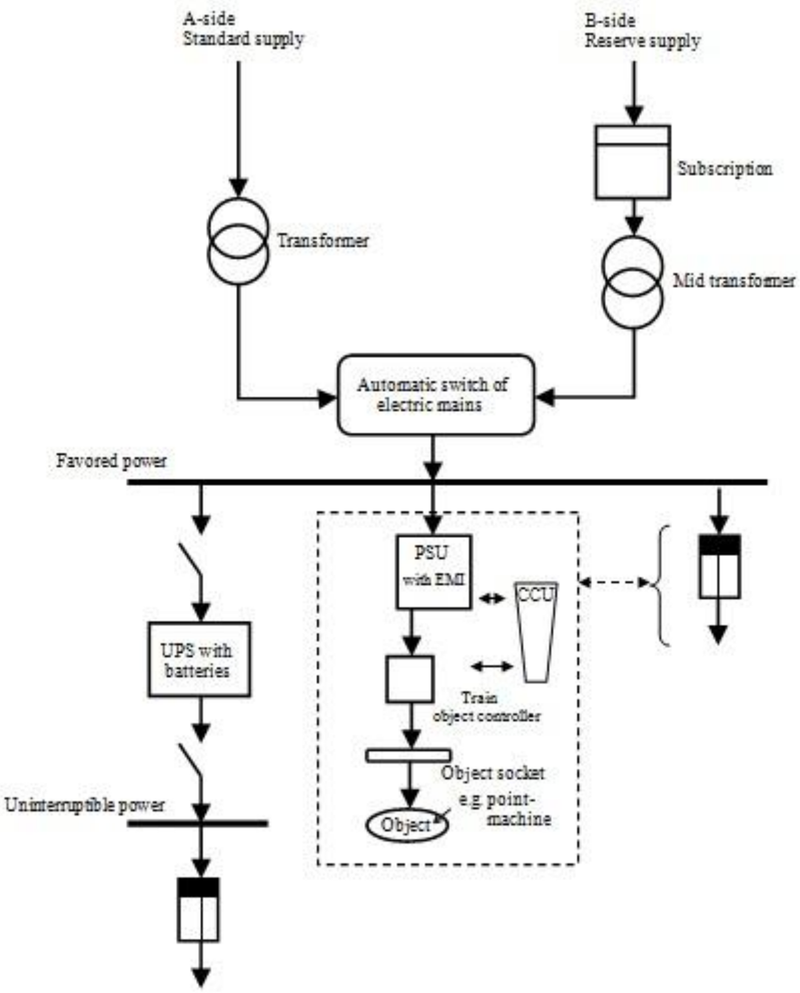


Figure 1 Simplified model over how the system for signal box type 95 is connected.

2.1 Signal box 300

Signal box 300 is situated in Olskroken. All the three analysed signalling stations have one single UPS placed in each station. This is not always the case for signal boxes type 95. E.g. the power supply to signal boxes in Malmö is structured with a centralized placed UPS at 160 kVA which feeds all the signalling stations around. The UPS in signal box 300 in Göteborg doesn't need to be as big since it only requires covering the power demand for the signal box own interruptible power supply. There are pros and cons with a UPS placed in each signalling station. The major benefits are that potential errors on the UPS only concerns one station. The error will then be less severe than a centralized UPS. The error will at the same time be easier to locate. Another benefit from having a UPS in every station is that the total cable length needed will be decreased. The negative aspects with a UPS in every station are mainly the high cost. It requires more components due to more UPS:s and batteries and also more space. Moreover there is a need for more energy subscriptions and backup networks with a UPS in every station.

Signal box 300 is installed with a UPS of size 30 kVA with 63 amperes fuses for incoming power to the station. The signalling station is dimensioned with a 25 metre incoming cable of type EXQJ 4x10/10 from a-side of the network and a 90 metre cable type FXQJ 4x16/16 from the b-side of the network, see Figure 1. Signal box 300 is the largest of the three stations measurements took place on. The station controls 21 switches see Table 1 below. There is bit unclear if an attempt to optimise the station can be done. This due to that the stations power requirements will increase when "Västlänken" appears in the future. How much the power supply has to be increased is today unclear. Measurements took place anyway at signal box 300 as the number of switches would give a wide data collection.

Table 1 Type of switch mechanism for switches belonging to station 300.

Switch number	Type of switch		Switch number	Type of switch cont.
387	2512 jea73 170		427	2512 jea73 170
388	2512 jea73 170		429	2501 jea72 170
394	2512 jea73 170		468	2512 jea73 170
395	2512 jea73 170		469	2512 jea73 170
398	2512 jea73 170		477	2512 jea73 170
409	2512 jea72 170		480	2512 jea73 170
410	2512 jea72 170		481	2512 jea73 170
411	2512 jea72 94		483	2512 jea73 170
419	2512 jea73 170		484	2512 jea72 170
426	2512 jea73 170		485	2512 jea72 170
427	2512 jea73 170		486	2512 jea73 170

2.2 Signal box 500

Station 500 is also located in Olskroken. This signal box is a lot smaller compared to signal box 300. It has an UPS of 8 kVA and the fuses are at 35 A for incoming power. The station controls six switches according to Table 2 below. The station is dimensioned with a 520 metre incoming cable of type AXQJ 4x95/29 from the a-side of the network. From the b-side the station is fed directly from a network station (T474/2) with favoured power. There are no known changes that will take place to the incoming power to the signal box today [9].

Table 2 Type of switch mechanism for switches belonging to station 500.

Switch number	Type of switch
461	2512 jea73 170
462	2512 jea73 170
463	2512 jea73 170
547	2512 jea73 170
550	2512 jea72 170
551	2512 jea72 170

2.3 Signal box 600

Signal box 600 is located in Kville. It has an UPS of 15 kVA and fuses at 63 A for incoming power. The station controls ten switches according to Table 3 below. The station is dimensioned with a 130 metre incoming cable of type FXQJ 4x16/16 from the a-side of the network. The incoming cable from the b-side of the network is of the same type and length. There are no known changes that will take place to the incoming power to the signal box today [9].

Table 3 Type of switch mechanism for switches belonging to station 600.

Switch number	Type of switch
607	2501 jea73 170
608	2501 jea72 170
614	2512 jea52 170
617	2512 jea52 170
618	2501 jea52 170
621	2512 jea73 170
623	2501 jea52 170
624	2501 jea73 170
625	2501 jea73 170
626	2501 jea52 170

2.4 Vendor of UPS:s to signal box 95

There are a lot of vendors of UPS:s on the market. The UPS that is in the signal box 95 is called “Powerware 9355”, made by Eaton. The batteries are integrated in the UPS, which makes it less space consuming. There is also a possibility to connect an external battery pack when needed. The UPS adjusts the charging of the batteries depending on their temperature, which makes the life time of the batteries longer. The 9355 model monitors its own operation the whole time and sends out an alarm in case anything is wrong in the system. If there is a fault, the systems switch to the outer manual bypass without any disruption of power supply to the sensitive components. When the fault is remedied, the UPS automatically connects back to its normal state. Powerware 9355 is available in seven sizes with associated recommended fuses, see Table 4 below [10].

Table 4 Mains fuse for Powerware 9355 UPS

Rated power UPS- Powerware 9355	Recommended mains fuse for traction power rectifier
8 kVA	3x16 A
10 kVA	3x 20 A
12 kVA	3x 25 A
15 kVA	3x 35 A
20 kVA	3x 35 A
30 kVA	3x 50 A
40 kVA	3x 80 A

3 Theory

This underlying theory will provide foundation for the report. The theory is quite in depth in order for the inexperienced reader within railway theory will understand the results in this thesis.

3.1 Traffic security within the railway system

A train could reach very high speed, which makes it hard for the train driver to stop within his distance of visibility. It is also impossible for the train to swerve for objects on the track. The combination of the high speed of the train and its heaviness can lead to release of very large amounts of energy, when the train is retarded uncontrolled. An eventual crash with another train or other heavy vehicles will end in a disaster. To prevent this there is s need of information and control systems that secures that the track is free from obstacles, for the train to travel safely. Such systems can include rules, work routines and plans, on technical equipments or a combination of all of them [11].

In simple terms one could say that the task of the security system is to prevent the trains from making unexpected movements, while the traffic control system steers the train into a free track section in the right point of time. This is very simplistic, since the systems are very tightly integrated in reality. For the security systems to work as designed it is vital that the trains and the railway system is maintained, which is done by rules and control programs [11].

The basic principle for railway traffic control is that only one train set at every time can be present on a block section. A block section is a delimited section with a power supply that is shorted, if another train is present on the same block section. If the block section is occupied by another train, main signals are showing a stop signal for all traffic on the section. All main signals are also complemented with pre-signals, placed ahead of the main signal. The pre-signals show status of the main signal at least breaking distance ahead of the main signal. This type of control is called automatic block system. The length of the block section can vary, but the trains are usually driven with a couple of kilometers in between each other on a double track. On a single track it is often the whole section between two stations that represents the block section [12].

In the main part of the railway system the security system is design in the way that no go signal could be shown before all conditions for "go" is fulfilled. The section the train is going into have to be free from all vehicles and a protection distance from these, as well as all switch blades should close tightly and be in locked state, for the train not to derail in the switch. If not all conditions are fulfilled the signal always shows stop. Stop signal is also the normal state for security equipments according to the errors principle. For example causes a power failure in a signal circuit that it is impossible to show go, instead stop is shown [12].

3.2 Signal security installations

The task for the signal security installations are to monitor so that trains are not colliding with other trains or other obstacles on the track, as well as monitor to high speed and not driving too far. When the signal securities have secured the section to being free from obstacles it gives the possibility to give go signal for the section. The older signal security systems are divided into two; station and line installations, depending on which function they provide. In the newer signal boxes of model 95, which this report analysis, includes both station and line installations [12].

3.2.1 Station installations

The station installations' assignment is to control signals, switches and possible barriers. Stations were the places where it was most crowdy in the beginning with most train at the same time and most switches for shifting track for the trains. The stations were at that time equipped with mechanical interlocking cabin that consisted of a set of different locks that was dependent of each other. When it came more and more switches to take care of, the mechanical interlocking cabins were displaced with all-relay interlocking box. Only a few of the mechanical interlocking cabins are in use in Sweden today. The big advantage of electrifying the interlocking cabins was the automatic control that was given and that they could be remotely controlled, so called centralized traffic control. The all-relay interlocking boxes also had the possibility to control if the section was free or taken by a train, which wasn't possible with the mechanical interlocking cabins. Since the 80-ties the new signal boxes have IT-technology in them, where software programs controls the functions of the signal box. They are built up accordingly to the same principle as before. They also have two independent software programs, which have to show the same result, for the signal to give a go signal. This is done due to improved safety. The computerized signal boxes can also give pre-programmed train routes, through automatic readout of the number of the train [12].

3.2.2 Line installations

The assignment of the line installations is to ensure that two trains never come to close to each other. There are different ways to regulate this. The oldest regulation, traffic planning system M, is still used on less traffic loaded routes in the railway system and on single track with only one train in motion between every station. This control system consists of block per telephone between movement inspectors between the stations to control that the section is free. To be able to drive trains with shorter distance between each other than the distance between stations, another type of control system was needed. This was where automatic line blocking came in; see 3.1 *Traffic security within the railway system*. Automatic line blocking together with distance controlled blocking (Centralized Traffic Control, CTC) and the system ATC (Automatic Train Control) forms traffic planning system H [12].

3.3 ATC och ERTCS

For the signals to be of any use, they have to be followed. Even an experienced train driver can read the signals wrong due to the human factor. To ensure that no such mistakes are happening large parts of the railway network is equipped with a system called ATC (Automatic Train Control) or another system called ERTCS (European Railway Traffic Control System). For ATC to be able to check if the signals are followed by the driver there are track coils placed along the tracks. These track coils are transponders mounted to the track that transfer information about the section and signals to the ATC system in the train. The ATC system is showing the same information to the driver as the signals, if he should have missed them. If the driver not follows the message to be within a certain speed, the ATC system starts to warn the driver. If the warnings not are followed by the driver, the train automatically starts to brake according to a calculated brake curve, for the train to be able to stop before a stop signal, as an example. The message from the track coil group is valid until the next track coil group. ATC is developed in Sweden and will be replaced in due time by ERTMS/ERTCS (European Railway Traffic Management System/ European Train Control System) in accordance with a European Union directive [13].

3.4 Traffic control

The control of the railway traffic on the network is normally managed automatically by the signal security installations. Often the traffic needs to be adjusted for the train to be able to be in time. The train traffic punctuality is very seldom 100 % according to statistics from Trafikverket. From July 2012 to June 2013 the punctuality was only 68.8 %[2] in the worst case for the fast trains and 88.9 % at its best [14]. This is where traffic control comes in and manages when the already delayed train has to be passed by another train. This is easiest managed in traffic planning system H, which also is the dominating system in use. The contact to the train is taken through the internationally standardized communication system GSM-R. Important to know is that the GSM-R system is only for guidance to the driver, the final decision is taken through the ATC system. Implementation of the combined signal and security system ERTMS is standard for all new track constructed. This is to make it easier for transboundary rail traffic. The ERTMS system can be divided into several levels, whereof level two will be the one mainly used in Sweden [15].

3.4.1 ERTMS level 0

Level 0 is a track section with no ERTMS system implemented [13].

3.4.2 ERTMS level 1

Level 1 is similar to the ATC system that is in use in the Swedish railway network today. Namely that level 1 is equipped with signals, track circuits and track coils [13].

3.4.3 ERTMS level 2

In level 2 the optical signals are taken away from the sections in the network. Basic information is given from traffic control via GSM-R. All other necessary information, like speed and signals are shown to the train driver in the cabin. Track coils are giving the positioning and track circuits controls that there is no obstacles on the section [13].

3.4.4 ERTMS level 3

Level 3 is like level 2, with the big difference that the track circuits have been taken away. The train reports its position itself to the traffic control. The block section then becomes a moving section instead of a fixed section, which can increase capacity on the network [13].

[2] A train start to count as delayed when it is more than 15 minutes later than planed

3.5 UPS

To be able to receive continuous power supply, which is demanded for the components in the signaling box sensitive for power blackouts, a so called UPS is used. UPS stands for Uninterruptible Power Supply and is an electrical component that delivers uninterruptible power, when the regular power supply disappears and before the backup power supply network is connected. Many UPS, especially those used in the signal boxes, can help to take away power problems that can appear in the electrical system. That could be power problems like current spikes, high frequenze transients and instability in network frequenze [16].

There are three main categories of UPS:s depending on how they are designed. These are online UPS, line-interactive UPS and standby UPS. The online UPS, which has best performance and best protection from disturbance of the three categories, is used for Signal box 95. This is necessary while the signaling box includes components that are very sensitive for power failure. In the online UPS, the incoming alternating current (AC) is rectified to direct current (DC) before it passes the rechargeable batteries. Then the DC is inverted into regulated AC to deliver uninterrupted power (B4 in the figure below) to the components. No power switches are needed in the system, since the batteries always are connected to the inverter. At normal operation, the largest load is taken care of by the inverter. When there is a power failure, the inverter is dropped out of the circuit and the batteries are carrying the load. The uninterruptable power to the components is during this process consistent and unchanged [17].

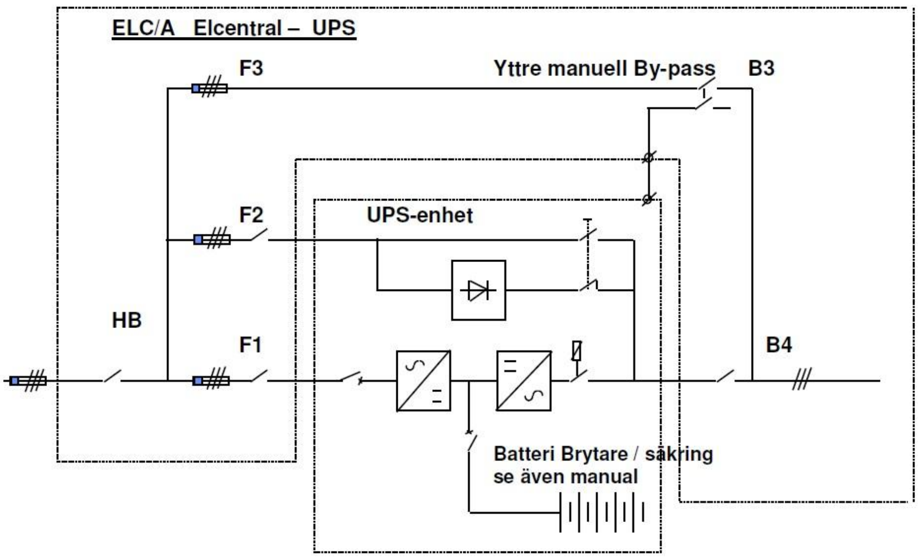


Figure 2 Circuit diagram for online UPS [18]

For the online UPS there is also an outer manual by-pass that can be connected during maintenance of the UPS. The load is then temporarily provided by favorized power from the regular power network until the switch is in normal state again. In this way, there is no influence on the components with uninterruptible power from other components connected to the UPS during the maintenance [18].

3.6 Railroad Switch

An important part of the railway system are the switches, which function is to lead the train into another track. Switches are very sensitive and demanding in regards to maintenance, as it is composed of many parts. The interaction between the railway vehicles and the railroad consist of wheels of steel running of top of steel rails. The wheels have a transverse profile that follows the rails along the track even when the train needs to move sideways, see Figure 3. At the inner part of the wheel the profile is ended in a steep conic flange. That flange normally don't touch the rail, but it the outermost protection for the train not to derail [12].

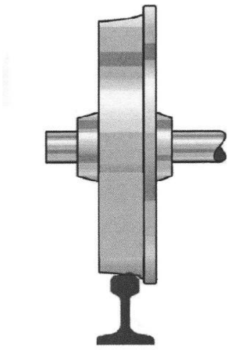


Figure 3 Transverse profile of a railway wheel [12].

When the wheel reaches the switch the train is guided in to a straight or a divergent track depending of the position of the switch blade. Further back in the switch is the frog, where the crossing of two rails happens, see Figure 4. The frog could either be casted or two pointed rails screwed together [19]. The frog could also be either fixed or movable. The movable point frog is for better comfort to the train ride and has less wear. In this case the frog is moved together with the switch blade [20]. For the switch with fixed frog of crossing there is a guard rail that ensures that the train follows the dedicated track and not derails [19].

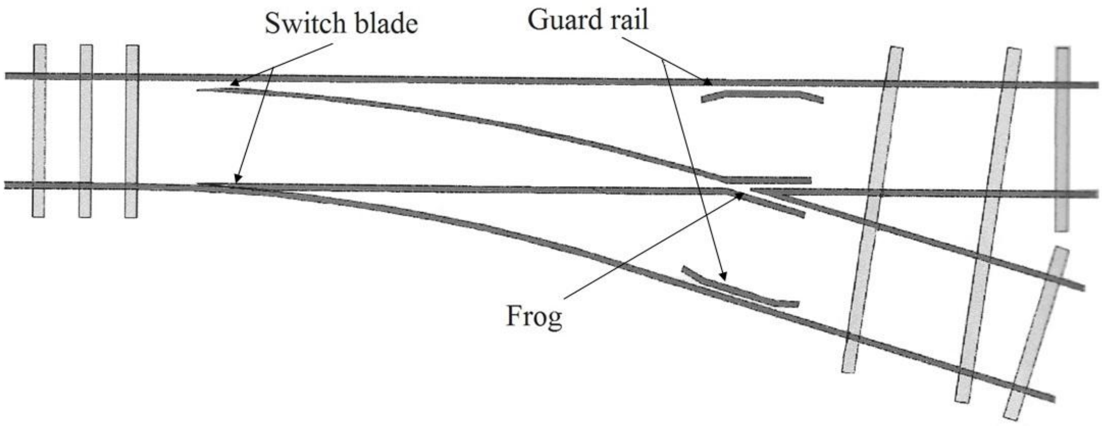


Figure 4 Elemental railway switch with fixed frog [12].

To get the switch blade into the right position, in the olden days, a lever was used to manually move the switch blade into the right position. This is still used in a few places, but nowadays mainly a remote controlled electrical motor is used to move the switch blade in the switch. The electrical motor, paired via a friction clutch to rods, that are connected to the switch blade is called point machine. One switch can have one or more point machines depending on the switch curve radius. Larger curve radius on switches is used at higher permitted speed and demands more point machines. There are a lot of different types of point machines. The point machines this report is focusing on are called JEA 52, JEA 72 and JEA 73. Reason being that these are the types of point machines used in the signal boxes, where the measurements took place. In the point machine there is a built in locking system that send a signal to the signal box when the switch is locked in the right position. When this has happened the trains are allowed to pass in on the block section and pass the switch [19], [21].

The description so far is around what happens in a trailing point switch, a switch seen from the direction where a track is branching into two tracks. The trains can also go facing point, which is the switch seen from the direction where two tracks goes into one through a switch. In this case it is not always the case that the switch blade has to be moved into the right position for a train to be able to pass. It is depending on if the switch is trailable or not. At non-trailable point machines the switch blades have to be in the right position, otherwise they will be damaged. For a trailing point switch, the attachment point for the rods to the switch blade is done in a way that they will break when a train passes. At passage, the wheels force the switch blades to the right position without them being damaged. The point machines JEA 52 and JEA 72 are trailable, while JEA 73 is not [22].

At an operation of a switch blade the motor in the point machine gets a high start current from the signal box. How big this current is will be analysed later on in this report. The friction clutch will then adjust to the force needed to move the switch blades to the right position. If there is an obstacle in the way or if the switch is badly maintained, the switch can demand a higher current and as a result the clutch will slip. How big this slip current can be can be found in Appendix C [21].

3.6.1 Block section for a switch

There are rules on how the block section (S_b) is to be determined for a switch. The block section consist of the movable part of the track switch is as well as the part before the switch in facing point switch direction (S_{bf}), see Figure 5 below. The length of section S_{bf} shall be sufficient enough, for a train with a velocity of 30 km/h, from it goes into the block section, cannot reach the nose of the switch before the switch throwing is performed. The time required to throw the switch is then a required variable, which consists of two parts;

- The signaling system's time of reaction, from the time a train has entered the block section until the status is changed to occupied, t_r.
- Time for a switch to throw, t_v.

S_{bf} is calculated according the formula:

$$S_{bf}(m) = \frac{30}{3{,}6} \times (t_r + t_v)$$

For signal box 95, the normal values t_r=3.0 s and t_v=2.7 s are used for point machines of type JEA 72/73, which gives a block section of 48 meter.

If there is a signal or a diverging switch within S_{bf}, then the block section is defined up to that object [23].

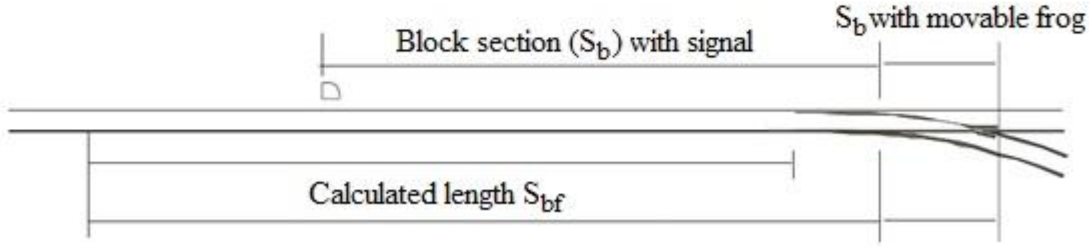


Figure 5 Block section for a railway switch [23].

3.7 Dimensioning of cables

According to Swedish Standard (SS 424 14 24 – translated) the cable area is determined from the following factors, the cables…:

- "…Not assumes damaging temperature during normal operation conditions.
- …Not are harmed thermal at a short circuit.
- ..Not are harmed mechanically due to a short circuit " [24]

From an owner/operator perspective the cost of the cable is also an important factor. Larger areas on the cable are giving less resistance and are at the same time more expensive.

The meaning of the first factor is to dimension the cable with respect to load capacity, so the cable is protected for overload. The condition that needs to be fulfilled is that the design load current must be less than the load capacity. In case the condition not is fulfilled, the allowed operational temperature will be exceeded and the cable will get damaged [24].

The second factor is about choosing the right short circuit protection. The overcurrent in the circuit cause a so called surge current according to $I^2 \cdot t$. The short circuit protection shall at a short circuit or ground fault, ensure protection for this surge current, so the cable isn't damaged thermally. It is also important to ensure that the short circuit protection not only protects against thermal impact, but also that it trigger fast enough, i.e. the trigger condition needs to be fulfilled [24]. According to EL-Vis (software solution for cable dimensioning), the control of the trigger condition is usually about designing in the way that it doesn't take too long time for short circuit protection to trigger. To ensure that the short circuit protection trigger fast enough it is important that the circuit doesn't have too high impedance and that the design cable is not too long [25].

The last factor only needs to be looked at when non-current delimiting circuit breakers are used. The condition that should be fulfilled is that the largest surge current that arise not overrides the highest surge current the cable can handle. If the surge current is higher than the condition for the cable it is mechanically damaged. The mechanical impact only happens for really heavy cables and when the current is very high (several kA) [24].

It is also is important to control in the cable is that the voltage drop isn't too high in the cable. The cable needs to be dimensioned, so the voltage drop not exceeds the nominal current more than four percentages, which is the limit used today by Sweco Rail. This voltage drop doesn't include the voltage drop that arises when the point machines start to operate [26].

The current that arises when a cable is loaded will always give a drop in voltage as the cable can be said to have a series inductance and series resistant [27]. While the cable length already is decided, it could be demanded that the cable area needs to be increased if voltage drop percentage is outside of the reasonable limit.

3.8 Fuses

It is hard to do electrical installations around the rail network. Interference in the form of traction from the trains together with interference from relay circuits may influence function of the electronics. One has to try to build stations as electromagnetic shielded as possible [28]. The power supply to the stations goes through a TN-S system. A TN-S system consists of the three phases, protective earth and neutral. This increases the security and lower interferences compared to a TN-C system that only consists of the three phases and neutral [27]. In the distribution board the fuses are connected to every phase. The different outgoing groups can have different sized fuses, seen from a three phase view, depending on the load for the group. Located prior to the distribution board there are the mains fuses for incoming power to the whole station. The mains fuses are the fuses that affect the incoming cable dimensioning for the station.

The fuse acts as a sacrificial device and interrupts the current at a specific cable or device when the current becomes too high. There are a lot of different fuses to choose from. At lower current a so called D-type fuse is used (diazed fuse with ceramic body). The D-type fuses are available in two different sizes depending on amperage. Size DII can be found at 6A, 10A, 16A, 20A and 25A. Size DIII on the thread can be found in size 35A, 50A and 63A. There are standard fuses (automatic fuses). They are found in more amp sizes (smaller interval between the sizes). At higher amperage than 63A so called NH fuses are used. These fuses are not relevant for this thesis [5].

The fuses will not interrupt the current directly at its given amperage. There are instead different melting curves for fuses at different ampacity. A fuse marked with 20A will melt after 5 seconds when the load is 57A. The same fuse will melt after just 0.4 seconds if the load instead is 100A. More information about nominal currents for fuses at different melting points could be seen in Table D-1 in Appendix D.

To get a good service continuity in the station it is important with a good selectivity. When electrical components are connected in series in a system a good selectivity will ensure that they not will melt simultaneously but instead only the component situated directly upstream the fault [29]. The selectivity is generated by choosing fuses with different ampacity. Two electrical devices both with fuses at 16A risks to melt simultaneously due to that the fuses are not selective with each other. If the devices in series instead would be with a 16A and 20A then only the first fuse (16A) will melt during a fault. I.e. a 16 ampere fuse is fully selective with a 20A fuse. But it is however not given that a fuse with higher ampacity is selective with a fuse with lower ampacity. This depends in if the total I^2t value for the fuse with lower ampacity is smaller than the melting-I^2t value for the fuse with higher ampacity, otherwise the smaller fuse will melt and interrupt the current. These ratios between different fuses are presented in Figure E-1 in Appendix E.

3.9 Diversity factor

Electric cables cannot withstand too high currents. The cables therefore need to be dimensioned to cope with a maximum current. At the same time it is also not good to oversize the cables seen from materials and cost perspective. Larger cables require more material and are therefore more expensive. Here there is a need for estimation on what the maximum current is seen from a probability perspective.

A cable can handle overload for short periods. So it may be acceptable to allow a given maximum to be exceeded if the probability of this happening is low. If a power supply is only connected to one outtake point, the maximum current through the cable is equal to the maximum outlet. This changes when more outlets are added to the power source. The probability is then less that all outlet points achieve their maximum at the same time. This is where the concept diversity factor becomes important. The diversity factor takes the probability of the outlets points' maximum into account when the cables are dimensioned. This leads to that the cables become less oversized. The diversity factor is one or less, depending on how many outlet points that are connected to the power source. The more exit points the lower the diversity factor [30].

4 Method

The method chapter is divided into five different subparts in order to structure the thesis. These parts are all interrelated, so to get a clear result in the end it was necessary that each subpart of the method was carefully analyzed. The method was divided into the following parts; data collection and inventory of the system, measurements, analysis of the measurements, a model and energy optimization. These subparts are described more in detail in the following chapters below.

4.1 Data collection and inventory of the system

To be able, in a later stage, to describe behavior of measured data a collection of necessary theories was needed. These data was later on structured in a way that interaction between the components in the system could be described. One of many difficulties in this project was to find relevant theories for the thesis. No similar analyses on the same problem have been found. Found close to the subject was an earlier thesis work from Chalmers by Anders Magnusson in 2004 [31]. His report investigates the power requirements for signal box 85, but nothing on how the power requirements can be optimized. Signal box 85 also differs in many ways from signal box 95, e.g. different installed components. But the signalling boxes 85 and 95 are also similar in other ways, e.g. both signalling boxes are computerized and can control the same type of point switches and signals. Therefore it is not obvious if theories from the existing thesis are applicable to this thesis.

Since this thesis does not measure on the power consumption for every individual component in signal box 95, a good estimate of these components was needed. Here data from Anders Magnusson's thesis were utilized when making the estimates. This thesis can thus be seen as an addition to Anders previous work as this thesis uses power requirements in a model in trying to make an energy optimization.

Another thesis useful for this study was "Calculation method for powering a tramway network" written by Jakob Ekstrand [32]. His thesis uses similar structure to this thesis. Although trams and trains are two completely different things, inspiration could be collected regarding the method from his work.

A lot of information described in this report is collected from Trafikverket's controlling and guiding documents. These documents are examined and updated continuously and are in that way credible. A book about the Swedish railway written by Bårström and Granbom has also been significant for the theoretical background.

Before any measurements could be done an inventory of the system was needed. An overview how the system is linked could be constructed by using Vecturas own documents over circuit diagrams and blueprints. This system is very complex and differs from signal box to signal box. An overall description of the system could however be done and can be found in the chapter 2 *System description*.

It was decided that measurements should take place in relatively new signal boxes as described in the scope. These new signal boxes are categorized as type 95. Measurements on newer signal boxes will facilitate the implementations from this study to new projections and is likely to resemble the future developed signal boxes.

4.2 Measurements

In the Gothenburg region there are several signal boxes of model 95. Measuring every signal box in the area would take too long time. After an overview of the available signal boxes, three was chosen to carry out measurements on. These signal boxes was also interesting from the perspective that they are relatively new (2011-2012). Measurements on newer signal boxes are most likely more energy effective, as development occurs constantly. Measurements on these newer signal boxes will get a clearer result on improvements that can be made on the current technical design. The three chosen signal boxes also had easier access which facilitated the measurements. One of the signal boxes, number 600, has at earlier measurements performed by Vectura, shown sign of over dimensioning.

The first thing to measure was the incoming power for the whole signal box. This is the total power needed to control all of the components in the signal box, both uninterruptible power and favored power. The measuring instrument was connected according to three phase Y, see Figure 6. The measurement instrument was connected in a similar way later on when the PSU 151 was measured, with the difference that the incoming cables for the PSU 151 was twinned doubled to get a better uptake from the current probes. This is not affecting the measuring result, as the instrument was set to halving the current. Both probes and the conductor where electrically isolated to reduce the risk for an electrical chock. The probe only has a fault in measurement of +/- 1% when the conductor is placed in the middle of the probe [33].

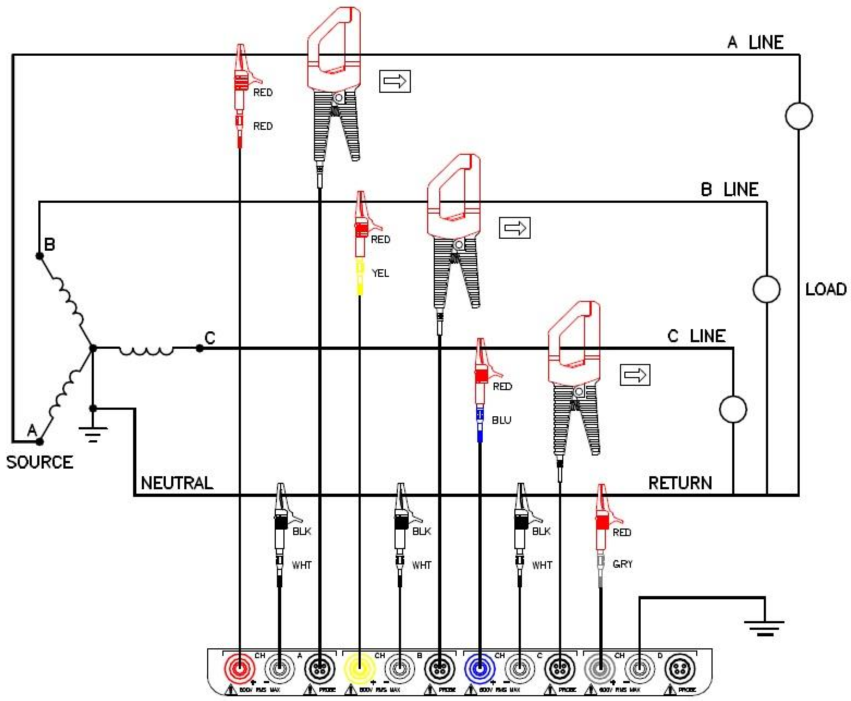


Figure 6 3 phase, four wire wye circuit connection for the A/D converter [33].

When an analog signal is measured by a digital measurement instrument one have to sample with enough frequency to reflect the analog signal. A too high sampling frequency gives too much measured data, which is not necessary and will quickly fill up the memory card. To resolve this issue the instrument was set to sample at a higher frequency when the current passed a certain threshold value. In this way it was possible to clearer recreate the analog signal at events worthwhile to analyze.

4.2.1 Measurement equipment

In order to collect and save relevant data from the measurements, an A/D converter was needed for the project. The equipment would also have to have a storage device in order for later analysis of the measured data. The equipment will measure both three-phase voltage and three-phase current at the same time thus the required minimum for the equipment is to have 6 differential channels (three for current and three for voltage). The measured data will then be transferred to a laptop with measurement software for easier analysis. In order to measure the current, a current probe compatible with the A/D converter was needed. The same applied when measuring the voltage. The current probe clamps around the conductor allowing it to take measurements without having to disconnect the circuit. A crocodile clip was used when measuring the voltage creating an electrical connection.

4.2.1.1 A/D converter

The converter used in this study was a portable, power quality analyser manufactured by Dranetz called PowerVisa, see Figure 7. The instrument can record and measure data on four voltage channels and four current channels simultaneously. The instrument has a colour touch screen and a lightweight design using a detection system telling the user if the instrument is connected successfully to the device under test. The measurements are saved to a four gigabyte compact flash memory card which can be removed. PowerVisa also includes troubleshooting, data logging, power quality surveys, energy and load balancing [34].

Figure 7 Front view of the Dranetz-BMI PowerVisa [34].

4.2.1.2 Current probe

The compatible clamp on probe used for the PowerVisa was of model TR-2550A and could measure a current in the interval 1A-100A. This interval was considered the best suitable for this project when examining the test measurements made by the supervisors before the project start. The probe is built on the Hall Effect and can measure both AC and DC current in the frequency interval from 10 Hz to 40 kHz [35].

4.2.2 Measurement software

The software used for analysing the data is called Dran-View Professional. After installation on a computer the software reads the .DBB file format saved to the flash drive in A/D converter. The file contains advanced analysis of sample points recorded and saved by the PowerVisa and are presented in the software as time plots event lists and event detail/waveform. The time plots and event detail/waveform graphs can also be zoomed in to get more detailed information. Date and time for the time plots was taken from an internal clock in the PowerVisa. The internal clock was set according to the railway system time in order for easier analyses in the later stages of the project.

4.3 Analysis of measurements

Measurements of voltage and current were loaded directly onto the memory card in the instrument. This card could then be read by the measurement software in the computer. The measurements could be plotted against time because of the internal clock in the measuring instrument. The graphs are characterized as horizontal lines with temporary current spikes according to Figure 8 below. This current spikes represents switching movements from the railway switches. A clearer view of this process could be obtained by zooming in on the spikes in the computer software.

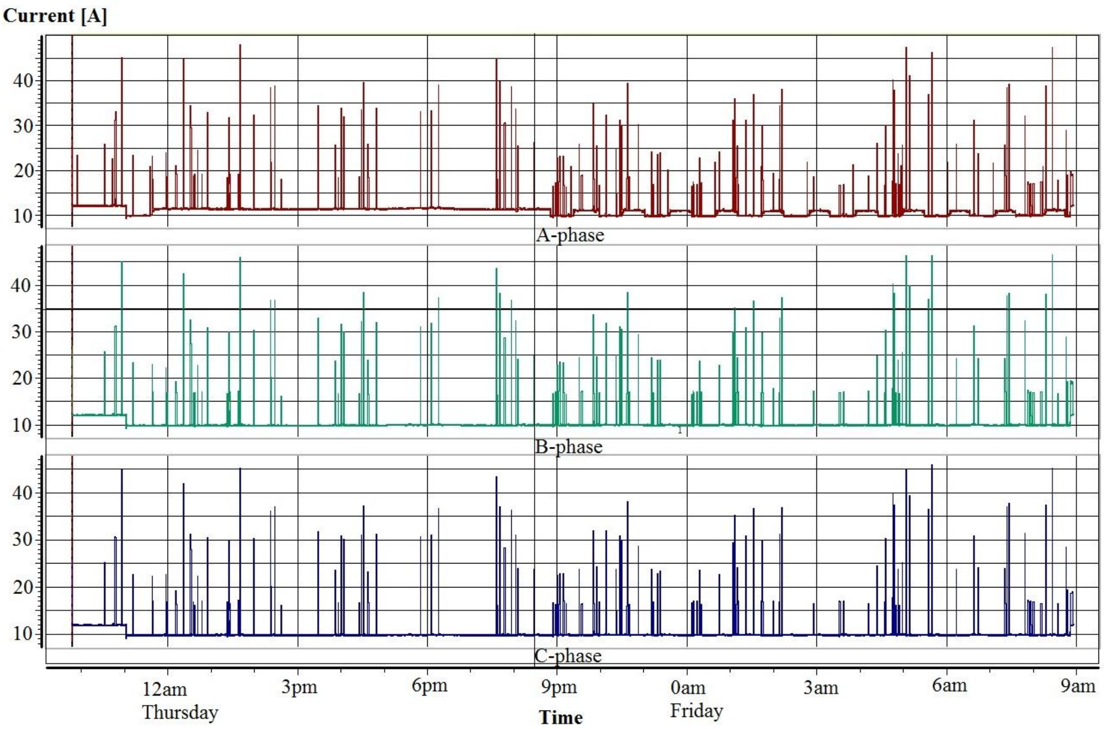


Figure 8 Current spikes viewed in Dran-View Professional

Values are obtained from multiple switches when measuring a PSU 151. After investigating signal drawings one could see which switches PSU 151 controlled but in order to connect each switch to a single current spike, additional information is needed. This information consisted of a switching log file for the whole signal box. This log file was obtained by mail from Trafikverket. The log file turned out only to be stored for a month back in time which leads to that a measurement for signal box 500 had to be retaken. The logs consist of a text file that indicates the switch turnout position and when this happened during the day. The switch position could either be left or right, ESTA-1 left and ESTA-2 right, see Figure 9 below.

```
<Event>2013-04-29 13:59:00    TRS2 SYN: ESTA2 GBG VXL 480 (15137)</Event>
<Event>2013-04-29 13:59:08    TRS2 SYN: ESTA2 GBG VXL 481 (15105)</Event>
<Event>2013-04-29 13:59:18    TRS2 SYN: ESTA2 GBG VXL 387 (14926)</Event>
<Event>2013-04-29 13:59:18    TRS2 SYN: ESTA2 GBG VXL 394 (14928)</Event>
<Event>2013-04-29 13:59:27    TRS2 SYN: ESTA2 GBG VXL 388 (14927)</Event>
<Event>2013-04-29 14:20:34    TRS2 SYN: ESTA1 GBG VXL 387 (14926)</Event>
<Event>2013-04-29 14:20:34    TRS2 SYN: ESTA1 GBG VXL 388 (14927)</Event>
<Event>2013-04-29 14:20:34    TRS2 SYN: ESTA1 GBG VXL 394 (14928)</Event>
<Event>2013-04-29 14:20:34    TRS2 SYN: ESTA1 GBG VXL 480 (15137)</Event>
<Event>2013-04-29 14:20:35    TRS2 SYN: ESTA1 GBG VXL 387 (14926)</Event>
<Event>2013-04-29 14:20:35    TRS2 SYN: ESTA1 GBG VXL 388 (14927)</Event>
<Event>2013-04-29 14:20:35    TRS2 SYN: ESTA1 GBG VXL 394 (14928)</Event>
<Event>2013-04-29 14:20:35    TRS2 SYN: ESTA1 GBG VXL 468 (15115)</Event>
<Event>2013-04-29 14:20:35    TRS2 SYN: ESTA2 GBG VXL 469 (15122)</Event>
<Event>2013-04-29 14:20:35    TRS2 SYN: ESTA1 GBG VXL 480 (15137)</Event>
```

Figure 9 A part of a switch log file from station 300.

One problem with this switch log is that the signal box sends an indication on the position of the switches at regular intervals, even if the switch didn't move at all. In Figure 9 one can see that there is a switching movement for switch number 480 at 14:20:34 from having been in right position 13:59:00. Switch number 480 is mentioned one second after the switching (at 14:20:35), but the switch still shows left position thus no switching happened. From Figure 9 it can also be seen that switch number 387,388 and 294 are switching, but in order know if switch number 468, 469 and 481 are switching one have to look further back in the log file. In order to more easily analyse the switching movements, a processing of the log file was needed. In this process all indications not showing switching movements were deleted. The new processed text file then gave a clear picture of how the train traffic was during the measurement period of the signal box.

4.3.1 Different graph shapes for switching movement

The shape of the switch graph between different switching movements was not consistent. Additionally the curvature of the graph where dependent on if the switch had one or two point motors. Figure 10 and Figure 11 below shows the different switch graph curve that arose during the measurement, for switches with one motor and switches with two motors. In order to study the maxima along the curve, the curve was divided into a number of points with straight lines in between which can be seen in Figure 10 and Figure 11. This also facilitates later calculations on the average power as the curve otherwise has no obvious function. A wide variety of switches were studied where the maximum value at each point along the curve was studied. This formed a new curve the worst possible from a power point of view, where calculations on average power and maximum peak power were performed on. The impact from the breakdown of the curve in points and straight lines assumed to be negligible as the lines follows the curve almost exactly. In Figure 10 and Figure 11 one can see that the high inrush current at the start of the graph curve and at the end the so called slip current occurs, see chapter 3.6 *Railroad Switch* for more information about this phenomena. The average power is higher the earlier this slip current occurs. When the worst possible curve was constructed the slip current was added directly after the inrush current and set slipping all the way to the end of the cycle.

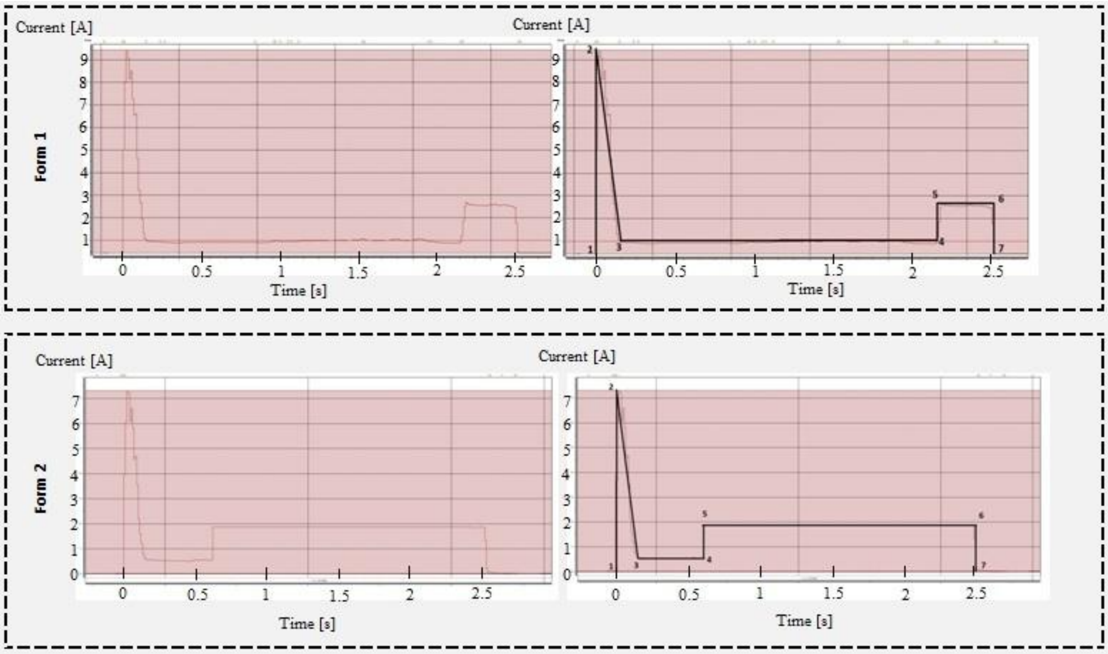


Figure 10 Left: Switch graph curves for switches with one motor, Right: The division in points and straight lines for these switch curves. Form 1 and form 2 are the two different curve shapes that appeared for switches with one motor.

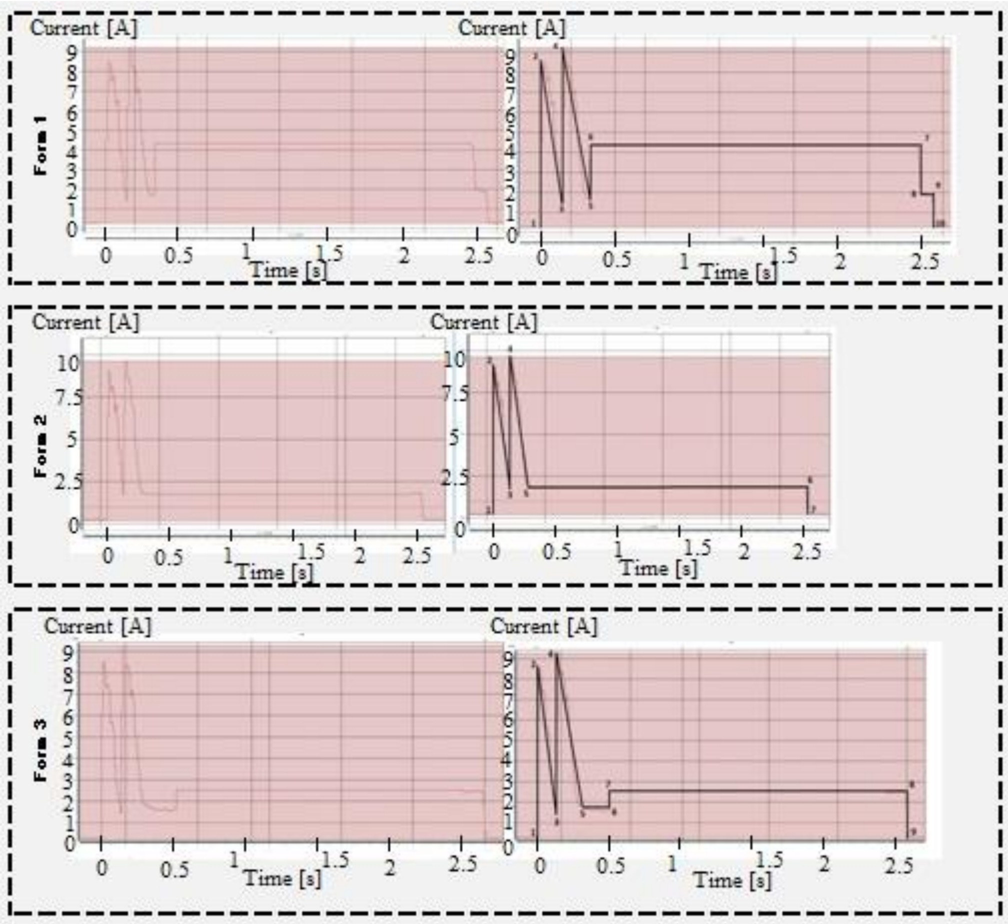


Figure 11 Left: Switch graph curves for switches with two motors, Right: The division in points and straight lines for these switch curves. Form 1, form 2 and form 3 are the three different curve shapes that appeared for switches with two motors.

4.4 Construction of the model

To get a clear structure of the power consumption in the signal box a model was needed to be built. The performed measurements show how much power the various PSU 151 consume during switching and how great the rest of the power consumption during the measuring period. However there is no knowledge about the individual contribution to the total power consumption (except PSU 151). To try and sort out this a model was put up for the power consumption for each station. The model was chosen to be made in two steps. The first model (model step 1) includes favored and uninterruptible power excluding PSU 151 and the other model (model step 2) study the behaviour for PSU 151 more in detail. The individual contribution from both of these two models is added at the end to get the total dimensioning power for the signal box. The breakdown into two models is due to that measured data is missing for the first model, i.e. the model including favored and uninterruptible power. This model uses the values from data sheets and estimated values. The second model i.e. PSU 151 model, is based on data from the analysis of the measurements. This model is generalizable for all signal boxes of type 95 that controls switches studied in this thesis work, namely the switches in Table 5.

4.5 Energy optimisation

The last part of the method was to make an energy optimisation of the system. The maximum value of the incoming power was retrieved from the model of the power consumption of the system. Important to mention is that it is not always the incoming power that dimensions incoming cables. It can also be the selective rules that determine the size of the incoming cables, see chapter 3.8 *Fuses*. For example, if there is an outgoing power group that requires 20 amp fuse, then the incoming cable must be secured with at least 25 A, even if the power demand requires only 10 amps.

The UPS in the signal boxes always had the highest rated fuse. Important for energy optimisation was then to see if this UPS could be reduced in size and thus get a lower fuse, especially if the power consumption required lower fuse than the UPS.

An energy optimisation was done both based on the measurement maximum values and the maximum values obtained from the model. The maximum values from the measurements gives an optimisation based on how the power requirements are in reality. However, it is not clear if the maximum power occurred during the measurement period. To sort out uncertainties the other part of the optimisation was based on the maximum values from the model.

4.5.1 Cable dimensioning in the software EL-Vis 10.1.0

The dimensioning software EL-Vis was used since it is present in the Sweco's software database, as well as being the most popular solution on the market [36]. The software calculates load capacity, trigger conditions and voltage drop according to Swedish standard (SS 4141424).

An alternative to the EL-Vis software is to use different tables and associated equation calculations. By using the software, the risk for faults during calculation is reduced, as well as the time for the dimensioning process.

5 Results

In the following sections, results from the measurements and the energy optimization model will be presented. To notice: when mentioning that switches are switching at the same time, it means that they start exactly at the same time with no delay in between. The graph curves will then be projected onto each other.

5.1 Measurements results from signal box 300

The first measurement took place at incoming power in order to get an overview of the power consumption for the whole signal box 300. This measurement was connected according to chapter 4.2 *Measurements*. The power consumption in the signal box depends a lot on how intense the train traffic was during the measurement period. Optimally the measurement would have been taken place when the train traffic is at its highest during the year, but this is not possible since the thesis work is carried out during a limited period. The measurement was instead performed during a Monday to Friday (3:00pm–7:00am). How large the maximum power consumption is in the signal box depends mostly on how many switches that operates at the same time. By using the method described in 4.3 *Analysis of measurements*, a pie chart could be created based on how frequent different kinds of switches are operated at the same time, see Figure 12.

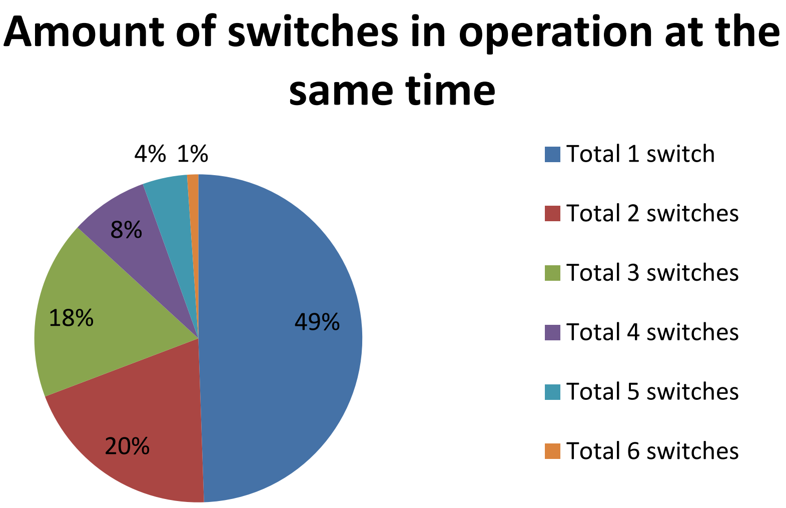


Figure 12 Amount of switches in operation at the same time for signal box 300.

In Figure 12 it can be seen that about half of the time only one switch is operating at a time. The probability that more switches will operate at the same time decreases the more switches that are operating at the same time. During the measurement there were up to 6 switches that were operating at the same time. This happened only once during the measurement period, which corresponds to about 2.55 seconds of 16 hours.

The consumption from the switches also depends on which type of point machine that controls the switch and how many of them. Which type of point machine every switch have is mentioned further back in the report in chapter 2 *System description*.

In Figure 13 switch number 395, 398, 480 and 481 operates most frequent. All these switches are located on the same street railway. A clearer view over when the different kind of switches are operating and whether they are operating at the same time as other switches can be found in Appendix A.1-*Switching operations at signal box 300* From there it can be seen that switch number 395, 398, 480 and 481 often are involved when multiple switches operates. Switch number 411, 419, 426 and 427 directs the trains into a train depot which explains why only a few of these switches were operating during the measurement period.

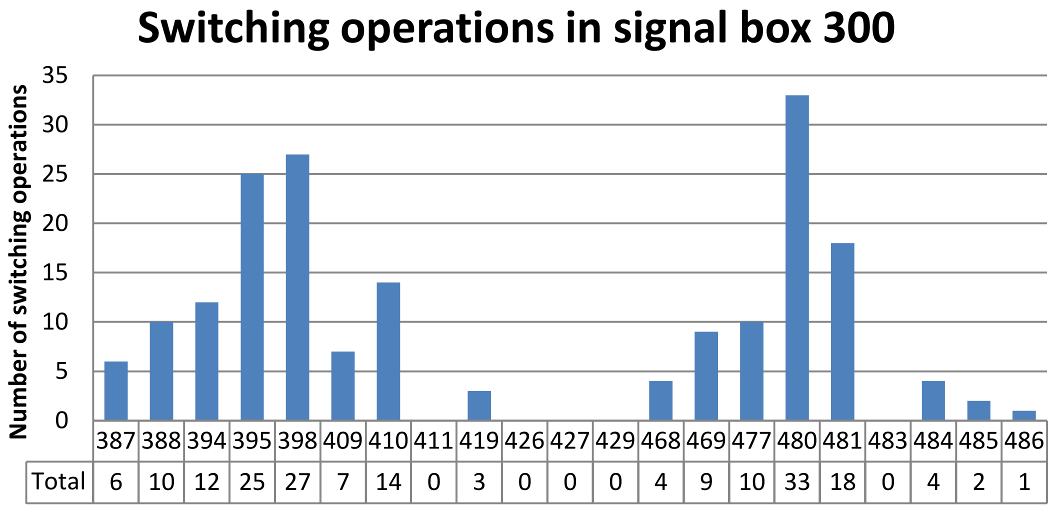


Figure 13 Number of switching operations for switches belonging to signal box 300

At the second measurement the instrument was connected to a single PSU 151 at signal box 300. This was done to study the PSU 151 as well as to exclude the possibility that other favored power groups are operating at the same time as the switches and thus get the correct power consumption value for the switches. The PSU 151 that was measured controlled four different switches, switch number 387, 388, 394 and 481. During the measurement period there were only up to 3 switches that operated at the same time, see Figure 14.

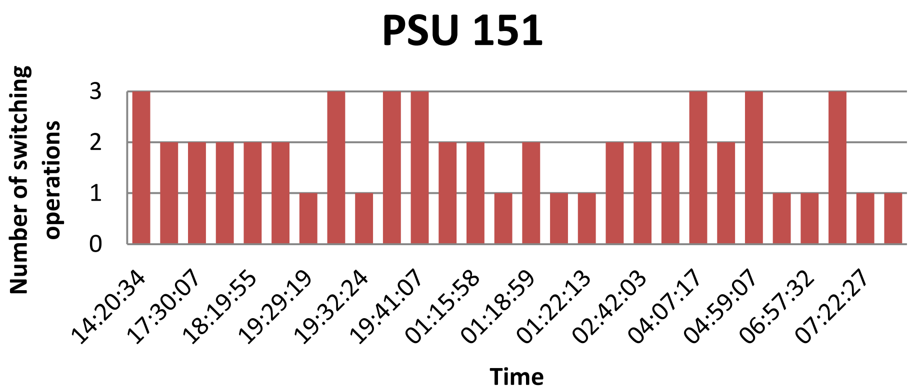


Figure 14 Number of switching operations for switches belonging to a specific PSU 151 in signal box 300.

5.2 Measurements results from signal box 500

In the same way as for signal box 300, measurement was performed on signal box 500. The measurement was done on a Monday (11.00 am–12:00pm). The pie chart below shows how frequent different kinds of switches are operated at the same time, see Figure 15.

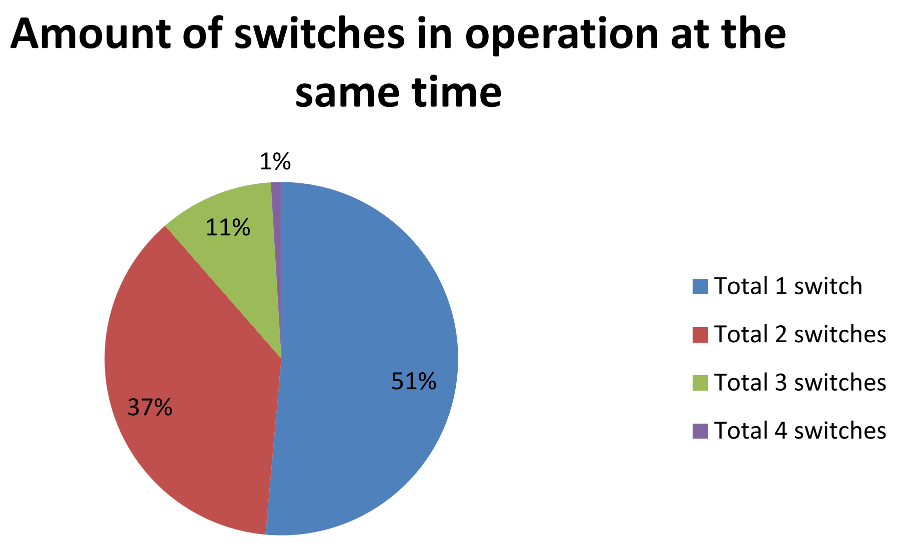


Figure 15 Amount of switches in operation at the same time for signal box 500

Figure 15 has similar structure as signal box 300. Where the probability decreases the more switches are operating at the same time. Signal box 500 had at most four switches that operated at the same time. This happened three times during the measurement period, which only represents approximately 7.65 seconds out of 13 hours.

Unlike signal box 300, signal box 500 controls several switches that are controlled by two point motors. The switches that are controlled by two point motors are switch number 462, 463,547 and 551. Figure 16 below shows how often these switches operated. Figure 16 also includes how often the other two switches, with only one point motor, operated.

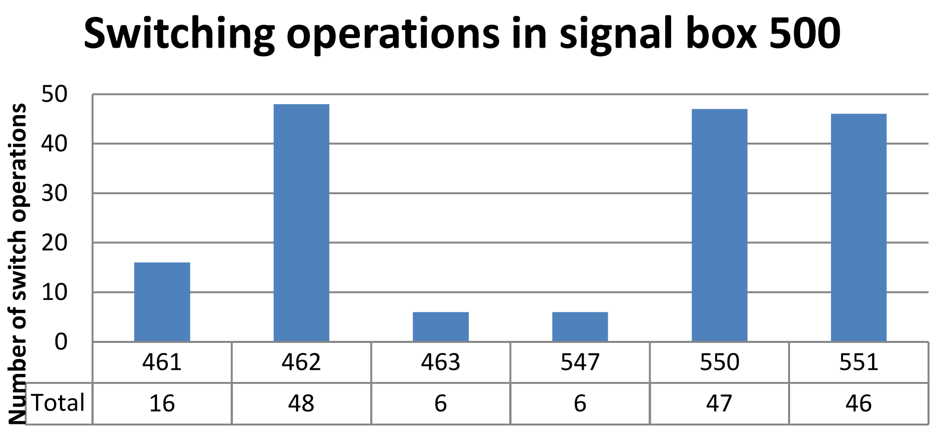


Figure 16 Number of switching operations for switches belonging to signal box 500

In Figure 16 it is shown that the two point motor switches 463 and 547 experience fewest switching operations of the switches in signal box 500. A closer look at the drawings over signal box 500 shows that the mentioned switches directs the trains into tracks that diverts in two completely different directions. The train traffic is smaller in those directions which explain fewer switching operations.

The power consumption from the switches controlled by two point motors is higher than switches controlled by one motor, but there is no proportional power relationship in between which can be seen in chapter 5.4. This makes it particularly important to see which kind of switches that are involved when more than one switch are operated at the same time, this can be seen in Appendix A.2. From there it can be seen that when two switches are operating at the same time it is usually in the combination of switch number 550 and 551. This switch combination includes one switch controlled by one point motor and one switch controlled by two point motors. Furthermore, the switch combination for three switches at the same time is either switch number 462, 550 and 551 or 461, 550 and 551. The first combination includes two switches that are controlled by two point motors each and one switch controlled by one point motor. The other combination includes two switches controlled by one point motor and one switch controlled by two point motors. The few times where 4 different switches operated at the same time was always in the combination 461, 462, 550 and 551 (two switches controlled by one point motor and two switches controlled by two point motors each). Although the signal box includes four switches controlled by two point motors, it never happens, during the measurement period, that more than two switches controlled by two point motors are operating at the same time.

A PSU 151 measurement was recorded also for this signal box. This to get data from switches controlled by two point motors that will be used to calculate power requirements for the switches, found in chapter 5.4. The PSU 151 controls switch number 462 and 463 which are both controlled by two point motors. In Figure 17 below it can be seen that it is more usual that only one of this switches operates at a time, than both of them at the same time.

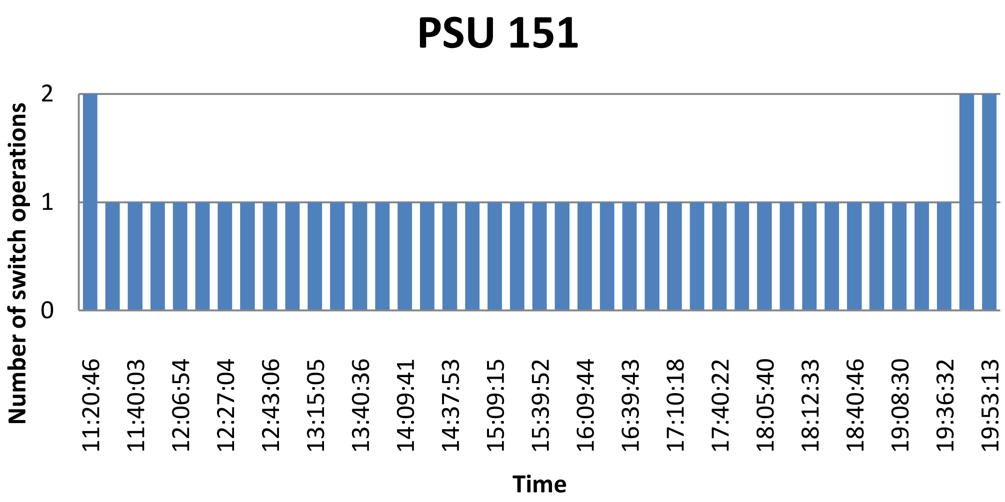


Figure 17 Number of switching operations for switches belonging to a specific PSU 151 in signal box 500.

5.3 Measurements results from signal box 600

The measurement of incoming power for signal box 600 was also performed during a Monday, here between 11:00 am and 10:00 pm. A pie chart was created from this measurement which below shows how frequent different kinds of switches are operated at the same time, see Figure 18.

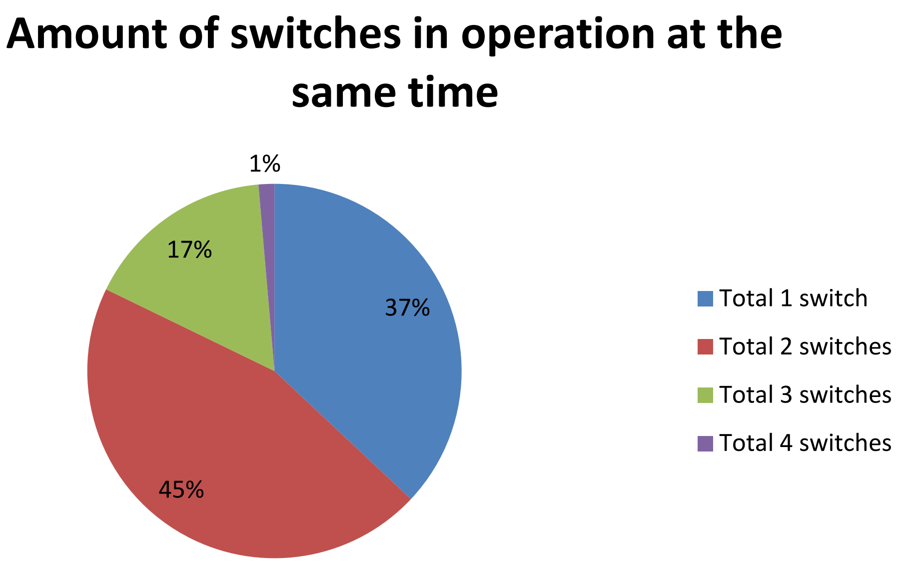


Figure 18 Amount of switches in operation at the same time for signal box 600

The structure of the pie chart is different from those in signal box 300 and 500. In this case it is more usual that two switches are operating at the same time than that one switch operates at a time. Although the signal box controls ten different switches, only a maximum of four switches operating at the same time was recorded during the measurement period, which represents only approximately 2.55 seconds of 11 hours.

Signal box has one switch that is controlled by two point motors, switch number 607. The rest of the switches are controlled by one point motor. Below in Figure 19 shows how often the switches controlled by signal box 600 are operating.

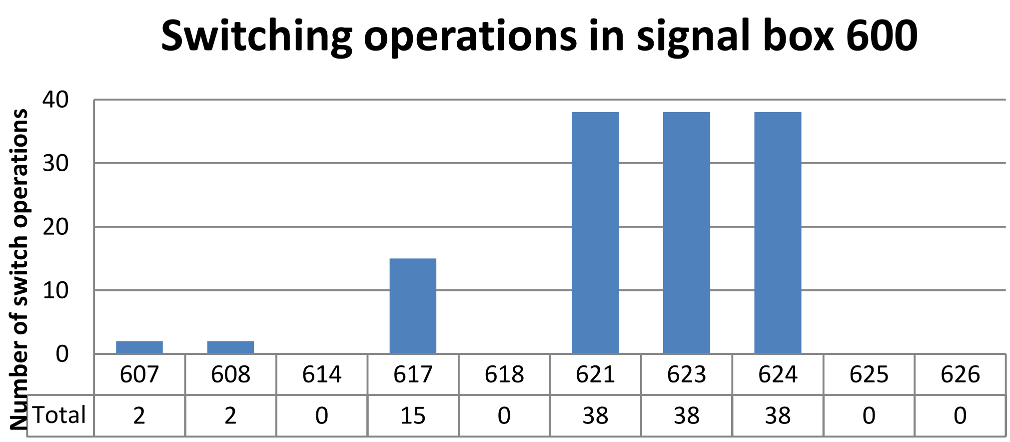


Figure 19 Number of switching operations for switches belonging to signal box 600

In Figure 19 it can be seen that the two point motor switch 607 and one point motor switch 608 operated significantly less times than other switches that moved during the same period. When three switches operated at the same time it was only in the combination 621,623 and 624 and when four switches operated at the same time it was in the combination 617,621,623 and 624, see Appendix B.3. Switches 621,623,624 often operate in combination with each other which can explain why the number of switching operations was the same for these switches during the measuring period. When studying drawings over signal box 600 it can be seen that switch number 621 and 623 can direct the train into a refudge siding. A refudge siding is a short track that ends with a buffer stop. These catching points have a task of leading the trains into a security track if the train passes a stop signal where the diverted line leads out to a main line [37].

Switches 614, 625 and 626 direct the trains into industrial railway that is not used as often as commercial trains, which can explain why no switching operation was recorded during the measurement period. Switch number 618 has less train traffic to diverging track hence no switching operation either for that switch.

A measurement recording of a PSU 151 was also made here but it registered too few switching operations in order to be analysed more in detail.

5.4 Calculated power consumption for different kind of switches

Table 5 below shows the results from the method described in chapter 4.3.1.

Table 5 Calculated power on different types of switches based on measured data.

Number of Point motors	Type of switch	Point motor	Stroke length [mm]	Average power [kW]	Max. power [kW]	Switching time [sec]
One	Jea 52 och 53	BKE 2501	170	0.70	2.13	2.55
			94	0.53	2.13	2.55
	JEA 72 och 73	BKE2501	170	0.72	2.13	2.55
			94	0.51	2.13	2.55
		BKE2512	170	2.20	6.42	2.55
			94	1.67	6.42	2.55
Two	Jea 52 och 53	BKE 2501	170	1.32	2.17	2.68
			94	1.01	2.17	2.68
	JEA 72 och 73	BKE2501	170	1.36	2.17	2.68
			94	0.97	2.17	2.68
		BKE2512	170	3.77	6.55	2.68
			94	3.15	6.55	2.68

The values in Table 5 are based on the maximum value from created maximum power curves. The maximum power curves thus consist of the largest inrush current from recorded data and the highest slip current. Furthermore the slip current is placed directly after the inrush current which never happened during the measurements. This table is therefore not a good description of how large power consumption the switches usually have, but rather the theoretical maximum power the switches require. These maximum values are used in the optimisation process for the signal boxes.

Most of the switches data was collected on were of motor type BKE 2512. The measurement equipment recorded too few switches with BKE 2501 motors. These motors were considered to behave similarly to BKE 2512 with the exception that the slip current is different. For the motors were data missing the slip current used was collected from Figure C-1 at Appendix C. In Table 5 it can be seen that the maximum power is nearly the same independent on if the switch is controlled by one point motor or two point motors. This is because the inrush current is slightly shifted between the two point motors in the switch. This shifting in inrush current is however not included when multiple switches are operating at the same time (the maximum power for two switches operating at the same time is the sum of the individual maximum powers for the switches). The switching operation time for a switch varied very little from different switching operations. The switches with two point motors have slightly longer switching operation time (14 hundredths of a second). This is due to the shifting in time of the inrush currents.

5.5 Incoming power from measurements and model with PSU 151 excluded

The power requirements for the signal boxes, i.e. the incoming power to the signal boxes, were calculated in two different ways. First by just reading of the recorded data results and secondly by using the created model described in method 4.4.

5.5.1 Incoming power from measurements with PSU 151 excluded

Table 6 below shows the result from readings of the measurements. The readings were done by subtracting the current spikes (PSU151) from the graphs (see Figure 8) and thereafter take an average of the remaining graph. The same thing was done for the voltage curve. The incoming power to the signal box was then collected by adding up the individual phase's power consumption.

Table 6 Incoming power at the signal boxes when using measurements excluding current spikes

	Signal box 300			**Signal box 500**			**Signal box 600**		
	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
Average current [A]	10.82	9.85	9.74	8.50	7.22	7.01	5.49	3.60	3.78
Average voltage [V]	225.06	225.61	225.59	229.66	230.75	231.38	233.97	235.52	236.01
Average power [kW] (Incoming power)	**6.85**			**5.24**			**3.02**		

5.5.2 Incoming power from model with PSU 151 excluded

This model uses the maximum output power from Bombardier's data sheets for the PSU:s that controls other equipment than switches, i.e. PSU 72, 370, 421 and 440. The output power groups in the signal box where no data was found on the sheet, the value was instead estimated. This was done by examining Anders Magnusson's thesis and by seeing how much similar components consume in power. The model takes into account whether the groups in the signal box are single phase or three phases. The signal box has a built in system that ensures that the cooling system does not start while the electric heating is on, which the model accounts for. The output power groups that were considered to have very little effect in relation to other power output groups, or no effect at all was set to zero in effect. As described in chapter 3.9 it is not realistic to assume that all output power groups will experience their maximum power simultaneously. This was taken into account and a diversity factor of 0.6 was used in the calculations. This value comes from that the signal box contains more than 10 different groups, which means that the value will be 0.6 according to SS–EN 60 439–1 [38] [3] . The signal box will also need some space for possible future expansions. The value that is required here is that there must at least be 30% free of the signal box total power need. Chosen effects for both favored and uninterruptible power output groups can be found in Appendix B. Signal box 300 is presented in Appendix B.1, signal box 500 in Appendix B.2 and signal box 600 in Appendix B.3. Table 7 below shows the

[3] Can be found on page 4 in that reference

results from the generated power model. Here a voltage of 231 V has been assumed for the phases.

Table 7 Incoming power at the signal boxes when using the model with PSU 151 excluded

	Signal box 300			**Signal box 500**			**Signal box 600**		
	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
Average current [A]	15.44	12.12	13.94	10,85	7,51	9,86	6,66	8,93	6,32
Average voltage [V]	231	231	231	231	231	231	231	231	231
Average power [kW] (Incoming power)	**9.58**			**6.52**			**5.06**		

5.6 Incoming power from PSU 151 model

The power consumption of a PSU 151 depends on a variety of parameters. For instance how many switches that is connected to the PSU 151 and which type of switches the PSU 151 controls. How often the railway switches are operated depends on where in the railway network they are located. Switches that are placed between two tracks with high intense traffic will operate more than switches located in the railway network between two tracks with less traffic. The method described in chapter 4.3 resulted in how often different type of switches operated and its power consumption, where detailed results can be found in Appendix A. These results were used when building up the PSU 151 model.

Fuses can handle an overload more than its ampacity for a short time, see chapter 3.8 *Fuses*. Therefore, it was not always the maximum number of switches that gave the dimensioning power consumption for the PSU 151.

The model first divides up the switches in how often they are operated. Switches belonging to a signal box that does not represent over a certain percent of the total switching in the signal box are highlighted. How high this percentage limit is depends on how many switches that are connected to the signal box according to Table 8 below.

Table 8 Switches are highlighted which does not meet the requirements in the table.

Number of switches belonging to the signal box	Percentage limit
1 to 10	≤15%
11-20	≤10%
21-30	≤5%
31-40	≤2.5%

For example, a switch that operates nine times when the signal box experience 100 switching operations during the same time will represent 9 % of the total. This switch is highlighted in a signal box that has between 21 and 30 switches but is not highlighted in a signal box that contains fewer switches.

Next step in the model is to apply this thinking when multiple switches are operating at the same time. If X[4] number of switches are operating at the same time and they represent less than 5 % of the total number of switches in the signal box, no switch in X can be highlighted (see Table 9) in order for the X number of switches to be dimensioning power. For example in Figure 12, six switches operating at the same time are representing approximately 1 % of the total. If any of the six switches are highlighted according to Table 8 above, then six switches operating at the same time will not become dimensioning power. Number of allowed highlighted switches in X number of switches operated at the same will change when X represent a higher percentage of the total than 5 %. If X number of switches represent a percentage higher than 5 but lower than 10 of the total then 1 highlighted switch is allowed in X for it to become dimensioning power. At higher percentages, the number of allowed highlighted switches in X number of switches will follow Table 9 below.

[4] X is an integer from 1 and upwards.

Table 9 Determines if X number of switches operating at the same time will become dimensioning power.

X number of switching operation in percentage of the total.	Number of switches that can be highlighted in X
0–5.00 %	0 highlighted switches
5.01–10.00 %	1 highlighted switch
10.01–15.00 %	2 highlighted switches
15.01–20.00 %	3 highlighted switches
20.01–30.00 %	4 highlighted switches

If the signal box has maximum X switches operating at the same time and this meet the requirements above, then the model will also test other combinations (X-1, X-2, X-3...). The maximum power from these combinations that satisfies all requirements will become dimensioning power. This is due to that fewer switches that operate at the same time can have higher power consumption than more switches operating at the same time. For example if two switches operate at the same time and both of them are driven by two point motors. Then the average power for two switches will become higher than if three switches driven by one point motor operate at the same time. Since the two switches then have four point motors and the three switches have only three point motors in total.

This method was applied to the signal boxes and the result is shown in Table 10 below. Two different power consumption are shown in the table: one that is based on using average power from PSU 151 and one power consumption that is based on the maximum power from PSU 151 (from inrush current). In Signal box 300, 5 switches at the same time (all driven by one point motor) became dimensioning power for PSU 151 according to the model above. For signal box 500, 3 switches at the same time (two switches driven by two point motors and one driven by one point motor) became dimensioning power for PSU 151. In signal box 600, 3 switches at the same time (all driven by one point motor) became dimensioning power for PSU 151.

Table 10 Dimensioning power from PSU 151 model at the signal boxes.

	Signal box 300	Signal box 500	Signal box 600
Power from PSU 151 model [kW]	11 average 32.1 max.	9.74 average 19.52 max.	3.62 average 10.68 max.

5.7 Dimensioning power

Here model step one (chapter 5.5.2) and step two (chapter 0) are added and the dimensioning power is showed. The dimensioned power from the model is also compared to the dimensioned power based on measurements (chapter 5.5.1 and chapter 0).

5.7.1 Dimensioning power from measurements

Table 11 below shows the resulting power consumption for signal boxes when the model for PSU 151 is added to Table 6. The table can then be seen as the total power required for the signal box. Two different dimensioning power consumption are shown in the table: One power consumption that is based on using average power from PSU 151 and one power consumption that is based on the maximum power from PSU 151 (from inrush current).

Table 11 Signal boxes dimensioning power when using measurements and the model for PSU 151.

	Signal box 300	Signal box 500	Signal box 600
Dimensioned power [kW]	**17.85 ; (38.95)**	**14.98 ; (24.76)**	**6.64 ; (13.7)**

5.7.2 Dimensioning power from model

Table 12 shows the resulting power consumption for signal boxes when the model for PSU 151 is added to Table 7. The table can then be seen as the total power required for the signal box. Two different dimensioning power consumption are shown in the table: One power consumption that is based on using average power from PSU 151 and one power consumption that is based on the maximum power from PSU 151 (from inrush current).

Table 12 Signal boxes dimensioning power when using the model.

	Signal box 300	Signal box 500	Signal box 600
Dimensioned power [kW]	**20.58 ; (41.68)**	**16.26 ; (26.04)**	**8.68 ; (15.74)**

5.8 Optimisation

Below are results from the optimisations performed on the three different signal boxes studied in this thesis. The optimisation was done in the cable sizing program EL-Vis described in chapter 4.5.1. Input data to EL-Vis was taken from the system description in chapter 2 and the dimensioned power in Table 11 and Table 12 with the difference that 30 % has been added to dimensioned power for possible future expansion, which is a requirement from Trafikverket.

5.8.1 Optimisation signal box 300

Table 13 below shows the results from the optimisation for signal box 300 with dimensioned power from measurements and dimensioned power from the model. Today the signal box has a main fuse at 63 ampere for incoming power on the a-side and the b-side. The optimisation results are slightly different depending on if the dimensioned power is taken from the model or from the measurements. The dimensioned power from the model results in 40 ampere fuse for incoming power. The incoming cable in signal box 300 could also have been decreased from 10 mm to 2.5 mm on the a-side and from 16 mm to 10 mm on the b-side, if the signal box would have been a new installation. Now when the signal box already is installed there are no incentives to replace the cable as a smaller cable will have higher voltage drop.

A 40 ampere fuse will however not work according to selectivity as the highest fuse in the signal box is at 35 ampere, see Appendix E. The nearest fuse that is selective to the 35 ampere fuse is the 63 ampere fuse. The highest fuse in the signal box belongs to the UPS. Thus, this UPS will have to be replaced with a smaller one in order get the 40 ampere fuse selective, but since there are great uncertainties if 30 % is sufficient for expansions in the future this will not be recommended. Consequently no change will be recommended to happen to signal box 300.

Table 13 Fuse and cable dimension for incoming cable to signal box 300. The dimensioned power is taken from measurements and model separately.

	A-side			B-side		
	Fuse	Cable dimension	Voltage drop [%]	Fuse	Cable dimension	Voltage drop [%]
Dimensioned power from measurements (average)	35	EKKJ 4x2.5/2.5	2.69	35	EKKJ 4x10/10	2.39
Dimensioned power from model (average)	40	EKKJ 4x2.5/2.5	3.1	40	EKKJ 4x10/10	2.76

5.8.2 Optimisation signal box 500

The power supply to signal box 500 is a bit different from the power supply to signal box 300 as the b-side in signal box 500 is fed directly from a network station. In Table 14 it can be seen that fuse became 32 ampere both for incoming power based on the measurements and based on the model. The existing cable (AXQJ 4x95/29) is not included in the EL-Vis program. The dimensioned cable became instead AXQJ 4x95/57. This is because the smaller size on the cable will have a voltage drop that lies on the upper limit recommended. The highest fuse in the signal box is at 16 ampere. This makes the 32 ampere fuse selective according to Appendix E. The existing fuse at 35 ampere can thus be replaced with a 32 ampere fuse.

Table 14 Fuse and cable dimension for incoming cable to signal box 500. The dimensioned power is taken from measurements and model separately.

	A-side			B-side
	Fuse	Cable dimension	Voltage drop [%]	Fuse
Dimensioned power from measurements (average)	32	AXQJ 4x50/29	4	32
Dimensioned power from model (average)	32	AXQJ 4x95/57	2.2	32

5.8.3 Optimisation signal box 600

Signal box is equipped with a main fuse at 63 ampere on both a- and b-side and cable FXQJ 4x16/16 on both sides. In Table 15 below, the cable size can be decreased to 4x6/6 on the a-side and 4x6/6 on the b-side. The fuse can also be replaced to as low as 20 ampere. However the UPS needs to be decreased in size in order to get the 20 ampere fuse selective. After a closer look at Table B-8 in Appendix B.3.1 it can be seen that the highest current is 11.27. The UPS could thus be decreased in size to 8 kVA and then have a fuse size of 16 ampere (instead of 25 before). The recommended fuse size of 20 ampere then becomes selective according to Appendix E.

Table 15 Fuse and cable dimension for incoming cable to signal box 500. The dimensioned power is taken from measurements and model separately

	A-side			B-side		
	Fuse	Cable dimension	Voltage drop [%]	Fuse	Cable dimension	Voltage drop [%]
Dimensioned power from measurements (average)	13	EKKJ 4x4/4	3.24	13	EKKJ 4x4/4	3.24
Dimensioned power from model (average)	20	EKKJ 4x6/6	2.83	20	EKKJ 4x6/6	2.83

6 Discussion

In the following chapter there will be a discussion around the reliability of the results based on the objectives in this thesis. This will be done by questioning the assumptions made and chosen method for this thesis. The discussion is divided into three parts, namely: assumptions and estimated parameters, modeling approach and discussion around optimization results.

6.1 Assumptions and estimated parameters

Many assumptions have been made in this thesis in order to come to results within a reasonable time period. If more time had been available, the measurements would contain more output power groups instead of being estimated. Seasonal variations could also have been taken into account. The estimates are based on other literature articles and datasheets from companies. Even if more measurements would have been done, the problem still remaining when the power output groups operate relative to other power output groups in the signal box. The optimal method would have been an instrument that could measure all output groups individually at the same time. This is not very realistic as there may be over 40 outgoing power groups in the signal box and some of them are three phase supplied. With more time a closer study could have been conducted around when in time the rail traffic is most intense. Measure that period and thus optimise the signal box from a known maximum power value. Uncertainties remain with this method; whether this really is the greatest maximum power value that can arise in the signal box or the future may prove that wrong. As described in this thesis a model was created around this in order to analyse the railway traffic more in detail. An uncertainty in the constructed model is the diversity factor used. This is not a problem that only this model has, but is out in most electrical installations. In order to see how great impact the diversity factor has on the results some other values on the diversity factor were studied. The results can be seen in chapter 6.3.

6.2 Modelling approach

The constructed model is based on data from three different signal boxes, namely: signal box 300, signal box 500 and signal box 600. The signal boxes are various in sizes from signal box 500 operating only 6 switches to signal box 300 operating 21 switches. The model could then be tested if it the results are consistent even if the sizes on the signal box vary. The dimensioned power used as an input in the EL-Vis software is based on the average power. As the fuses can handle a higher current for a shorter time (current spikes will only last for approximately ten hundredths of a second). Additionally, the current spikes should have been shifted in time from each other according to Anders Magnusson's thesis and signal engineers at Sweco Rail. However, this was not the case for the data recorded during the measurement periods. The shift in time between current spikes could only be found in switching operations at switches controlled by two point switch motors.

Worth mentioning is that the built up PSU 151 model is based on measurements taken in this thesis work. The measurements then represent how intense the railway traffic is today. Train routes can be changed and added which may alter the input data to the PSU 151 model and thus also alter the results.

Today the optimisation is done with help of different kind of data sheets. If this approach compared to the approach taken in this thesis, one can find both advantages and disadvantages with respective method. The disadvantages to continue to use the approach today can be many. For instance, the power mentioned in the data sheets does not always have to be the actual power the components consume. The actual power may just be a fraction of the power requirement written in the data sheets. The suppliers may deliberately set a higher power value in order to be on the safe side. This causes among other things; thicker cables, higher subscription rate and bigger UPS installations than really needed. The advantages to stay with today's approach are for example that it is known and it works. An unknown method can take time to learn and it will also take time to perform accurate measurements on all existing components in the signal box. Dedicating time to this can in the beginning be a loss in terms of cost but will likely to be paid back in the longer run. Furthermore the approach used today conflicts with Trafikverket's vision: "Alla kommer fram smidigt, grönt och tryggt" [39], which in English can be translated to something like "Everyone should arrive easy, green and safely". Where green refers to sustainability and it is not that sustainable to have over dimensioned signal boxes.

The optimization performed in this thesis does not only lead to a financial gain. Resource savings results in less material used in the manufacturing processes of e.g. UPS and power cables. Seen from a bigger perspective, energy needed in all stages of these components life cycles is reduced. The components have thus the same function at a lower energy input. According to International Energy Agency energy efficiency results in e.g. reduced investment in energy infrastructure, improved welfare and reduction of greenhouse gases emissions. [40]

6.3 Discussion around optimisation results

To see if the dimensioned power from the model was credible, it was compared to the dimensioned power from the measurements. In Table 11 the dimensioned power became: 17.85 kW in signal box 300, 14.98 in signal box 500 and 6.64 in signal box 600. The dimensioned power from the model (Table 12): 20.58 in signal box 300, 16.26 in signal box 500 and 8.68 in signal box 600. The model sorts the signal boxes in the same power size order as the measurements. Moreover, the values from the model are not very different to the measurements, (between 1.28 kW to 2.73kW). This indicates that the model provides credible results. The earlier performed measurement that Vectura did in signal box 600 was 7.7 kW which also is not that different to the model's 8.68 kW. The final optimisation results differ somewhat depending if the power used is taken from the model or from the measurements even if the difference between the power requirements isn't that huge. To be on the safe side the optimisation was in the end based on the dimensioned power from the model. The result from this is presented in Table 16 , Table 17 and Table 18 below. The values marked with red in the tables are the optimisation result taken from chapter 5.8.

The diversity factor may have an impact on the optimisation results, as discussed in chapter 6.1. In order to study this, other values for the diversity factor was used in the model. The values tested for the diversity factor ranged from 0.4 to 1 with interval of 0.1.

Table 16 shows how the optimisation results are affected with changed diversity factor. As there is an uncertainty about how high the power requirement will be in the future for signal box 300, it was chosen that no changes should happen to signal box 300. This means that the signal box should still have its fuse at 63 ampere.
The diversity factor does not need to be taken into account according to the table at that fuse size.

Table 16 Fuse and cable dimension for incoming cable to signal box 300 for different diversity factors. The dimensioned power is taken from the model.

Diversity factor	A-side			B-side		
	Fuse	Cable dimension	Voltage drop [%]	Fuse	Cable dimension	Voltage drop [%]
0.4	35	EKKJ 4x2.5/2.5	2.62	35	EKKJ 4x6/6	3.92
0.5	40	EKKJ 4x2.5/2.5	2.86	40	EKKJ 4x10/10	2.54
0.6	40	EKKJ 4x2.5/2.5	3.1	40	EKKJ 4x10/10	2.76
0.7	50	EKKJ 4x4/4	2.08	50	EKKJ 4x10/10	2.97
0.8	50	EKKJ 4x4/4	2.23	50	EKKJ 4x10/10	3.19
0.9	50	EKKJ 4x4/4	2.38	50	EKKJ 4x10/10	3.4
1	63	EKKJ 4x4/4	2.53	63	EKKJ 4x10/10	3.62

In Table 17 it can be seen that the recommended cable size for signal box 500 stands a higher diversity factor. At higher diversity factor than 0.8 the fuse becomes higher than the already installed fuse in the signal box today. Signal box 500 was proven to be the already best optimised signal box out of the three studied. However it can still be recommended to be optimised one step lower in fuse size as the model is built on worst case scenario for the railway switches.

Table 17 Fuse and cable dimension for incoming cable to signal box 500 for different diversity factors. The dimensioned power is taken from the model.

Diversity factor	A-side			B-side
	Fuse	Cable dimension	Voltage drop [%]	Fuse
0.4	32	AXQJ 4x50/29	3.82	32
0.5	32	AXQJ 4x95/57	2.06	32
0.6	32	AXQJ 4x95/57	2.2	32
0.7	32	AXQJ 4x95/57	2.35	32
0.8	35	AXQJ 4x95/57	2.5	35
0.9	40	AXQJ 4x95/57	2.64	40
1	40	AXQJ 4x95/57	2.79	40

After a closer study of Table 18, a conclusion is drawn that signal box 600 is most over dimensioned of all signal boxes. As the UPS size could be decreased the fuse size could be decreased from 63 ampere to as low as 20 ampere. Even here the cable dimension is constant and independent on how high the diversity factor is. However the voltage drop is increased but lies within a reasonable limit (4 %). Here a fuse of size 20 is recommended but a fuse size of 25 ampere will also make a huge difference to the subscription rate. As described in chapter 2, a smaller main fuse will decrease the subscription cost. The subscription rate will differ with 10 000 SEK/year if a main fuse of 20A will be installed instead of 63A [41].

Table 18 Fuse and cable dimension for incoming cable to signal box 600 for different diversity factors. The dimensioned power is taken from the model.

Diversity factor	A-side			B-side		
	Fuse	Cable dimension	Voltage drop [%]	Fuse	Cable dimension	Voltage drop [%]
0.4	16	EKKJ 4x4/4	3.41	16	EKKJ 4x4/4	3.41
0.5	16	EKKJ 4x4/4	3.82	16	EKKJ 4x4/4	3.82
0.6	20	EKKJ 4x6/6	2.83	20	EKKJ 4x6/6	2.83
0.7	20	EKKJ 4x6/6	3.1	20	EKKJ 4x6/6	3.1
0.8	20	EKKJ 4x6/6	3.38	20	EKKJ 4x6/6	3.38
0.9	25	EKKJ 4x6/6	3.65	25	EKKJ 4x6/6	3.65
1	25	EKKJ 4x6/6	3.93	25	EKKJ 4x6/6	3.93

Finally, all the recommended optimization options for the studied signal boxes in this thesis can be further optimized if some other variables are reviewed. This includes the slip current for the point machines in the switches. The slip current results in higher average power. If this slip current somehow can be eliminated or controlled by maintenance, then the dimensioned power will decrease. Another major variable is when in time the switches are switching. Instead of having four switches in operation at the same time during 2.55 seconds, see Table 5, the switching could be controlled by the signal box to operate two switches at a time. The switching operation will thus only increase by 2.55 seconds and at the same time decrease the average power by a factor of 2.

7 Conclusion

In this thesis, a model based on measurements and datasheets was successfully developed with a purpose of optimising different signal boxes of type 95. The proposed method of optimisation is based both on the created model and measurements separately. The two different results are discussed and a recommendation on optimisation is given from these results.

The model created in this study makes it possible to investigate both uninterruptible power and favored power and in the end a combination of them both. The performance of the model was determined by comparing it to earlier proposed optimization measurements and by testing the model on different sizes of signal boxes.

The goal of the proposed method was to see if the signal boxes could be optimised. The proposed method revealed that all the signal boxes were over dimensioned. However, no recommendations on optimisations were conducted on signal box 300 due to uncertainties about future development. Signal box 500 could be equipped with one smaller step in fuse size and the fuse size in signal box 300 could be decreased drastically from 63 ampere to 20 ampere, lowering the subscription cost with 10 000 SEK/year.

7.1 Future work

- Study the uninterruptible power closer with the goal to see if the UPS could be decreased even further.
- Measure several outgoing power groups simultaneously and thus get a clearer picture on the power consumption in the signal box.
- Investigate if the slip current could be reduced or eliminated and thus decrease the average power from the switches.
- Implement software that keeps down the number of switching operations that could be conducted at the same time.

8 References

[1] Jarnvag.net. (n.d.). *Kort svensk järnvägshistoria*. Retrieved April 8, 2014, from Jarnvag.net: http://www.jarnvag.net/index.php/banguide/historia.

[2] Trafikverket. (2012, April 2). *Vem gör vad av myndigheterna inom transportområdet?* Retrieved April 8, 2014, from Trafikverket: http://www.trafikverket.se/Om-Trafikverket/Trafikverket/Vem-gor-vad-av-myndigheterna-inom-transportomradet/.

[3] Trafikverket. (2014, January 27). *Sveriges järnvägsnät*. Retrieved April 8, 2014, from Trafikverket: http://www.trafikverket.se/Privat/Vagar-och-jarnvagar/Sveriges-jarnvagsnat/.

[4] Trafikverket. (2011, September 2). *Underhålls- och reinvesteringsbehov signalställverk*. Retrieved April 8, 2014, from Trafikverket: http://www.trafikverket.se/PageFiles/65047/rapport_underhalls_och_reinvesteringsbehov_signalstallverk_20110902_version_1_0.pdf.

[5] Antonsson, C. (2013, September 12). (P. Sigvardsson, Interviewer).

[6] Trafikverket. (2013, May 10). *Elkraftanläggningar*. Retrieved April 8, 2014, from Trafikverket: http://ida8iext.banverket.se/bvdok_extern/ViewPdfDoc.aspx?docGUID=300a24e0-db55-4eb9-9baf-2e10ebe99af4.

[7] Trafikverket. (2012, May 18). *Grundläggande projekteringsregler för Ebilock 950 anpassad för Trafikverket*. Retrieved April 8, 2014, from Trafikverket: http://www.trafikverket.se/PageFiles/57735/projekteringsregler_CBSS_BV_ATC_L1_120620.pdf.

[8] Toshiharu, M. (1992). *Patent No. US5175730 A*. Japan.

[9] Svahn, E. (2013, September 12). (P. Sigvardsson, Interviewer).

[10] Eaton. (2009, July). *Eaton 9355 UPS*. Retrieved April 8, 2014, from Eaton: http://powerquality.eaton.in/Products-services/Backup-Power-UPS/9355.aspx?cx=36&GUID=DDB5DC59-5174-4925-855B-21F5C1A1C282.

[11] Stenström, C. (2012). *Maintenance performance measurement of railway infrastructure with focus on the swedish network*. Luleå: Luleå University of Technology.

[12] Bårström, S., & Granbom, P. (2012). *Den svenska järnvägen*. Borlänge: Trafikverket.

[13] Trafikverket. (2012, Mars 15). *ERTMS i Sverige - Nuläge och viktiga vägval*. Retrieved April 8, 2014, from Trafikverket: http://www.trafikverket.se/PageFiles/68345/ertms_sverige_20120315_ny.pdf.

[14] Trafikverket. (2014, Mars 6). *Statistik för punktlighet*. Retrieved April 8, 2014, from Trafikverket: http://www.trafikverket.se/Om-Trafikverket/Trafikverket/Manatlig-trafikrapport/Transport-pa-jarnvag-i-ratt-tid/Statistik-for-punktlighet/.

[15] Järnvägsstyrelsen. (2008, April 18). *GSM-R-installationer i fordon*. Retrieved April 8, 2014, from Transportstyrelsen: http://www.transportstyrelsen.se/Global/Jarnvag/Vagledning/Godkannande/vagledning_gsm_r_installationer_i_fordon_v01.pdf.

[16] ELFA. (2007). *Faktasidor*. Retrieved April 8, 2014, from ELFA: https://www1.elfa.se/data1/wwwroot/webroot/Z_STATIC/sv/pdf/fakta.pdf.

[17] EMERSON Network Power. (2000, November). *High-availability power system, part 1: UPS internal topology*. Retrieved April 8, 2014, from EMERSON Network Power: http://www.emersonnetworkpower.com/documentation/en-us/brands/liebert/documents/white%20papers/high-availability%20power%20systems,%20part%20i_ups%20internal%20topology.pdf.

[18] Sweco Rail. (n.d.). *Säkringsdimensionering av Eaton-Powerware UPS 0.7 – 500 VA*. Retrieved April 14, 2014, from Sweco Rail.

[19] Trafikverket. (2013, April 15). *Spårväxel definition, benämning och förkortning*. Retrieved April 8, 2014, from ida8iext.banverket: http://ida8iext.banverket.se/bvdok_extern/viewpdfdoc.aspx?docGUID=ac8c59e1-1b92-46ed-803d-40313f3527b5.

[20] Trafikverket. (2012, November 30). *Spårväxel med fast och rörlig korsningsspets*. Retrieved April 8, 2014, from Trafikverket: http://www.trafikverket.se/PageFiles/93755/bvs_1522.pdf.

[21] Statens järnvägar. (2009, April 10). *Omläggningsanordning för växlar*. Retrieved April 8, 2014, from ekeving: http://www.ekeving.se/t/sthb/SH_35-57.pdf.

[22] Svahn, M. (2013, November 8). (P. Sigvardsson, Interviewer).

[23] Trafikverket. (2009, September 30). *Spårväxlar och spårspärrar grundläggande signaleringskrav*. Retrieved April 8, 2014, from Trafikverket: http://www.trafikverket.se/PageFiles/15448/BVS544.98025.pdf.

[24] SEK svenska elekriska kommissionen. (2005, January 10). *Svensk standard SS 424 14 24* . Retrieved April 8, 2014, from enav-sis-se.proxy.lib.chalmers: https://enav-sis-se.proxy.lib.chalmers.se/sv/Sok/?q=SS+4241424+&fpPublisher_SS=on&fd1=off.

[25] ELinfo. (n.d.). *Beräkna spänningsfallet*. Retrieved April 8, 2014, from EL-Vis 10.1.0 (software).

[26] SEK svensk elstandard. (2010). *Svensk standard SS 436 40 00 + R1*. Retrieved April 8, 2014, from EL-Vis 10.1.0 (software).

[27] Institutionen för Elteknik. (2008). *Elteknik*. Göteborg: Chalmers Tekniska Högskola.

[28] Banverket. (2008, May 1). *Signalställverk modell 85 och 95 - installation av skåp, kurar och kiosker*. Retrieved April 8, 2014, from ida8iext.banverket: http://ida8iext.banverket.se/bvdok_extern/ViewPdfDoc.aspx?docGUID=d9975502-f899-4952-816e-f6702c1cb678.

[29] Schneider Electric. (2010). *Tabellsamling säkringsfri teknik 2010*. Retrieved April 8, 2014, from engineering.schneider-electric: http://www.engineering.schneider-electric.se/Attachments/ed/guide/Tabellsamling2010%5B1%5D.pdf.

[30] Wallnerström, J. C. (2005). *Algoritm för uppskattning av den maximala effekten i eldistributionsnät*. Stockholm: KTH - Kungliga Tekniska Högskolan.

[31] Magnusson, A. (2004). *Utredning av effektbehovet för signalsäkerhetsutrustningar vid den svenska järnvägen*. Göteborg: Chalmers.

[32] Edstrand, J. (2012*). Calculation method for powering a tramway network*. Göteborg: Chalmers.

[33] Dranetz - BMI. (2005). *PowerVisa User Guide*. Edison, New Jersey, USA.

[34] Dranetz. (n.d.). *PowerVisa*. Retrieved April 8, 2014, from Dranetz: http://dranetz.com/portable/powervisa.

[35] Dranetz. (n.d.). *Current Probes*. Retrieved April 8, 2014, from Dranetz: http://dranetz.com/accessories/current-probes.

[36] El Info. (n.d.). *EL-Vis kabel*. Retrieved April 8, 2014, from EL-info: http://el-info.se/produkter/el-vis-kabel/.

[37] Smith, M. (n.d.). *Refuge Sidings Exchange Sidings and Marshalling Yards*. Great Britain.

[38] Svensk standard SS EN 60 431-1. (1998, May). *ABB LV Systems*. Retrieved April 8, 2014, from ABB: http://www05.abb.com/global/scot/scot209.nsf/veritydisplay/33890c8ca6e39a6cc1256af000364282/$file/1tsc906019d3401.pdf.

[39] Malm, G. (2014, Mars 29). *Vision*. Retrieved April 8, 2014, from Trafikverket: http://www.trafikverket.se/Om-Trafikverket/Trafikverket/.

[40] International Energy Agency. (n.d.). *Energy efficiency*. Retrieved April 27, 2014, from International Energy Agency: http://www.iea.org/topics/energyefficiency/.

[41] Sweco Rail. (2012). *Effektmätning av signalanläggningar*. Retrieved April 24, 2014, from Sweco Rail.

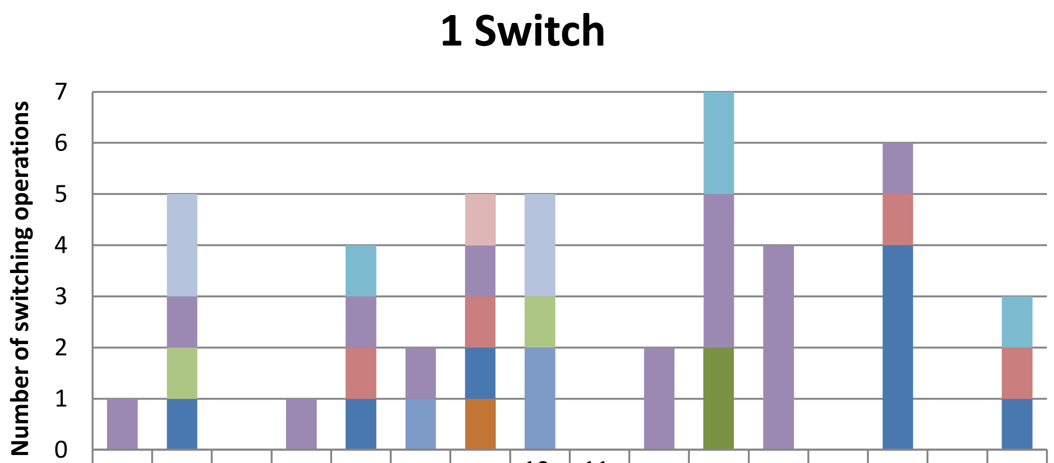
[42] Banverket. (2004, Mars 10). *Funktionsvärden för signalteknisk utrustning*. Retrieved April 8, 2014, from ida8iext.banverket: http://ida8iext.banverket.se/bvdok_extern/ViewPdfDoc.aspx?docGUID=79408fc6-9355-42ad-b750-5679e53322ce.

[43] Sweco Rail. (n.d.). *Nominella strömvärden för IFÖ NH-säkringar vid olika smälttider*. Retrieved April 14, 2014, from Sweco Rail.

[44] Sweco Rail. (n.d.). *Smält-och totala I^2t-värden*. Retrieved April 14, 2014, from Sweco Rail.

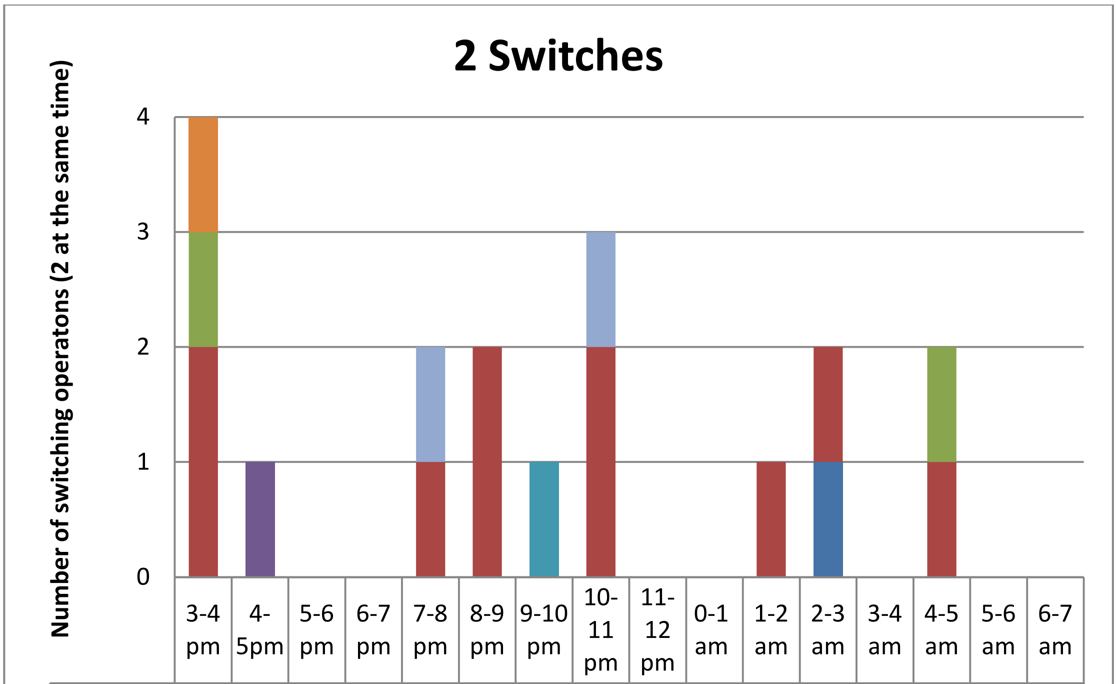
Appendix A Switching operations

Appendix A.1 Switching operations at signal box 300



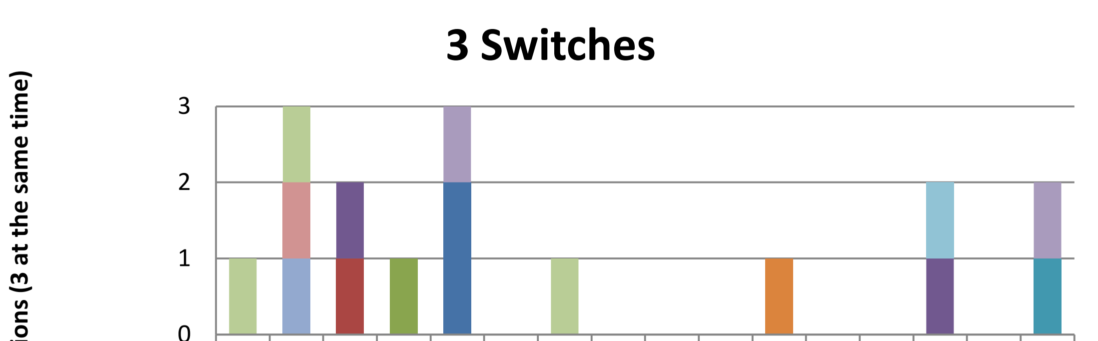
	3-4 pm	4-5pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm	0-1 am	1-2 am	2-3 am	3-4 am	4-5 am	5-6 am	6-7 am
486	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
485	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
484	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0
483	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
481	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	1
480	1	1	0	1	1	1	1	0	0	2	3	4	0	1	0	0
477	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
469	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	1
468	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0
429	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
427	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
426	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
419	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
411	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
410	0	1	0	0	1	0	1	0	0	0	0	0	0	4	0	1
409	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
398	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
395	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
394	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
387	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure A-1 Switching operations in signal box 300 when only one switch operates at a time.



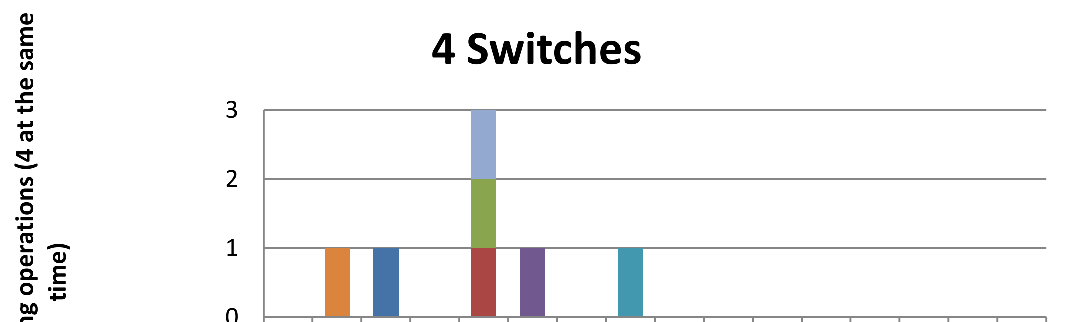
	3-4 pm	4-5pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm	0-1 am	1-2 am	2-3 am	3-4 am	4-5 am	5-6 am	6-7 am
477,480	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
469,477	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
410,419	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
409,485	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
409,410	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
395,398	2	0	0	0	1	2	0	2	0	0	1	1	0	1	0	0
394,481	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Figure A-2 Switching operations in signal box 300 when only one switch operates at a time.



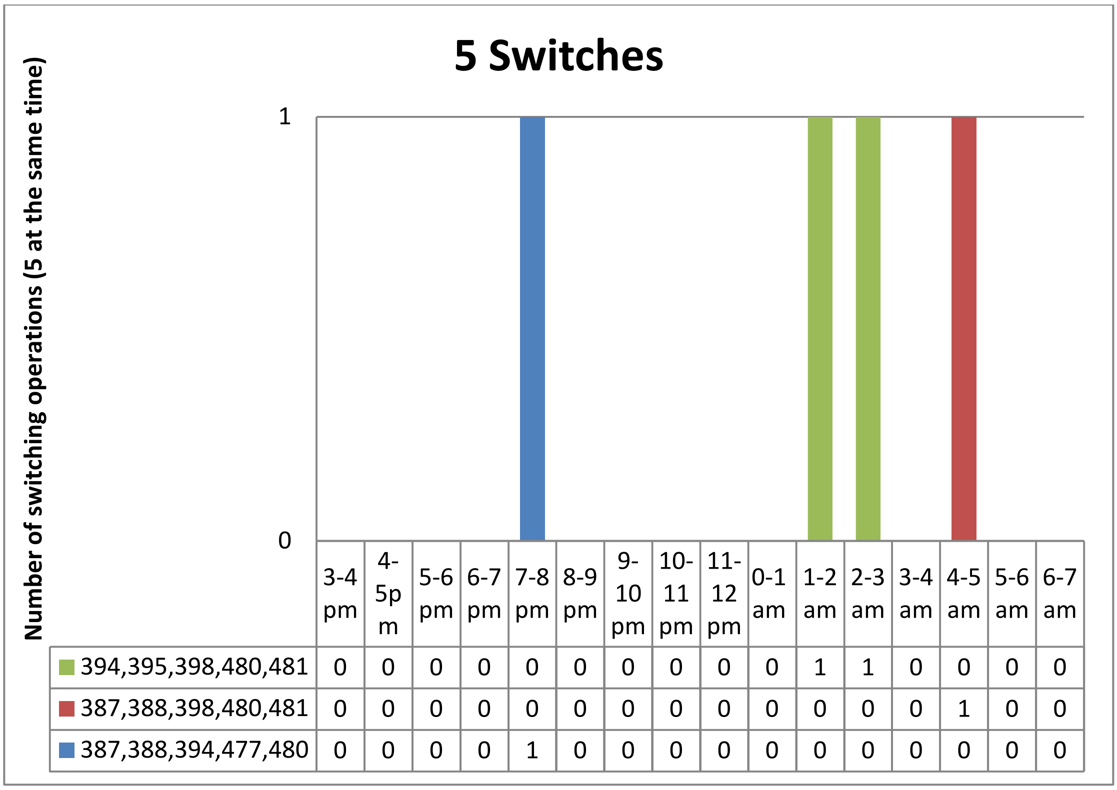
	3-4 pm	4-5pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm	0-1 am	1-2 am	2-3 am	3-4 am	4-5 am	5-6 am	6-7 am
486,409,410	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
409,410,419	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
395,398,480	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
395,398,477	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
395,398,469	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
394,480,481	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
394,477,480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
388,398,481	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
388,395,481	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
387,388,481	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
387,388,394	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0

Figure A-3 Switching operations in signal box 300 when three switches operate at the same time.



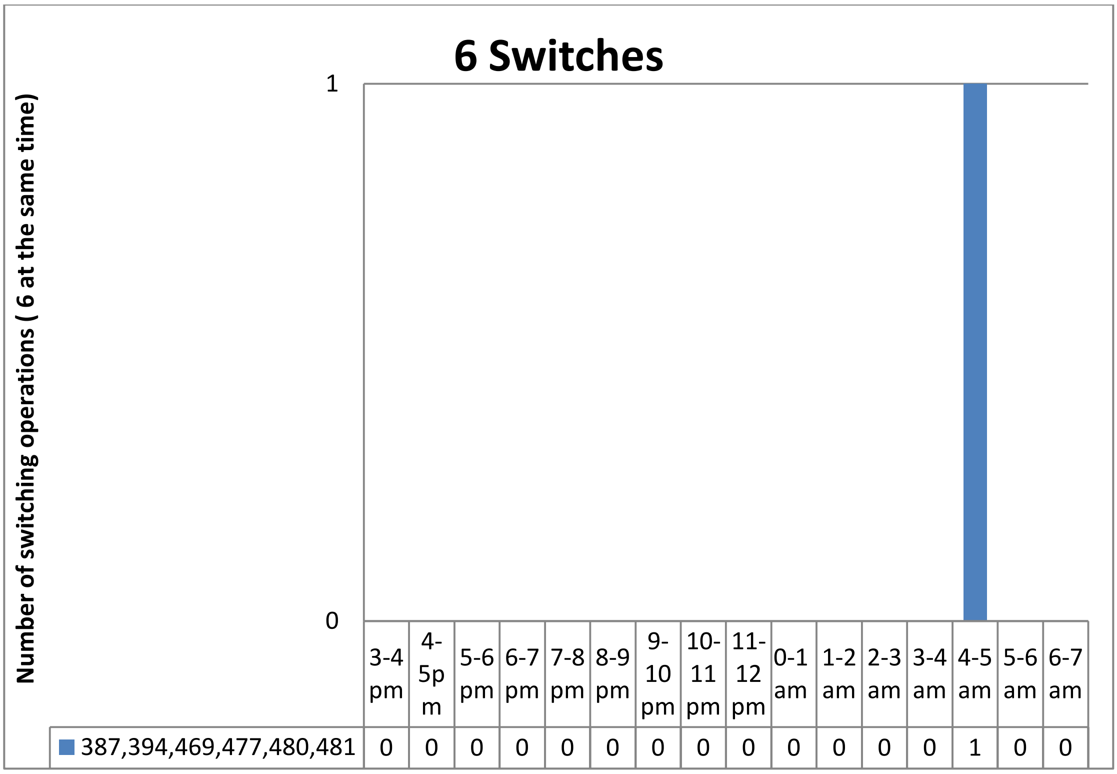
	3-4 pm	4-5pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm	0-1 am	1-2 am	2-3 am	3-4 am	4-5 am	5-6 am	6-7 am
395,398,480,481	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
395,398,477,480	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
395,398,469,480	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
395,398,468,480	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
394,395,398,481	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
388,469,480,481	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
388,395,398,481	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure A-4 Switching operations in signal box 300 when four switches operate at the same time.



	3-4 pm	4-5pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm	0-1 am	1-2 am	2-3 am	3-4 am	4-5 am	5-6 am	6-7 am
394,395,398,480,481	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
387,388,398,480,481	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
387,388,394,477,480	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

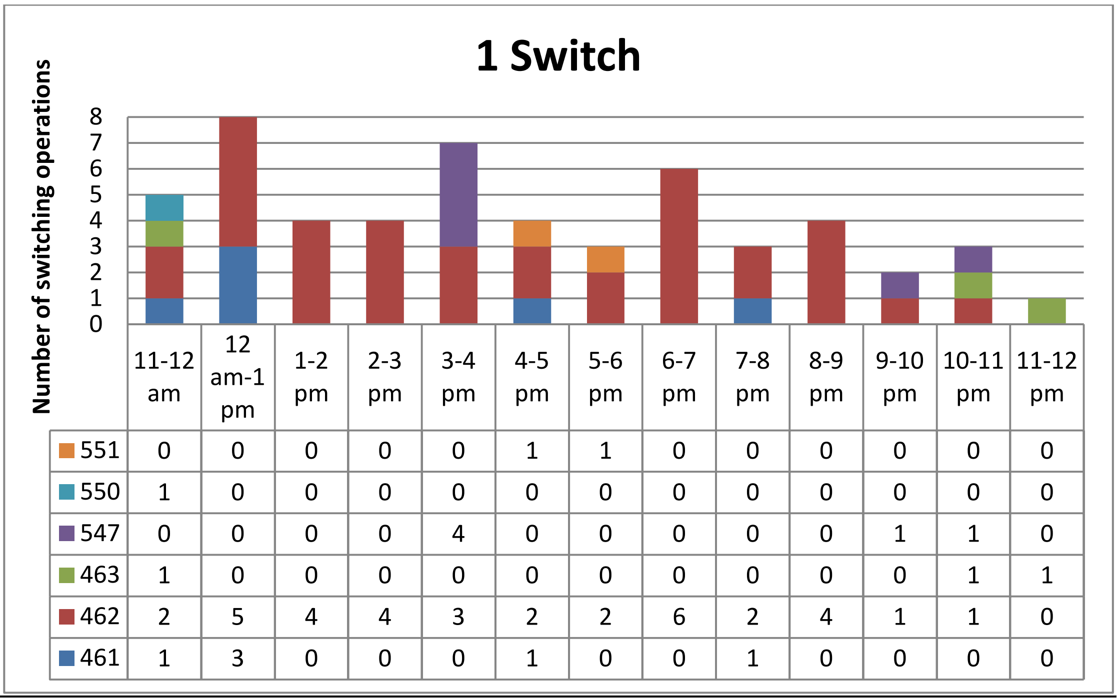
Figure A-5 Switching operations in signal box 300 when five switches operate at the same time.



	3-4 pm	4-5pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm	0-1 am	1-2 am	2-3 am	3-4 am	4-5 am	5-6 am	6-7 am
387,394,469,477,480,481	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Figure A-6 Switching operations in signal box 300 when six switches operate at the same time.

Appendix A.2 Switching operations at signal box 500

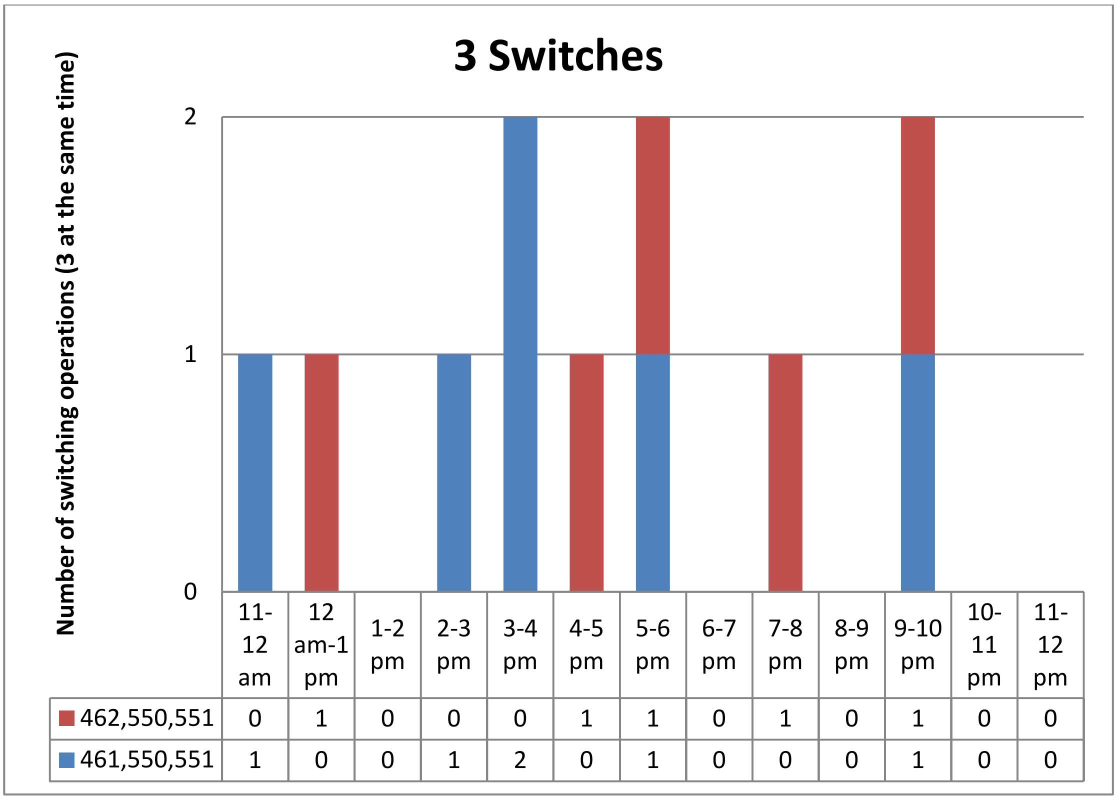


	11-12 am	12 am-1 pm	1-2 pm	2-3 pm	3-4 pm	4-5 pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm
551	0	0	0	0	0	1	1	0	0	0	0	0	0
550	1	0	0	0	0	0	0	0	0	0	0	0	0
547	0	0	0	0	4	0	0	0	0	0	1	1	0
463	1	0	0	0	0	0	0	0	0	0	0	1	1
462	2	5	4	4	3	2	2	6	2	4	1	1	0
461	1	3	0	0	0	1	0	0	1	0	0	0	0

Figure A-7 Switching operations in signal box 500 when only one switch operates at a time.

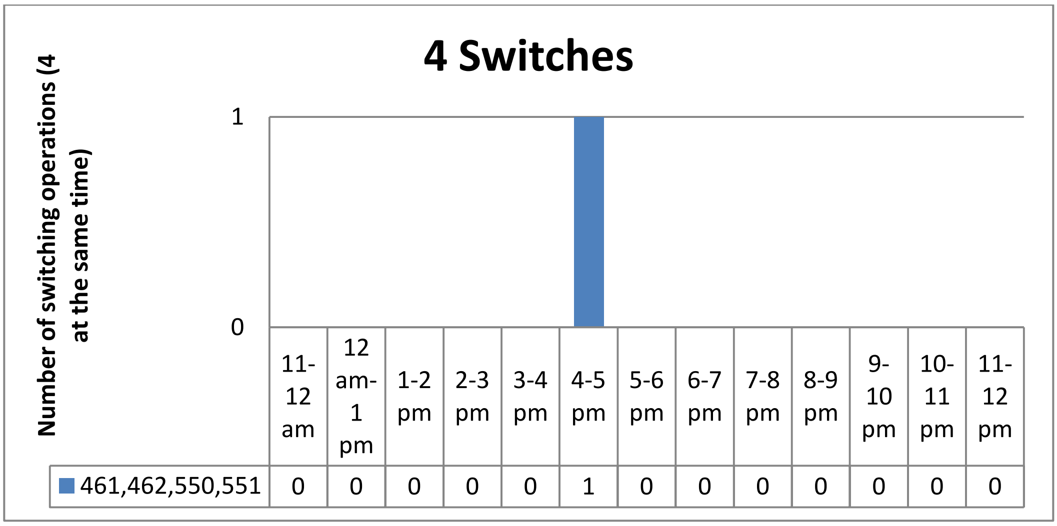
	11-12 am	12 am-1 pm	1-2 pm	2-3 pm	3-4 pm	4-5 pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm
461,550	0	0	0	0	0	1	0	0	0	0	0	0	0
462,463	1	0	0	0	0	0	0	0	2	0	0	0	0
461,462	0	0	0	0	1	0	0	0	1	0	0	0	0
550,551	3	0	1	4	3	4	3	4	3	4	2	2	0

Figure A-8 Switching operations in signal box 500 when two switches operate at the same time.



	11-12 am	12 am-1 pm	1-2 pm	2-3 pm	3-4 pm	4-5 pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm
462,550,551	0	1	0	0	0	1	1	0	1	0	1	0	0
461,550,551	1	0	0	1	2	0	1	0	0	0	1	0	0

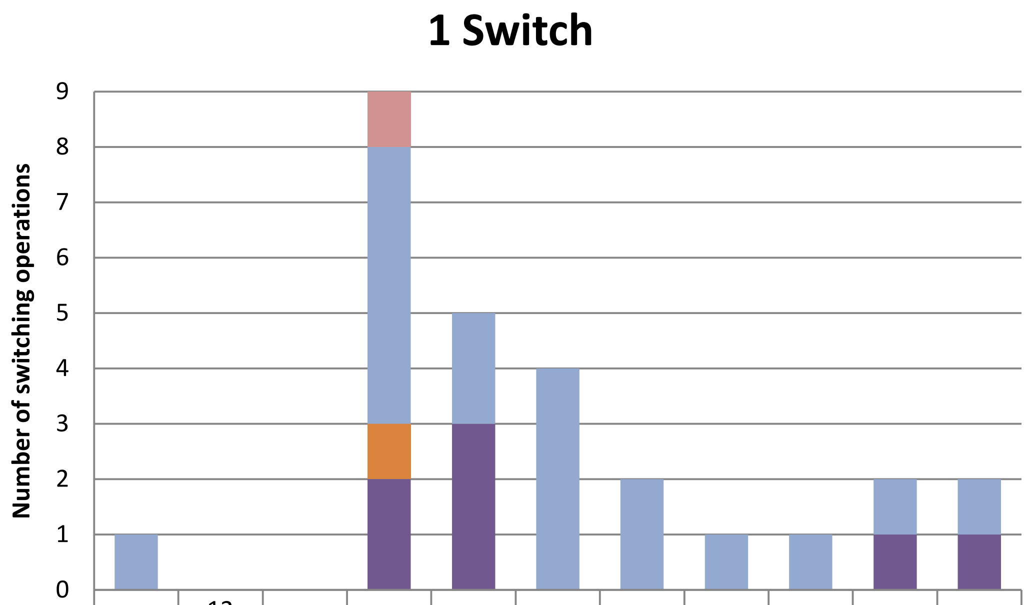
Figure A-9 Switching operations in signal box 500 when three switches operate at the same time.



	11-12 am	12 am-1 pm	1-2 pm	2-3 pm	3-4 pm	4-5 pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm
461,462,550,551	0	0	0	0	0	1	0	0	0	0	0	0	0

Figure A-10 Switching operations in signal box 500 when four switches operate at the same time.

Appendix A.3 **Switching operations at signal box 600**



	11-12 am	12 am-1 pm	1-2 pm	2-3 pm	3-4 pm	4-5 pm	5-6 pm	6-7 pm	7-8 pm	8-9 pm	9-10 pm
626	0	0	0	0	0	0	0	0	0	0	0
625	0	0	0	0	0	0	0	0	0	0	0
624	0	0	0	1	0	0	0	0	0	0	0
623	1	0	0	5	2	4	2	1	1	1	1
621	0	0	0	1	0	0	0	0	0	0	0
618	0	0	0	0	0	0	0	0	0	0	0
617	0	0	0	2	3	0	0	0	0	1	1
614	0	0	0	0	0	0	0	0	0	0	0
608	0	0	0	0	0	0	0	0	0	0	0
607	0	0	0	0	0	0	0	0	0	0	0

Figure A-11 Switching operations in signal box 600 when only one switch operates at a time.

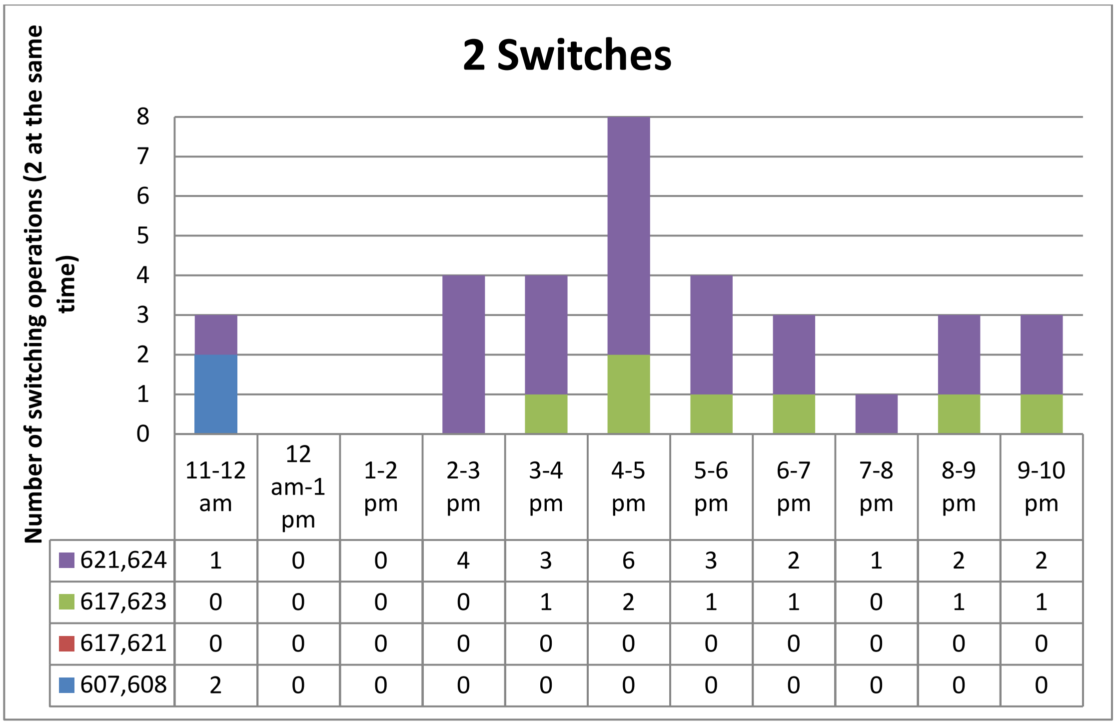


Figure A-12 Switching operations in signal box 600 when two switches operate at the same time.

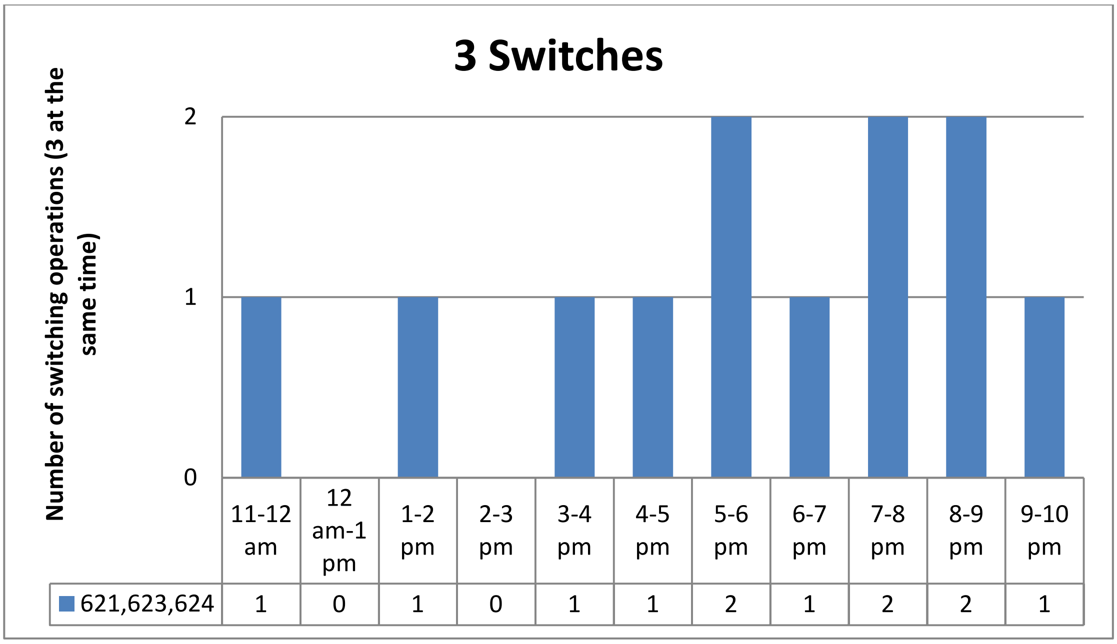


Figure A-13 Switching operations in signal box 600 when three switches operate at the same time.

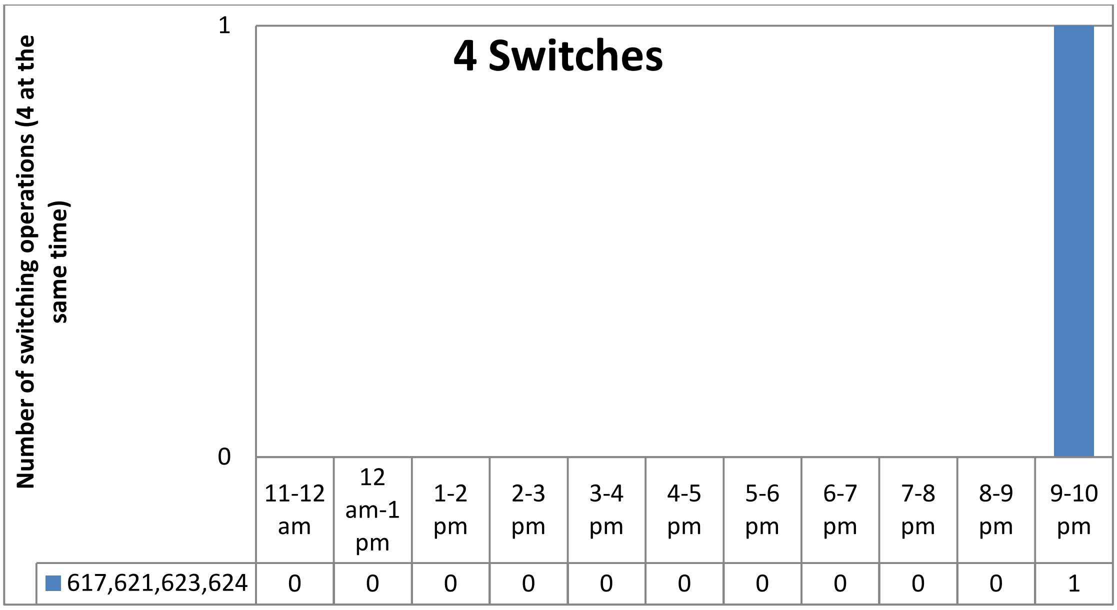


Figure A-14 Switching operations in signal box 600 when four switches operate at the same time.

Appendix B Signal box power consumption

Appendix B.1 Signal box 300 power consumption

Appendix B.1.1 Uninterruptible power signal box 300

Table B-1 Uninterruptible power for different outgoing power groups in signal box 300

Plinth	Group index	Ampacity (W)	Voltage (one phase/ 3-phase)	Phase L1/L2/L3 or 3-phase	Min. current need (A)	Proposed fuse (A)
F50	Yard object Distribution box =N1A17/+455	1000	3-phase	3-phase	1,443375673	25
F51	*Free*		3-phase	3-phase	0	0
F52	*Free*		3-phase	3-phase	0	0
F53	*Free*		3-phase	3-phase	0	0
F54	Distribution box =N1A3/+455	0	3-phase	3-phase	0	16
F55	Distribution box =N1A4/+455	1080	3-phase	3-phase	1,558845727	20
F56	Distribution box =N1A5/+455	0	3-phase	3-phase	0	16
F57	Lighting	500	3-phase	3-phase	0,721687836	6
F58	*Free*		3-phase	3-phase	0	0
F59	OBC1.H7.11 Power supply unit PSU72	540	One phase	L1	2,347826087	10
F60	OBC1.H7.21 Power supply unit PSU72	540	One phase	L2	2,347826087	10
F61	OBC1.H7.31 Power supply unit PSU370	540	One phase	L3	2,347826087	10
F62	OBC1.A3.11 Power supply unit PSU440	96	One phase	L1	0,417391304	10
F63	*Free*		One phase	L2	0	0
F64	*Free*		One phase	L3	0	0
F65	OBC2.H7.11 Power supply unit PSU72	540	One phase	L1	2,347826087	10
F66	OBC2.H7.21 Power supply unit PSU72	540	One phase	L2	2,347826087	10
F67	OBC2.H7.31 Power supply unit PSU370	540	One phase	L3	2,347826087	10
F68	*Free*		One phase	L1	0	0
F69	*Free*		One phase	L2	0	0
F70	*Free*		One phase	L3	0	0
F71	OBC3.H7.11 Power supply unit PSU72	540	One phase	L1	2,347826087	10
F72	OBC3.H7.21 Power supply unit PSU72	540	One phase	L2	2,347826087	10
F73	OBC3.H7.31 Power supply unit PSU370	540	One phase	L3	2,347826087	10

Table B-1 cont.

F74	OBC3.H7.41 Power supply unit PSU370	540	One phase	L1	2,347826087	10
F75	*Free*		One phase	L2	0	0
F76	*Free*		One phase	L3	0	0
F77	OBC4.H7.11 Power supply unit PSU72	540	One phase	L1	2,347826087	10
F78	OBC4.H7.21 Power supply unit PSU72	540	One phase	L2	2,347826087	10
F79	OBC4.H7.31 Power supply unit PSU370	540	One phase	L3	2,347826087	10
F80	OBC4.H7.41 Power supply unit PSU370	540	One phase	L1	2,347826087	10
F81	*Free*		One phase	L2	0	0
F82	*Free*		One phase	L3	0	0
F83	*Free*		One phase	L1	0	0
F84	*Free*		One phase	L2	0	0
F85	RTU-cabin	0	One phase	L3	0	10
F86	Control circuits in central	0	One phase	L1	0	6
F87	Rect. 1	0	One phase	L2	0	6
F88	*Free*		One phase	L3	0	0

Table B-2 Shows the uninterruptible current needed for phase L1, L2 and L3 in signal box 300.

Phases	Sum uninterruptible current need [A]
L1	18,22825706
L2	13,11521358
L3	13,11521358

Appendix B.1.2 **Favored power signal box 300**

Table B-3 Favored power for different outgoing power groups in signal box 300

Plinth	Group index	Ampacity (W)	Voltage (one phase/ 3-phase)	Phase L1/L2/L3 or 3-phase	Min. current need (A)	Proposed fuse (A)
F1	UPS ordinary feed (from uninterruptible power)	10269,95606	3-phase	L1	18,22825706	35
				L2	13,11521358	35
				L3	13,11521358	35
F2	UPS inner bypass	0	3-phase	3-phase	0	35
F3	UPS outer bypass	0	3-phase	3-phase	0	35
F4	Train depot	3000	3-phase	3-phase	4,330127019	35
F5	*Free*		3-phase	3-phase	0	0
F6	*Free*		3-phase	3-phase	0	0
F7	GEMINI cabin A-power	500	3-phase	3-phase	0,721687836	10
F8	GEMINI cabin B-power	500	3-phase	3-phase	0,721687836	10
F9	PSC1.H2 Power supply unit PSU151	0	3-phase	3-phase	0	16
F10	PSC1.H3 Power supply unit PSU151	0	3-phase	3-phase	0	16
F11	PSC1.H4 Power supply unit PSU151	0	3-phase	3-phase	0	16
F12	PSC1.H5 Power supply unit PSU151	0	3-phase	3-phase	0	16
F13	PSC1.H6 Power supply unit PSU151	0	3-phase	3-phase	0	16
F14	PSC1.H7 Power supply unit PSU151	0	3-phase	3-phase	0	16
F15	*Free*		3-phase	3-phase	0	0
F16	Distribution box =N1A18/+455	0	3-phase	3-phase	0	20
F17	Air-condition KA1	0	One phase	L1	0	10
F18	Free	0	One phase	L2	0	0
F19	El. heating room 1	1000	One phase	L3	4,347826087	10
F20	Ventilation fan	200	One phase	L1	0,869565217	6
F21	*Free*		One phase	L2	0	0
F22	El. heating room 2	0	One phase	L3	0	10
F23	Outer lighting	200	One phase	L1	0,869565217	6
F24	Power outlet Room 1	300	One phase	L2	1,304347826	10
F25	Power outlet Room 2	0	One phase	L3	0	10

Appendix B.2 Signal box 500 power consumption

Appendix B.2.1 Uninterruptible power signal box 500

Table B-4 Uninterruptible power for different outgoing power groups in signal box 500

Plinth	Group index	Ampacity (W)	Voltage (one phase/ 3-phase)	Phase L1/L2/L3 or 3-phase	Min. current need (A)	Proposed fuse (A)
F50	Distribution box =N1A4/+455	500	3-phase	3-phase	0,721687836	16
F51	*Free*		3-phase	3-phase	0	0
F52	*Free*		3-phase	3-phase	0	0
F53	*Free*		3-phase	3-phase	0	0
F54	Information sign tunnel north	200	3-phase	3-phase	0,288675135	6
F55	Power supply unit PSU72 +OBC1.H7.11	540	One phase	L1	2,347826087	10
F56	Power supply unit PSU72 +OBC1.H7.21	540	One phase	L2	2,347826087	10
F57	Power supply unit PSU370 +OBC1.H7.31	540	One phase	L3	2,347826087	10
F58	Power supply unit PSU370 +OBC1.H7.41	540	One phase	L1	2,347826087	10
F59	*Free*		One phase	L2	0	0
F60	*Free*		One phase	L3	0	0
F61	Power supply unit PSU72 +OBC2.H7.11	540	One phase	L1	2,347826087	10
F62	Power supply unit PSU72 +OBC2.H7.21	540	One phase	L2	2,347826087	10
F63	Power supply unit PSU370 +OBC2.H7.31	540	One phase	L3	2,347826087	10
F64	Power supply unit PSU370 +OBC2.H7.41	540	One phase	L1	2,347826087	10
F65	*Free*		One phase	L2	0	0
F66	*Free*		One phase	L3	0	0
F67	Power supply unit PSU72 +OBC3.H7.11	540	One phase	L1	2,347826087	10
F68	Power supply unit PSU72 +OBC3.H7.21	540	One phase	L2	2,347826087	10
F69	Power supply unit PSU370 +OBC3.H7.31	540	One phase	L3	2,347826087	10
F70	Power supply unit PSU440 +OBC3.A3.31	96	One phase	L1	0,417391304	10
F71	Power supply unit PSU421 +OBC3.A3.11	96	One phase	L2	0,417391304	10
F72	Power supply unit PSU421 +OBC3.A3.21	96	One phase	L3	0,417391304	10
F73	*Free*		One phase	L1	0	0
F74	*Free*		One phase	L2	0	0
F75	*Free*		One phase	L3	0	0
F76	*Free*		One phase	L1	0	0
F77	*Free*		One phase	L2	0	0
F78	*Free*		One phase	L3	0	0
F79	RTU-cabin	0	One phase	L1	0	10
F80	Info-stand	100	One phase	L2	0,434782609	10
F81	*Free*		One phase	L3	0	0
F82	*Free*		One phase	L1	0	0
F83	*Free*		One phase	L2	0	0
F101	Signal cabin 500n	300	One phase	L1	1,304347826	16
F102	Signal cabin 500k, 500m	300	One phase	L2	1,304347826	16
F103	Signal cabin 500f, 500h	300	One phase	L3	1,304347826	16
F104	*Free*		One phase	L1	0	0
F105	*Free*		One phase	L2	0	0

Table B-5 Shows the uninterruptible current needed for phase L1, L2 and L3 in signal box 500.

Phases	Sum uninterruptible current need [A]
L1	14,47123254
L2	10,21036297
L3	9,775580362

Appendix B.2.2 Favored power signal box 500

Table B-6 Favored power for different outgoing power groups in signal box 500.

Plinth	Group index	Ampacity (W)	Voltage (one phase/ 3-phase)	Phase L1/L2/L3 or 3-phase	Min. current need (A)	Proposed fuse (A)
F1	UPS ordinary feed	10025,964	3-phase	L1	14,47123254	16
				L2	10,21036297	16
				L3	9,775580362	16
F2	UPS inner bypass	0	3-phase	3-phase	0	16
F3	*Free*		3-phase	3-phase	0	0
F4	GEMINI B-power	500	3-phase	3-phase	0,721687836	16
F5	GEMINI A-power	500	3-phase	3-phase	0,721687836	16
F6	Power supply unit PSU151 +PSC1.H2	0	3-phase	3-phase	0	16
F7	Power supply unit PSU151 +PSC1.H3	0	3-phase	3-phase	0	16
F8	Power supply unit PSU151 +PSC1.H4	0	3-phase	3-phase	0	16
F9	*Free*		3-phase	3-phase	0	0
F10	*Free*		3-phase	3-phase	0	0
F11	*Free*		3-phase	3-phase	0	0
F12	*Free*		3-phase	3-phase	0	0
F13	Air-condition KA1	0	One phase	L1	0	10
F14	Crankcase heat KA1	0	One phase	L2	0	10
F15	El. heating	1000	One phase	L3	4,347826087	10
F16	Ventilation fan	200	One phase	L1	0,869565217	10
F17	*Free*		One phase	L2	0	0
F18	*Free*		One phase	L3	0	0
F19	*Free*		One phase	L1	0	0
F20	*Free*		One phase	L2	0	0

Table B-6 cont.

F21	Control circuits in central	0	One phase	L3	0	10
F22	by JF1	0	One phase	L1	0	0
F23	Power outlet and outer lighting by JF2	200	One phase	L2	0,869565217	10
F24	Lighting	200	One phase	L3	0,869565217	10
F25	Power outlet room 2	300	One phase	L1	1,304347826	10

Appendix B.3 Signal box 600 power consumption

Appendix B.3.1 Uninterruptible power signal box 600

Table B-7 Uninterruptible power for different outgoing power groups in signal box 600

Plinth	Group index	Ampacity (W)	Voltage (one phase/ 3-phase)	Phase L1/L2/L3 or 3-phase	Min. current need (A)	Proposed fuse (A)
F50	Yard object distribution box =N1A5/+04 (cabin 600c)	500	3-phase	3-phase	0,721687836	10
F51	Yard object distribution box =N1A6/+00 (cabin 600f)	500	3-phase	3-phase	0,721687836	10
F52	*Free*		3-phase	3-phase	0	0
F53	*Free*		3-phase	3-phase	0	0
F54	*Free*		3-phase	3-phase	0	0
F55	*Free*		3-phase	3-phase	0	0
F56	Distribution box =N1A3/+04	540	3-phase	3-phase	0,779422863	16
F57	*Free*		3-phase	3-phase	0	0
F58	*Free*		3-phase	3-phase	0	0
F59	OBC1.H7.11 Power supply unit PSU72	540	One phase	L1	2,347826087	6
F60	OBC1.H7.21 Power supply unit PSU72	540	One phase	L2	2,347826087	6
F61	OBC1.H7.31 Power supply unit PSU370	540	One phase	L3	2,347826087	10
F62	OBC1.A3.11 Power supply unit PSU421	96	One phase	L1	0,417391304	6
F63	OBC2.H7.11 Power supply unit PSU72	540	One phase	L2	2,347826087	6
F64	OBC2.H7.21 Power supply unit PSU72	540	One phase	L3	2,347826087	6
F65	OBC2.H7.31 Power supply unit PSU370	540	One phase	L1	2,347826087	10
F66	OBC2.H7.41 Power supply unit PSU390	1000	One phase	L2	4,347826087	10
F67	*Free*		One phase	L3	0	0
F68	*Free*		One phase	L1	0	0
F69	*Free*		One phase	L2	0	0
F70	*Free*		One phase	L3	0	0
F71	*Free*		One phase	L1	0	0
F72	*Free*		One phase	L2	0	0

Table B-7 cont.

F73	*Free*		One phase	L3	0	0
F74	*Free*		One phase	L1	0	0
F75	RTU-cabin	0	One phase	L2	0	10
F76	*Free*		One phase	L3	0	0
F77	Control circuits in central page. 30	0	One phase	L1	0	6
F78	rec. 1 page. 30	0	One phase	L2	0	6
F79	Lighting	200	One phase	L3	0,869565217	10

Table B-8 Shows the uninterruptible current needed for phase L1, L2 and L3 in signal box 600.

Phases	Sum uninterruptible current need [A]
L1	7,335842015
L2	11,2662768
L3	7,788015928

Appendix B.3.2 Favored power signal box 600

Table B-9 Favored power for different outgoing power groups in signal box 600

Plinth	Group index	Ampacity (W)	Voltage (one phase/ 3-phase)	Phase L1/L2/L3 or 3-phase	Min. current need (A)	Proposed fuse (A)
F1	UPS ordinary feed	5082,420434	3-phase	L1	7,335842015	25
				L2	11,2662768	25
				L3	7,788015928	25
F2	UPS inner bypass	0	3-phase	3-phase	0	25
F3	UPS outer bypass	0	3-phase	3-phase	0	25
F4	*Free*		3-phase	3-phase	0	0
F5	*Free*		3-phase	3-phase	0	0
F6	*Free*		3-phase	3-phase	0	0
F7	GEMINI cabin A-power	500	3-phase	3-phase	0,721687836	10
F8	GEMINI cabin B-power	500	3-phase	3-phase	0,721687836	10

Table B-9 cont.

F9	PSC1.H2 Power supply unit PSU151	0	3-phase	3-phase	0	16
F10	PSC1.H3 Power supply unit PSU151	0	3-phase	3-phase	0	16
F11	PSC1.H4 Power supply unit PSU151	0	3-phase	3-phase	0	16
F12	*Free*		3-phase	3-phase	0	0
F13	*Free*		3-phase	3-phase	0	0
F14	*Free*		3-phase	3-phase	0	0
F15	*Free*		3-phase	3-phase	0	0
F16	*Free*		3-phase	3-phase	0	0
F17	Air-condition KA1	1000	3-phase	L1	1,443375673	10
F18	Crankcase heater KA1	500	One phase	L2	2,173913043	6
F19	El. heater	0	One phase	L3	0	10
F20	Ventilation fan	200	One phase	L1	0,869565217	6
F21	*Free*		One phase	L2	0	0
F22	*Free*		One phase	L3	0	0
F23	*Free*		One phase	L1	0	0
F24	*Free*		One phase	L2	0	10
F25	Power outlet and outer lighting	300	One phase	L3	1,304347826	10

Appendix C Function values for railway switches

Driv typ	Motor	Slaglängd (mm)	Dragkraft vid slirning (N)	Motorström vid slirning (A)
JEA 23	--	--	3500 ± 500	2,0 ± 0,3 DC
JEA 52 och 53	BKE 2501	170	3500 ± 500	2,9 ± 0,3 DC
		94	3500 ± 500	2,1 ± 0,4 DC
JEA 72 och 73	BKE 2501	170	6000 ± 1000	3,0 ± 0,5 DC
		94	6000 ± 1000	2,0 ± 0,3 DC
	BKE 2512 (R1A och R2A)	170	6000 ± 1000	3,5 ± 0,5 AC [3]
		94	6000 ± 1000	2,0 ± 0,2 AC [3]
Siemens 9A	--	--	3500 ± 500	--

Figure C-1 Function values for traction and slip current for different kind of switches. English from left to right: type of switch, motor, stroke length, traction during slip, slip current [42].

Appendix D Nominal current values for Fuses

Table D-1 Nominal current values for Hicap Eco gG 6-100A 500 V~ at different melting times [43]

	Meltind times													
Rated current	0,01 sec.	0,04 sec.	0,08 sec.	0,1 sec.	0,4 sec.	1 sec.	2 sec.	3 sec.	5 sec.	10 sec.	20 sec.	30 sec.	50 sec.	1 h
6A	84A	52A	42A	40A	29A	24A	20A	19A	17A	16A	14A	13A	13A	10A
10A	162A	102A	83A	77A	54A	43A	37A	34A	31A	28A	25A	24A	22A	16A
16A	234A	147A	120A	113A	80A	65A	56A	51A	46A	40A	36A	34A	32A	23A
20A	302A	189A	152A	141A	100A	82A	70A	64A	57A	51A	45A	42A	40A	29A
25A	421A	257A	206A	192A	128A	102A	87A	79A	71A	63A	57A	53A	50A	36A
32A	566A	338A	266A	248A	166A	131A	112A	102A	92A	82A	74A	69A	64A	46A
35A	620A	381A	305A	280A	185A	147A	124A	113A	102A	90A	81A	76A	72A	51A
40A	736A	456A	357A	338A	217A	173A	146A	132A	119A	105A	94A	88A	83A	58A
50A	982A	593A	469A	438A	292A	233A	199A	180A	163A	144A	129A	120A	112A	75A
63A	1127A	701A	564A	516A	258A	293A	253A	232A	290A	187A	164A	154A	141A	94A
80A	1547A	1032A	856A	802A	564A	452A	380A	352A	314A	276A	247A	226A	207A	119A
100A	2047A	1363A	1126A	1053A	732A	585A	498A	445A	395A	344A	300A	276A	253A	142A

Appendix E Pre-arcing- and total I^2t-values

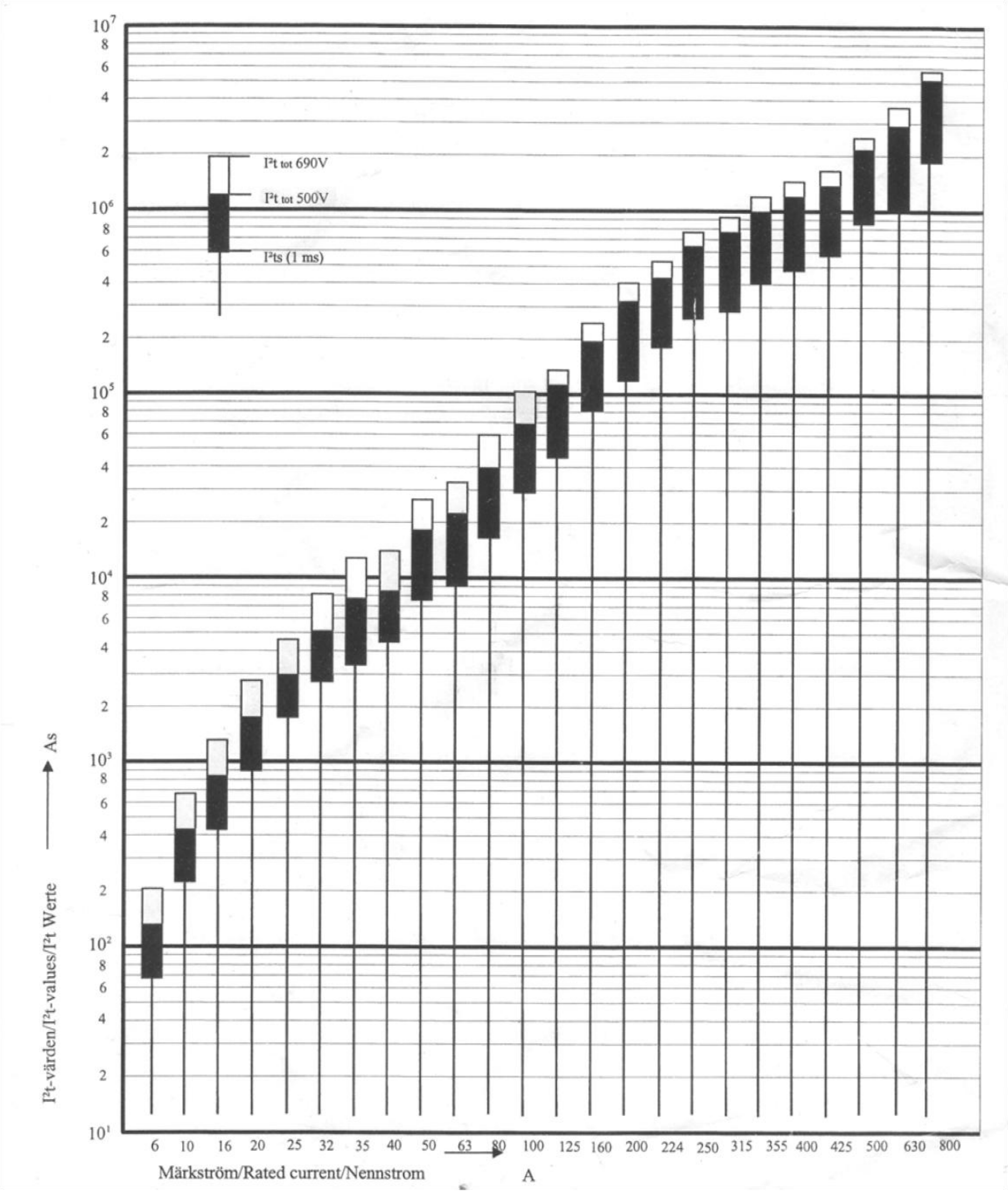


Figure E-1 Pre-arcing- and total I^2t-values for fuses type Hicap Eco gG 6-800 A [44].