CHALMERS
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Strategy for designing solar powered UPS systems

in hospitals in Eastern Africa

Master's thesis in Electric Power Engineering

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Abstract

In Eastern Africa a stable supply of electricity from the grid cannot be taken for granted. It is therefore important to investigate possibilities on how to improve the supply for areas of the society that suffers the most from these flaws. A power outage during an ongoing operation at a hospital could in the worst case be fatal for the patient and therefore hospitals is one of the areas in the greatest need of help. The UPS technology has come far but has not yet become a common part in electric system for hospitals in the region. It is in the topic of how to design a UPS system with solar power for a hospital in this region of the world that this thesis focuses on.

A strategy is presented for how to design and dimension all major parts of a UPS system with solar power. The strategy discussed UPS topology, UPS system configuration, solar power inclusion, batteries, installation and future expandability. If the strategy is followed correctly an efficient solution can be found for the majority of all hospitals in the region.

The strategy was tested and improved during a case study at Kolandoto hospital in Tanzania. In the case study a UPS system was designed and installed with the purpose to supply three operations theatres and the wards at the hospital. The UPS system installed was a decentralised system with hybrid UPS/solar units what functions both as a solar inverter and a UPS unit. Solar power was installed to be able to supply the loads both during a power outage and during normal operations. The final tests of the systems revealed that the system was fully functional but slightly oversized.

Keywords: Eastern Africa, Solar power, Strategy, UPS, Case study

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Simon Rohlén & Martin Skilbred
Gothenburg, August 2016

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1
Introduction

Due to the unstable supply of electricity in Eastern Africa there is a rising need for electric power backups systems. The increase of electrified equipment in hospitals makes the increase of the need of power backup systems especially prominent in this sector of the society. Along with the increasing need follows dilemmas which needs to be comprehended in order to have electrical arrangements of this sort adequately designed and dimensioned. In parallel with this longing is the continuously increasing need for establishing solar power generation where it is essentially needed, in places where the sun is basically always shining but the economical incentives are often shaded. How do we effectively integrate solar power into UPS systems in hospital and what are the critical parameters to account for when doing so? These are just a few questions which needs to be interpreted. Simply put, a strategy needs to be formed in order to maximize potential success whilst performing such ventures.

1.1 Background

In Eastern Africa electricity is not a generic commodity. The infrastructure is in many areas deficient which has led to a devalued grid network with unstable power distribution throughout the region. Power outages in these areas are therefore occurring several times per month. The vulnerability for power outages differentiate depending on which part of the society is struck. Social functions which are notably vulnerable are hospitals due to the importance of their operations. The demand for a sustainable power supply, especially solar energy, in eastern Africa has never been as noticeable as it is today. This creates interests in conducting work related to power distribution in the region. The differing electrical compatibilities of hospitals can however be a major difficulty and might hence lower the quality of the designed product. This thesis aims to investigate these differences and to form a strategy on how to design back-up systems as efficient as possible. The intention is to ease the establishment for organisations and corporations who intend to design similar systems in the region.

As hospitals, during the industrialized era, has moved into being more sophisticated with personnel being more reliant on electrical machines fulfilling extensive work the need for backup power has risen. Even though the UPS has been around for decades the urge for the technology has not yet been customised for hospitals in Eastern Africa in the same manner as they are nowadays obligated to be installed in hospital in the west. But as the cost for the technology is dropping and other high technological devices in the hospital industry are introduced, the need for UPS systems in hospitals in Eastern Africa are nowadays more prominent.

1.2 Kolandoto hospital

In order to achieve credibility in the proposed strategy, a case study at Kolandoto Hospital in Tanzania was conducted. The purpose of the case study was to collect input to the strategy and at the same time apply parts of the strategy to an ongoing installation of a solar powered back-up system and thus examine the strategy's capability. The design of the UPS system were carried out by the authors of this thesis in collaboration with Engineers without borders.

Kolandoto hospital is located in the rural countryside of the region of Shinyanga, about 14 km northeast of Shinyanga town. The history of Kolandoto hospital reaches back to 1913 when two American missionaries from the Africa Inland Mission started to perform medical work in Kolandoto. The hospital has since received aid in terms of medical equipment, medical knowledge and clothings from several non-profit organizations worldwide. As of 2016, Kolandoto hospital has roughly 180 inpatients beds for medical treatments with four operating theatres and employs 135 people for various services around the hospital. The theaters are the eye theater, the maternity theater and the general theater, which in practise consists of two separate theaters. The location of Kolandoto is disclosed in figure 1.2.

Figure 1.1: Kolandoto in Tanzania [2]

The hospital's housing design consists of several buildings which are individually associated with specific departments. The houses are not all built at once which translates into the buildings being of various conditions and standards in terms of electrical installations and building structure.

The hospital is irregularly experiencing power outages which complicates the hospital's daily activities, and especially any ongoing surgical operation. The hospital has hence been requesting a power back-up system to maintain a stable power balance so that any ongoing operation can be terminated safely without jeopardizing patient well-beings. The hospital has a diesel generator which is started when any power outage occurs, but since the generator is not automated it takes approximately 15 minutes from when the power is cut off until the generator is in full operation. This time can be crucial which is why Kolandoto hospital has called for an UPS arrangement to smoothen the transition of power sources.

The national grid owner is the parastatal organization TANESCO which controls all generation-, transmission- and distribution of electricity in Tanzania. Some reports has shown that the national grid in Tanzania would greatly benefit from reinforcement in all three branches as extensive losses in the grid are recorded annually. Because of the quality of the grid the operations of the grid are sometimes deficient, which is further distinguished at Kolandoto as irregular power outages. In order to avoid a total blackout of the system, rotational load shedding is a measure which is performed on a daily basis at TANESCO. The power outages at Kolandoto are approximately occurring two times per week but can in some cases be up to five-six times per week depending on the season. The outages durations are varying from 30 minutes to up to 24 hours. As of today TANESCO are not planning to reinforce the feeding transmission to Kolandoto which is why the issue of power outages are being settled locally [1].

The hospital management were requesting a back-up system to feed certain instruments, machines and lighting which are considered to be essential for the hospital's activities. The loads has been decided upon by the directory of the hospital. The loads are mainly concentrated to the operating theaters but also appears in some of the inpatient wards. The following figure (figure 1.2) shows an overview of the hospital area.

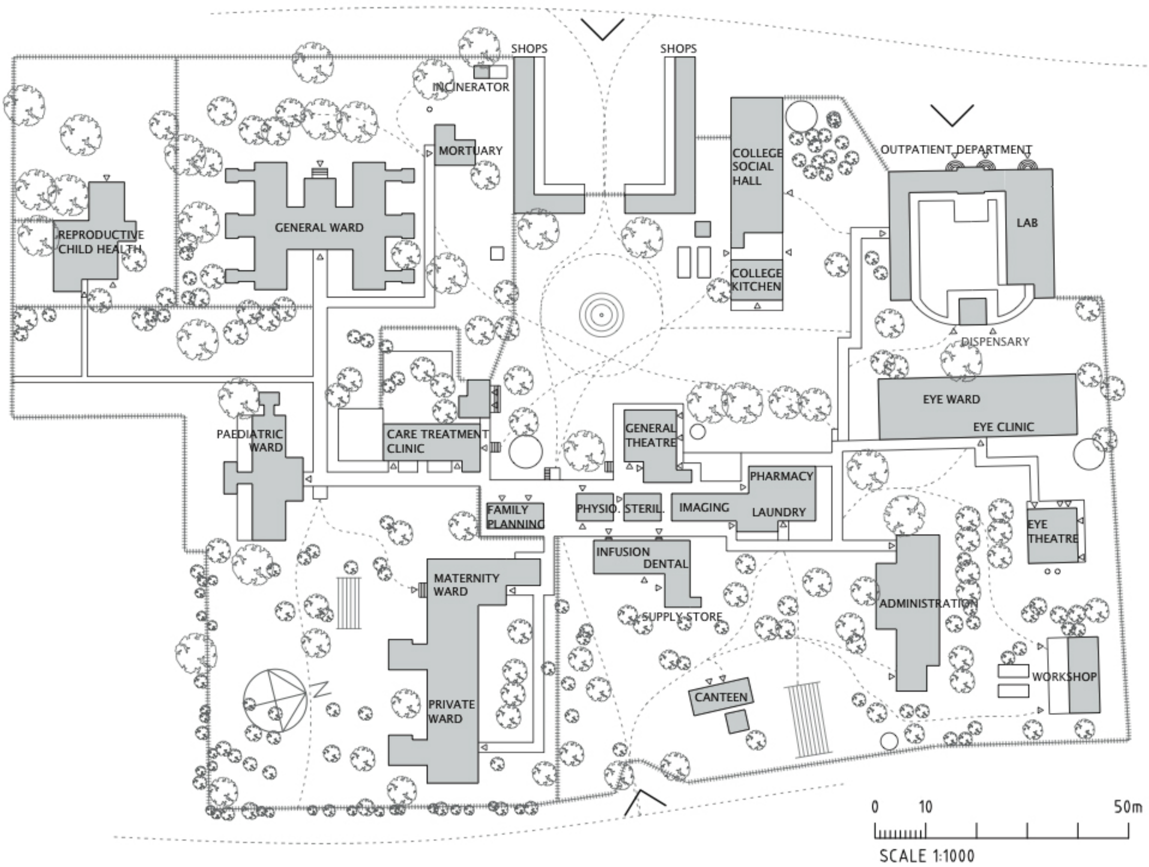

Figure 1.2: Overview of Kolandoto hospital

The loads are hence unevenly scattered around the hospital area in the different departments and are hereon referred to as critical loads.

1.3 Purpose

The purpose of this master thesis is to set a strategy for how to design UPS systems with feeding solar arrays to a hospital in East Africa with substandard national grid connection.

1.4 Delimitation

This work will exclusively treat issues related to designing UPS systems with a feeding solar panel. The thesis will further disclose problems related to designing said system on hospitals in Eastern Africa. Limitation to only hospitals is due to its crucial vulnerability to power outages. Batteries will be the only devices for energy storing, mainly due to the lack of other viable options which can easily be obtained in Eastern Africa.

Moreover will this thesis exclusively treat problems which are related to the local electrical system of the facility. Other electrical arrangement which are not directly affecting the UPS system nor the solar panel will be examined.

1.5 Issue clarification

The intention of this master thesis is to form a strategy for how to design solar cells and UPS systems on existing hospitals with substandard national grid connection in rural areas in Eastern Africa. The strategy shall also feature possibilities for future demand of expansion along with being an environmentally sustainable and safety orientated choice of strategy. The strategy will thus contain the following.

- How to approach different electrical arrangements on hospitals in Eastern Africa
- How UPS system for this application should be designed
- What components should be included and how they should be chosen
- How to integrate a new electrical system with an existing system
- How to expand an existing solar powered UPS system for future demand and optimization

2

Theory

2.1 UPS system

An Uninterruptible Power Supply (UPS) serves as a backup source of energy that protects loads whenever a fault occurs in the main utility. The power supply is referred to as uninterruptible since the fundamental objective of an UPS is to always be available and thus uninterruptible. An UPS can further also to serve as a suppressing filter from fluctuating frequencies and voltage spikes that may occur in the main grid. The UPS includes several power electronic components with different purposes. A rectifier that converts incoming AC power to DC, an inverter that converts the DC power back to AC, filters which suppresses fluctuating frequencies or elevated voltages and a backup source of power, oftentimes a battery. For accomplishing synergy within the UPS system there are several switches which direct the system between different modes [3].

The working principle of the UPS is to serve as an additional source of energy which is either stored (e.g. battery), generated during outage (e.g. diesel generator) or as a combination of both. The UPS is not only, as the name indicates, an alternative source of energy but can also operate as a complementary device for ensuring power quality. Depending on the technology the UPS can be modified to work for almost any amount of time, from few seconds to several hours, depending on the intended objective of the backup. For the short period serving UPS the objective is mainly to supply a critical load during the time it takes for an additional source of energy to start and for the longer time serving UPS systems the load is often smaller which then can be maintained by only a battery storage [4].

UPS systems are mainly referred to as static or rotary which aims to the system being backed by battery storage or rotating mechanical energy. The static UPS systems are further divided into three designs with different unique topologies and objectives, the online UPS (also know as double conversion), the offline UPS (further know as passive stand-by) and the line interactive UPS. The rotary UPS system will not be covered.

2.1.1 Offline UPS

The Offline UPS (figure 5.9) is the most elementary working UPS out of the three designs of static UPS. During normal operating mode the load is solely fed by AC power from the main utility provider and the storage battery capacity is charged. As the load is not isolated during this mode it is left unaffected in case of irregularities in the power quality and load could possibly be harmed. When a power outage occurs and the voltage is dropping a semiconductor switch will change the mode of the UPS and the load will instead be fed by the battery bank. The switching period is generally less than 10 ms and will not interfere with the functionality robuster load. The offline UPS may have a filter at the output voltage to compromise for the switching period [4].

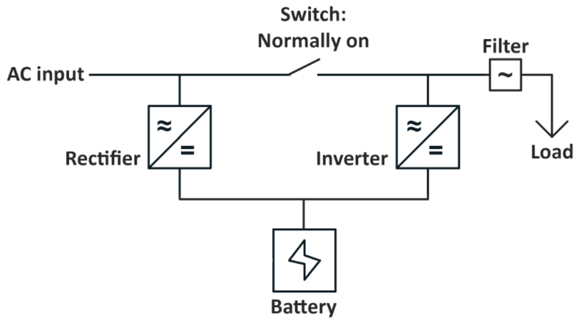

Figure 2.1: Topology of the Offline UPS

2.1.2 Online UPS

The Online UPS topology is similar to the offline UPS with a couple of exceptions. During normal mode the load is fed by the power utility with a power flow being both rectified and inverted. The disadvantage with this design is that the there will always be a power loss during the conversion but the provided power to the load will be superb. This since the rectifier is connected in series with the load which means there will be no transition time as for the Offline UPS. The rectifier must further be dimensioned to both supply the battery and the load unlike for the offline UPS were the rectifier were dimensioned for only the battery. When the voltage drops out of the preset tolerance threshold the battery together with the DC/AC inverter will continue to supply the load until the battery is discharged. The Online UPS often comes with a maintenance bypass making it easier to repair or inspect the UPS and still have the loads being fed by the main utility. The Online UPS topology is disclosed in the following figure [4].

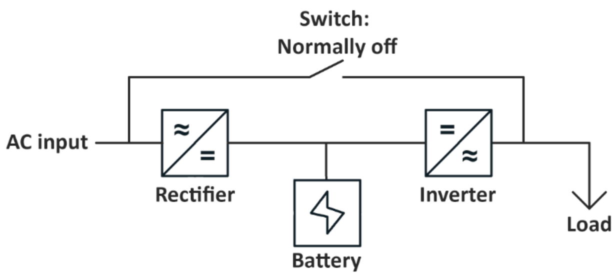

Figure 2.2: Topology of the Online UPS

2.1.3 Line interactice UPS

This topology differs from the previously described design mainly in terms of power conversions. Instead of having both a rectifier and an inverter the Line interactive UPS is equipped with a bidirectional converter. The line interactive UPS can work as an offline UPS or an Online UPS because of its design. During normal operation mode the utility is feeding the load and the battery bank. During this mode the bidirectional converter operates as AC/DC rectifier. When the power fails or the voltage moves out the thresholds band the bidirectional converter changes mode to DC/AC inverter and the static switch is opened in order to seclude the main grid. The main advantage of this design is its simplicity and the disadvantage is the same as for the offline UPS, the load is never completely isolated from a failing grid [4].

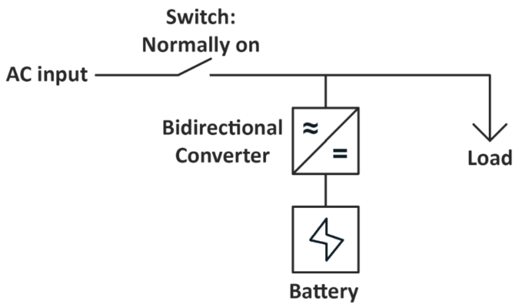

Figure 2.3: Topology of the Line interactive UPS

2.2 Photovoltaic system

The solar cell (photovoltaic cell) is an electric apparatus that converts sunlight to electrical energy. A solar panel consists of several solar modules which futher are comprised by many solar cells. Together does several solar panels make up a so called solar array. The cells are of semi-conductive material, often silicon Si, and aggregates a mass of p-n junction in the module. The process of how the electricity is generated follows in different steps. First a photon (radiation) is absorbed by the semi-conductive material. Then the material emits an electron making the electron free to either dispatch into heat, return to its initial state in the material or travel down the module until it reaches a conductive electrode. When the latest process is realized, in mass, a direct current is generated. The direct current is then directed straight to either a battery or through an inverter which converts the DC to AC so it can be consumed. Depending on the nominal voltage of the battery or the inverter the solar array might need to be constructed with the modules being connected in parallel or in series. This in order to achieve the system voltage of the inverter which oftentimes is either 12 V, 24 V or 48 V depending on the size [5].

2.3 Battery

There are mainly three battery technologies for battery storage which are used for UPS applications, the valve-regulated lead-acid battery (VRLA), the vented lead-acid battery (VLA) and the Nickel-Cadmium battery (Ni-Cd). The VRLA technology itself constitutes of two different designs, the gel electrolyte design and the absorbed glass mat electrolyte (AGM) design. The most outstanding difference between the two designs is the gel electrolyte design capability for deeper discharging as the AGM is more suitable for higher current feedings [5].

The working principle of the lead-acid batteries lays in the electrochemical reaction in the cells. A cell consists of two plates, cathode and anode (leads), and the electrolyte (acid) in between them. When the battery is discharging the active material of the lead and acid are releasing electrons and when the battery is charging the leads and acid are recombining the electrons within the cells. In theory this process could continue forever but due to corrosion in the surpassing grid and deterioration of the active materials the battery does eventually wear out. An additional factor which will eventually cause the battery to fail is the depth of discharge factor (DOD). The DOD has a great impact of how many number of cycles the battery can produce during a lifespan as the number of cycles are limited due to the tearing process described [5].

The working principle for the Ni-Cd battery i similar to the lead-acid battery with some exceptions. The most conventional Ni-Cd battery configuration is the pocket plate technology where the active materials (positive nickel hydroxide and negative cadmium hydroxide) are included within a pocket for nickel plated strips. The electrolyte can hence obtain free movement within each stack. The electrolyte is a water based solution, often potassium hydroxide and lithium hydroxide, and is exclusively used for ion transfer and is not chemically degraded during charging or discharging. The Ni-Cd technology is therefore one of the more longer lasting technologies as of today [6].

2.4 Climate impact in Eastern Africa

Eastern Africa is roughly described as all countries in between Eritrea in the north to Mozambique in the south. The conclusion consists of 18 countries and will hereon be referred to as Eastern Africa. Though all countries are located on tropical latitudes the different parts of Eastern Africa are exposed to different climate conditions. These different climate conditions are favorable to acknowledge when installing electrical equipments as they imposes different impacts. The different climate types are mainly the equatorial climate, the moist tropical climate, the dry tropical climate, the desert climate, the alpine climate and the monsoon climate. The recognition of the temperature and its influence on certain electrical equipments is necessary when designing UPS systems. Notably during the point of deciding the physical location of the constituting equipment since too high temperatures are generally harmful for the lifespan [7].

The battery is the most temperature sensitive part of the UPS system. An elevated temperature within the cells of the battery will cause the floating current acceptance to increase as the floating voltage is kept constant. Hence if the current requires an increase for charging the grid corrosion rate will also increase. An additional negative outcome of a risen temperature is the pressure within the sealed battery. An increased pressure will impact the ongoing chemical process during charge and discharge. The temperature level and its impact on solar module lifespan is however meager but not negligible. A high ambivalent temperature in combination with high radiance will reduce the efficiency of the solar panel. This due to a decreased voltage as a result of reduced band gap of the conducting material in the semiconductors. A high temperature itself is not particularly harmful for the panel, but in a shifting weather during rain season where temperature can shift dramatically the modules can take beatings as a result of thermal downshock [8].

The different climate condition does in addition bring different level of contamination. Contaminations are especially downgrading to the solar panels which loses efficiency when covered. Climates which is particularly leads to contaminations are monsoon climates, dry tropical climate and desert climate [7].

2.5 Grid stability

There are a great number of measures which can be carried out to establish a good sense of the stability of the grid. If the measures however are narrowed down to the ones which are of explicit interest for the the grid customers there are especially two key figures which are generally looked at, CAIDI (Customer Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index). Data in terms of number of customers in the grid, number of outages and power cutoff duration are statistics which are collected by the TSO (Transmission System Operator).

The most interesting index for system reliability estimation is CAIDI, the measure gives an estimate of how long the average power outage last for the average customer in the grid. The measure is also referred to as the average restoration time. The measure is essential for sizing the battery package of the UPS. Almost equally as useful is the SAIFI, though here the regularity of power outages are examined. The SAIFI reveals the number of times the average customer is experiencing a power outage annually. The SAIFI is especially convenient to acknowledge in the pursuance of evaluating the discharge frequency of the batteries [9].

3
Method

During the UPS- and solar power installation at Kolandoto hospital all events during the project were attended. By doing so it was assured that all the results which were significant for the strategy would be considered. Attendance during the entire project did further reassure reliability of the collected information and data. Prior to the initiation of the installation the general electrical system of the hospital were examined supposing to determine the widespread condition of the system and its design. The different options for housing of electrical equipments were also examined in pursuance of resolving the best fitted option to this specific project. Prior to the installation the different loads were investigated to ensure that their critical level was matched with the technical feasibility at Kolandoto hospital. The general strategy were then composed after the assembling of the results from the case study at Kolandoto hospital. First then were the taken measures fully convenient for formation of the the general strategy for eastern Africa in particular realised.

4
Result - Appliances

This chapter intends to present the necessary appliances to account for when using the strategy. Prior to an UPS installation, with potential of a solar panel feeding, it is important to recognize the central parameters which will frame the intended design. In order to determine these parameters, classifications must first be resolved. The intent of the following subchapters are to present the relevant parameters along with the associated classifications. All the parameters are classified as “A” being the most favourable and then decreasing consecutively, with an exception of the subchapter regarding classifications of loads where the classifications are not graded.

4.1 Classification of present electrical system

An examination of the condition of the electrical system in the hospital is decisive to carry out prior to an UPS installation, and also a solar power integration. Information needs to be gathered in order to establish a feasibility level for integration of new electrical arrangement. The quality and health of the electrical system for different areas of the hospital can be branched into three different classes depending on several factors. The definition of a electrical system for this subchapter concludes all electrical equipments which are installed in between the main feeding cable to the hospital and the outlets. The different classes are used to diagnose the system and to evaluate the need for improvements.

Class 1A

This classifications indicates that no improvement of the system is needed. The system is of a quality that imposes no risk of injuries to person nor damage to property. The system does seemingly not endure any compression of power quality nor any voltage drops due to its design. Conditions for this classification are as follow.

- Correct cable dimensioning according to the International Electrotechnical Commisions standards
- Isolated conductors
- Factual cable installation (no sharp edges etc.)
- Correct protection against intrusion, dust, water or accidental contact
- Protection by earth leakage circuit breakers and fuses
- Homogeneous grounding system

Any enhancement of systems with classification 1A is unnecessary since it is already of sufficient quality.

Class 1B
The second most sufficient classification is when improvements would be beneficial but is not a necessity. The system aggregates no or low risk of injuries to person nor damage to property. Class 1B further includes cases where parts of the system is of good condition but are in risk of deterioration that would introduce high risks of injuries to person or damage to property. The reasons for the deterioration could be high stress, installation conditions or environmental wear. Systems falling within this classification fulfill at least one of the following conditions.

- Incorrect cable dimensioning according to the International Electrotechnical Commisions standards
- Deficient isolated conductors
- Deficient installation of cables (sharp edges etc.)
- Faulty protection against intrusion, dust, water or accidental contact
- Insufficient protection by earth leakage circuit breakers and fuses
- Inhomogeneous grounding system

Enhancements of a system with classification 1B is favourable but not necessary. If enhancements are to be performed, the improvements which are necessary to not be classified as a 1C system should be carried out first.

Class 1C
The least favourable classification of electrical system is when improvements are required. The quality of the system could potentially cause injuries to persons and/or damage to property. In order to fall within this classification at least one of the following essential conditions needs to be fulfilled.

- Exposed conductors
- Major part of the installation has no protection against intrusion, dust, water or accidental contact
- Major part of the installation has no protection by earth leakage circuit breakers and fuses
- Inadequate grounding system
- Overloading of conductors

In areas of the hospital where explosive or other hazardous materials are located these criteria should be examined with extra cautious due to its possible devastation. If no earth leakage circuit breaker is installed in moist areas the 1C classification is given due to the increased risk. Enhancements of the system with this classification is seen as necessary and should be performed prior to any other new installation.

4.2 Classification of surroundings of climate sensitive equipment

The housing designs and its condition is an important measure which needs to be comprehended in order to establish a good sense of the surroundings of the UPS equipments. The houses that make up the hospital may at times be of poor standard and even houses which are newly built may lack basic capabilities to house an UPS system. There are especially three parameters which needs to be considered when choosing the space for installation; max temperature, temperature variation and airflow. The specification of these three parameters are essential to comprehend prior to installation of climate sensitive equipment. Climate sensitive UPS equipments are primarily referred to as batteries, but can also be inverters. Depending on the state of the parameters one has to determine what kind of insulation, ventilation and cooling which is necessary to install in order to have the system last as long as possible. The classification are accounting for areas in the hospital which are already existing and not areas which needs to be built prior to the installation.

Class 2A
This classification is set to be the most optimal surrounding for the equipment. This space is equipped with a good ventilation which will keep the airflow consistent throughout the day. The room also lacks windows which will have the outside sun radiance not being reflected into the room. The space is also good isolated which will have the temperature difference between maximum and minimum being as small as possible. The walls and ceilings are of such condition that water nor evaporation can be penetrated into the room. The ambient temperature in the room is under normal conditions from 15 °C to 28 °C.

Class 2B
This classification is when the surrounding is decent enough to house the UPS but still needs improvements in order to maintain the durability of the equipments. The room might have a window which will result in extra heating as a result of radiance. The isolation is mediocre making the temperature in the room differentiating substantially between maximum and minimum throughout the day. The condition of wallings and ceilings are moderate but not perfect. The doors and walls might have disparities and the ceiling could have defection such as damages caused by damp. The ambient temperature in the room is generally over 28 °C.

Class 2C
The least favorable classification is class 2C. This class conclude housings which need great improvement in order to fulfill the requirements obligated to store UPS equipments. The housing has heavy exposure towards the sun making the room being heated quickly. As a result of the poor insulation the maximum and minimum are differing extensively. The ceilings and walls has plenty of faultiness and are in need of enhancement like changing of doors and/or coverings of the windows. The ambient temperature in the room is under normal conditions over 28 °C.

4.3 Classification of solar panel arrangement

In furtherance of a solar panel installation there are several factors which needs to be recognized. The foundation for this classification will lay in the availability for placement, the distance to inverter, the possibility for good cardinal orientation and the level of security. When considering the availability for placement it is preeminent to have a location which is secluded from non-authorised, preferably on top of a building or within a fenced area. This is not only important due to safety reason but may also be convenient when considering the prospect of theft. The orientation aspect is an additional parameter which needs to be recognized. The placement should preferably be installed in a manner that is at most efficiency to the sun orientation throughout the day along with never being shaded by nearby obstacles like trees or buildings. The distance in between the solar panel and the inverter is an additional parameter which needs to be comprehended. This parameter will found the essential framework of the installation as the distance needs to be sufficient enough to not compromise for any drop in the voltage level.

Class 3A
The classification of which lays the most favourable base for a successful solar panel installation is classification 3A. The placement is a closeby secure place where there is no shading throughout the day.

Class 3B
The moderate classification is when some compromising may need to be completed in order to have an efficient placement of the panel. The bearings of the roof might not be of satisfying condition and/or the panel might be too accessible for non-authorised. The physical orientation of the panel might be imperfect but still tolerable.

Class 3C
The least supportive classification originates several complications in need of settlement prior to an installation. In the pursuance of having an ample voltage level the parameters which sets a good solar panel installation needs to be enhanced. The enhancement might be to construct a fence secluding the panel or strengthen the bearings of the supporting roof. The enhancement could also be to cut down trees to avoid shading. This classification is also given when there are no clear evidence that it is feasible to install a solar panel.

4.4 Classification of power outage regularity

Information regarding the grid stability of the power provider is important to acknowledge. This is especially essential when deciding upon the dimensions of the UPS and the feeding solar panel. The main objective of the UPS is to compensate for power outages but are also to protect from other already stated obstacles that may occur. The number of power outages and each specific duration is vastly deviating depending on the geographical position. It is hence of decisive importance to establish a sense of the occurring factor of blackouts for the hospital. Conducive to classify the feeding stability of a specific situation, classification may correspond approximately to each class. The following table gives a summary of the classification of regularity of power outages where 4A represent a mediocre year for a Swedish grid operator to a 4C being a rough year for the Tanzanian grid operator Tanesco.

Table 4.1: Summary of classifications of regularity and length of power outages.

	CAIDI		
SAIFI	**6 min**	**12 min**	**24 min**
4 >	4A	4A	4B
4 - 25	4B	4B	4C
25 <	4C	4C	4C

The classifications are developed in collaboration with Göteborg Energi where the target indexes are less than 4 and 6 respectively for SAIFI and CAIDI.

4.5 Classification of load

The essence of integrating loads to an UPS system lays in the weight of labeling the different loads. Three load categories are adopted; the critical-, the semi-critical and the non-critical load. Together with these load categories are the categories of which how the loads are located and spread across the hospital.

<u>Critical load</u>
These are the most important loads of the hospital. In case of a power outage, the absence of these loads may threaten any patients well-being and significantly complicate any ongoing life preserving activity or operation. The fundamental loads in this category are equipments, machines and lights which are essential for any surgical activity or medical treatment. The loads could potentially consist of anaesthesia machines, baby warmers, operation lights, operation beds, suctions machines or electrosurgical devices.

<u>Semi-critical load</u>
The loads for this category includes equipments necessary for the daily operation of the hospital, but are not life supporting. The absence of these loads are not threatening the well-being of any patient but complicates any ongoing treatment. Equipments like computers, routers and internet receivers are further included in this category due to their necessity for performing administrational tasks. Laboratory equipments for diagnosing patients or storing test samples are also included in this category. As these loads are not essential for life preserving activities they are not considered to be critical, but are however considered as semi-critical as they constitutes a significant importance for the necessary daily operations of a hospital.

Non-critical load
The least critical loads are categorized as equipments that is neither considered as a necessity for operating a hospital nor being a requirement for life preserving. Equipment for maintenance such as laundry machines, vacuum cleaners and sterilization machines are included in this category as an absence of these function would not have any major influence of the hospital activities. These loads are roughly described to be boosting comfort of the hospitals patients and workers.

Apart from categorizing loads after their gravities it is also imperative to acknowledge the actual location of the loads and their quantities. This is especially needful when deciding upon the modelling of the UPS system, whether it should be centralized or in what extent it could be decentralized. The feeding loads are generally widely spread over the hospital and should therefore have their composition of different load categories represented as densities. Hence three classes for load concentration is introduced.

Class 5A
This classification indicates a feeding location of the hospital where a significant percentage of the critical load of the hospital is located. The feeding location could possibly be a room for surgical operations or a ward for premature births.

Class 5B
The second classification is for feeding locations which could have a few critical loads but for most parts constitutes of semi-critical loads. The location could be a laboratory, a specialist department or an administration for billings.

Class 5C
The most common classification for feeding locations is where there are no critical loads but could have a few semi-critical load but mainly constitutes of non-critical loads. A location of this classification could be a general ward, a waiting area or a cafeteria.

4.6 Classification of need for power quality stabilization

The quality of the incoming power and its correlation to the sensitivity level of the loads are essentials which needs recognition before designing the UPS system. Different loads have different thresholds against variation of power quality and can in worst of cases breakdown or malfunction during an event of insufficient power quality. To found a good sense of the power quality, measurements should ideally be carried out over long periods of time. But as long periods of data collection could be impractical this particular approach of classification will presume the possibility measuring periods of at least seven days. The data collection will exclusively hold interest in voltage- and frequency variations. The voltage- and frequency variation are two parameters which could easily be obtained through a multimeter and gives the uppermost indications of power quality. The classifications of the power quality will further be combined with the sensitivity of the loads. The classification will be carried out by setting the ranges for the voltage- and the frequency variations and categories for the sensitivity of the loads. When this is done a classification of need for power quality stabilization can be done.

Voltage variation

When examining the voltage level there are three different ranges of voltage to look for, whether or not the ranges has been exceeded or not will determine the voltage level score of the measured voltage. The most preferred voltage level to acquire is a level within ±8% from nominal voltage and are referred to as range 1. If the voltage have exceeded this frame but still has not gone outside the range of -30% and +15% from the nominal voltage the frame becomes a range 2. If the voltage has exceeded the range of -30% or +15% the range is referred to as range 3. A summary for the different frames and their appointed range is stated in table 4.2. The levels for voltage variation of ±8% are taken from the Swedish Electrical Board of Safety and appoints a voltage level within the range as reasonable nominal voltage. The voltage level of range 2 are appointed as a result of functionality of the different UPS designs [12].

Table 4.2: The voltage frames and their corresponding ranges from 1 to 3.

Nominal voltage	**Range**
$15\% < U$	3
$8\% \leq U \leq 15\%$	2
$-8\% < U < 8\%$	1
$-30\% \leq U \leq -8\%$	2
$U < -30\%$	3

Frequency variation

The second parameter to look for in the collected data is the frequency and whether or not it has exceeded 0.1 Hz. The frequency variation in Sweden is tolerated up to 0.1 Hz from the nominal frequency and will lay the foundation for this classification. The ranges are appointed in the same manner as for the voltage ranges, see table 4.3. If the frequency deviation once during the measuring was greater than 0.1 Hz the assigned range is Y or else it is assigned X.

Table 4.3: The frequency frames and their corresponding range from X and Y.

Nominal frequency	Range
$0.1Hz < f$	Y
$-0.1Hz \leq f \leq 0.1Hz$	X
$f < -0.1Hz$	Y

Load sensitivity
The loads fed by the UPS are divided into three different categories, Robust-, Sensitive and Especially sensitive loads. The categorisations are each referring to the level of withstands from insufficient power quality. The robust loads are loads which never breaks or malfunctions when experiencing bad power quality. Sensitive loads are loads which might break and be damage or malfunction by insufficient power quality and especially sensitive loads refers to loads which run a high risk of breakdown or malfunction when undergoing low levels of power quality. The Robust load category is referred to as category A, Sensitive load as B and Especially sensitive load as category C.

Table 4.4: Categorisation of the sensitivity of the loads.

	Category
Robust load	A
Sensitive load	B
Especially sensitive load	C

When the ranges are settled for the voltage- and frequency variation and the categorisation of the load sensitivity the factual classification can be carried out. When setting the classification of the need for power quality stabilization the following table 4.5 is adopted. Together with the ranges for voltage- and frequency variation and the categorisation of the load sensitivity a classification can be determined. The classification 6A corresponding to all combinations with green, 6B for all orange combinations and 6C for all red combinations.

Table 4.5: Summary of all possible combination of voltage, frequency and load sensitivity with corresponding classification color.

A1X	B1X	C1X
A1Y	B1Y	C1Y
A2X	B2X	C2X
A2Y	B2Y	C2Y
A3X	B3X	C3X
A3Y	B3Y	C3Y

6A
6B
6C

Classification 6A express an unnecessary need for any stabilization equipments and class 6B points towards are strong consideration to include power quality assuring functions into the UPS system. Class 6C does apart from 6A and 6B requires a stabilization unit to comprehend any scanty power quality

5
Result - General

This chapter describes how the UPS system should be designed for a specific case with different preconditions. The application of the appliances from chapter 4 are first described. When the tools have been adopted and the classification of the hospital for each specific category is known the design topologies are described in section 5.3. In section 5.4 more specific design choices and the sizing of each component are coordinated.

5.1 Fulfillment of appliances

In chapter 4 “Result - Appliances” the necessary tools, with each variation of classifications, were compiled in furtherance of setting the framework of the strategy. Collection of necessary data and information is however required in order to determine what class in each appliance that should be adopted. Guidelines on how to gather these informations are therefore required.

5.1.1 Electrical system

Information regarding the health of the current electrical system should be collected by a thorough investigation on each area of the hospital which may be included in the UPS system. The first step in the examination is an optical observations. This is decisive in contemplation for detecting exposed conductors and in general poor installations. Signs of a poor installation could be cables strapped around sharp edges or improperly installed cables. Secondly should the protection level of the installation be examined by investigating the isolation of cables and sockets. If information regarding the classification of the protection level of the hospital can be collected it should be evaluated if it may be of concern for the UPS installation. If no information of the protection classification is available an optical investigation should be carried out. If recent documentation of the electrical installation is available it should be consulted during the investigation. The protection of the system should be determined by investigating the fuses and testing the earth leakage circuit breaker. In preference to a self-organized investigation of the electrical system, the company which initially carried out the installation of the electrical system could be contacted for collection of further information.

5.1.2 Surroundings of climate sensitive equipments

Investigation of the housings is necessary for determination of its potential influence on the sensitive equipments which is included in the UPS. The first thing which needs to be done is to establish a dialogue with the hospital management. This since they have a good sense of where would be a good place for storage without interfering with future plans of reconstruction of buildings or with the hospitals daily activities in particular. Preferably a few options for storage should come out of this discussion. Second step is to review the options and determine which is the most suitable for the situation. Temperature plays an important role in the decision making and in order to determine this it is recommended to use a thermometer which logs the temperature throughout the day. Then it is possible to get a decent sense of how the temperature behaves in the room. When choosing a location it is further good to acknowledge its exposition. Since the equipments concluding the whole UPS system might impose a hazard risk if the location were to have unauthorized personnel working close by. Therefore it is favourable to have a storage which has a lock and do not interfere with any other function of the hospital.

5.1.3 Solar panel arrangement

The key essence of determining the placement of the solar panel is to have it exposed to the sun for as many hours as possible throughout the day. It is then commending to first recognize the cardinal directions in order to realize in what direction the sun is rising and setting. Fortunate for eastern Africa and especially for locations close to the equator is that the direction is of little matter for the efficiency of the . This is due to the fact that the average sun movement from east to west over the day is a straight direction and not circular as for areas further away from the equator. Thumb rule is however to strive for having the directed in a northern direction if the hospital is located south of the equator and vice versa. Similar to the placement determination as for the previous section, a dialogue with the hospital management is the best approach to have when deciding the location. This as they will likely know best in what condition the ceilings are and where the could be place without risking unauthorized persons interfering with them.

5.1.4 Power outage regularity

In Eastern Africa there are a large number of power providers and the specific provider which is feeding the hospital should be contacted prior to any determination on UPS design and dimension. This is important since it is of great gravity to acknowledge at what regularity the UPS will operate. It is custom for utility companies to document information about the number of power outages per year and the average duration of each outage. These information and data is generally not considered to be classified by any means and should hence be of little effort to acquire. If complication should arise the hospital personnel together with the local inhabitants may be able to approximate the necessary information about the outages and its regularity and duration. Load shedding is a measure which the power providers sometimes adopts in order to maintain grid stability. This is especially important to acknowledge due to the risk of battery drain during these events.

5.1.5 Load

To determine the classification of the loads of the hospital a thorough investigation should be conducted in all affected areas of the hospital. Operation theatres and patient wards should be examined first and most thoroughly followed by laboratory and administration areas. Medical staff should if possible be present when investigating the different areas to explain the use of equipment when there is doubt on its function. When performing the investigation each equipment should be analyzed and its function should be documented as well as a preliminary classification. After the entire hospital has been investigated the documentation should be revised and a list of all equipments with correct classification should be made. The list should be presented to knowledgeable staff at the hospital so that they can validate that all equipment classifications are correct and suggestions from the staff should be documented. The suggestions from the staff should be comprehended and corrections to the lists should be made accordingly in order to make a final list that later will be used to decide which equipment should be included in the UPS-system. All loads which together with the medical staffs are considered to be non-critical equipments should be re-advised.

With the information about the load classification a decision can be made of which loads should be included in the system. The physical location of each load also affects the decision making. In order to make the information more manageable it is necessary to make groups of individual loads based on their physical location. The first step in the grouping is to collect all loads located in the same room and put them in a group. If the hospital consist of several smaller houses the groups from the rooms should be made into groups of the loads for each house.

5.1.6 Need for power quality stabilization

In order to determine the sensitivity level of the equipments underlying the UPS, each specific load needs to be investigated. The first step of doing so is to look at all the loads which are to be included. The load with the highest level of sensitivity precaution will set standard for all of the loads. Loads which are generally not sensitive are lights and loads which are particularly sensitive are heart monitoring machines and x-rays. It is difficult to set a general guideline for all different loads and their individual sensitivity level which is why datasheets should be examined for the equipment when the level is uncertain.

Determining the quality of the frequency and the voltage requires practical electrical knowledge. First an outlet or a junction box has to be located. The measurements of the frequency can be carried out at any outlet or junction box but the voltage measuring should preferable be carried out at the junction box where the UPS most likely will be installed. The measurements are preferably carried out by using a logging multimeter but any other device with the same function is sufficient.

5.2 Design alternatives

As an additional, yet necessary, supplement to the strategy is to determine how the UPS should be design to in a the most effective way suit different load demands and other surrounding restraints which needs to be comprehended. In this section nine different design topologies are proposed and later in subchapter 5.3 the process of deciding on which to use will be described. A summary of the following design alternatives are revealed in table 5.1.

Table 5.1: Summary of the nine different design alternatives and their disparities

1-phase system
3-phase system

	Solar secluded from UPS		**Solar included in UPS**		**Separately integrated solar**	
Centralized system	1A	1B	2A	2B	3A	3B
Decentralized system	1C		2C		3C	

1A - Centralized three phase UPS without solar power

This option includes a UPS system that is centralized and not primarily located close to the loads. The system is dimensioned to supply all loads in the hospital and no separation between critical loads and non-critical loads is done. The UPS system uses three phase power as input and output power. The system can be adopted without installing any additional wiring to the loads. Solar power is not included in this design proposal.

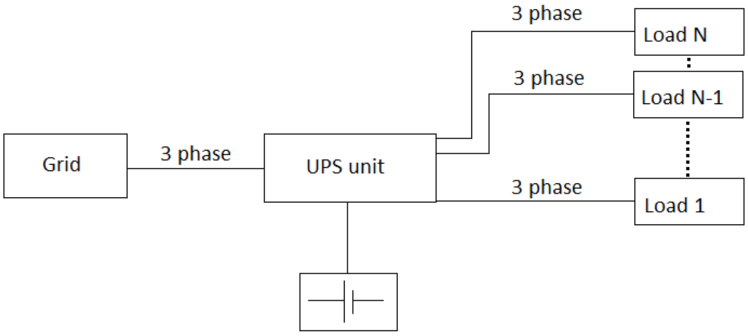

Figure 5.1: Centralized three phase UPS without solar power

1B - Centralized single phase UPS without solar power
This option includes a UPS system which is centralized and not primarily located close to the loads. The system is dimensioned to supply all loads on one phase. Separation can be made between critical and non-critical load by connecting all critical loads to one phase. The UPS system uses one phase power as input and output power. Rewiring may be needed in order to collect all the critical loads on one phase. If the hospital uses a one phase system already no rewiring needs to be done. Solar power is not included in this design proposal.

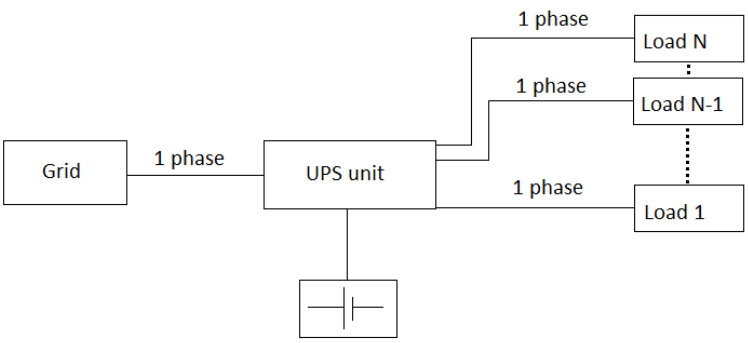

Figure 5.2: Centralized single phase UPS without solar power

1C - Decentralized single phase UPS without solar power

The options include one or multiple UPS systems that is located close to the loads. The systems are dimensioned to supply the loads that is connected to each individual UPS system. Separation between critical and non-critical loads can be made by only connecting the critical load at the load location. The individual uses primarily one phase power as input and output but three phase power solutions may be required in special cases if three phase equipment is considered critical. Rewiring may be needed to separate critical loads from the non-critical. No solar power is used in this option.

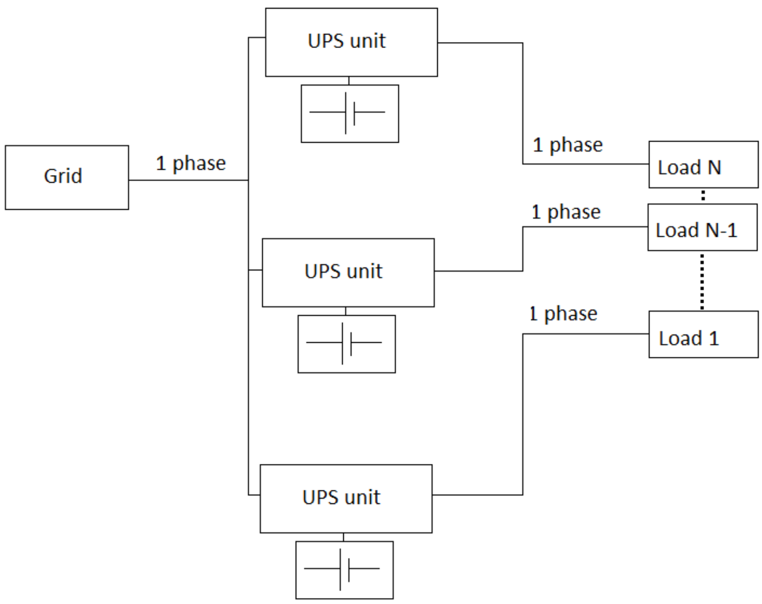

Figure 5.3: Decentralized single phase UPS without solar power

2A - Centralized three phase hybrid UPS with integrated solar power
This option includes a UPS system that is centralized and not primarily located close to the loads. The system is dimensioned to supply all loads in the hospital and no separation between critical loads and non-critical loads is done. The UPS system uses three phase power as input and output power. The system can be used without doing any additional wiring to the loads. Hybrid UPS unit is used to utilize solar power. The solar panel is connected to the UPS system and the solar power is automatically distributed by the UPS unit.

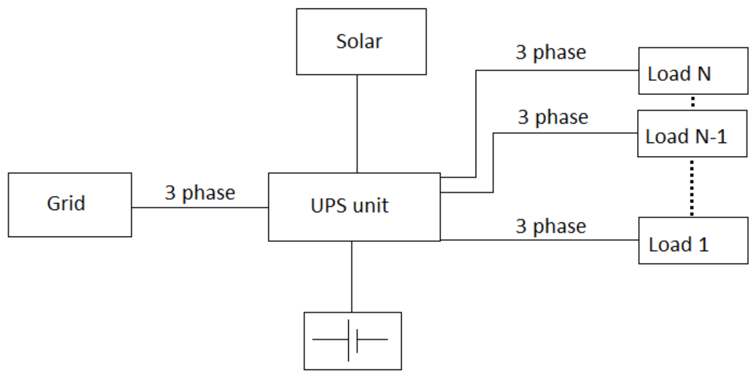

Figure 5.4: Centralized three phase hybrid UPS with integrated solar power

2B - Centralized single phase hybrid UPS with integrated solar power
This option includes a UPS system that is centralized and not primarily located close to the loads. The system is dimensioned to supply all loads on one phase. Separation can be made between critical and non-critical load by connecting all critical loads to one phase. The UPS system uses one phase power as input and output power. Rewiring may be needed in order to collect all the critical loads on one phase. If the hospital uses a one phase system already no rewiring needs to be done. Hybrid UPS unit is used to utilize solar power. The solar panel is connected to the UPS system and the solar power is automatically distributed by the UPS unit.

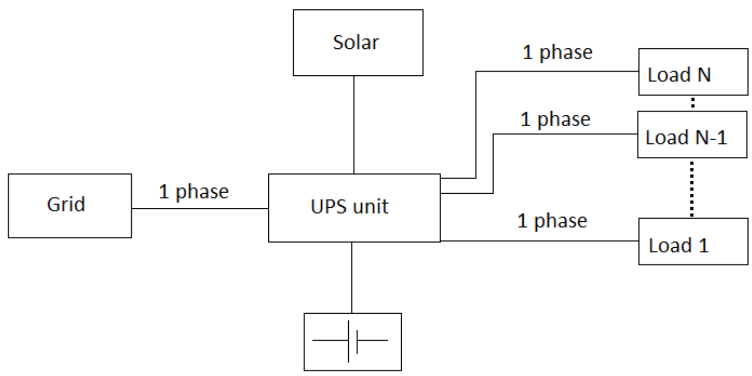

Figure 5.5: Centralized single phase hybrid UPS with integrated solar power

2C - Decentralized single phase hybrid UPS with integrated solar power
This options include one or multiple UPS systems that is located close to the loads. The systems are dimensioned to supply the loads that is connected to each individual UPS system. Separation between critical and non-critical loads can be made by only connecting the critical load at the load location. The individual uses primarily one phase power as input and output but three phase power solutions may be required in special cases if three phase equipment is considered critical. Rewiring may be needed to separate critical loads from the non-critical. Hybrid UPS units is used to utilize solar power. The solar panel is connected to the UPS system and the solar power is automatically distributed by the UPS units.

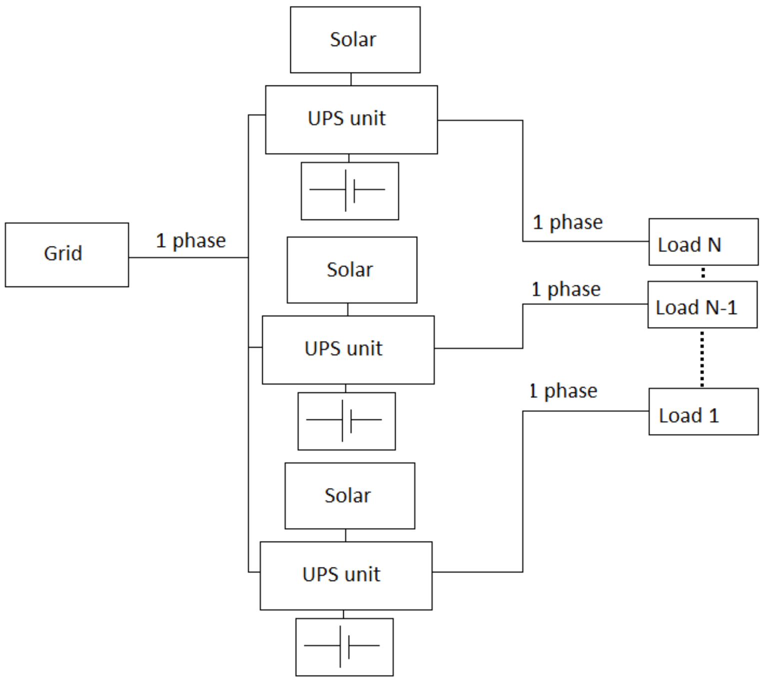

Figure 5.6: Decentralized single phase hybrid UPS with integrated solar power

3A - Centralized three phase UPS with separate solar power
This option includes a UPS system that is centralized and not primarily located close to the loads. The system is dimensioned to supply all loads in the hospital and no separation between critical loads and non-critical loads is done. The UPS system uses three phase power as input and output power. The system can be used without doing any additional wiring to the loads. A separate solar inverter is used to utilize solar power. The solar inverter is connected between the UPS system and the main incoming feeding utility.

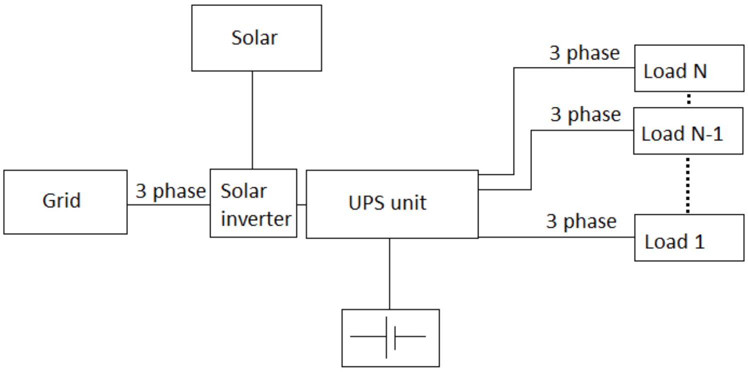

Figure 5.7: Centralized three phase UPS with separate solar power

3B - Centralized single phase UPS with separate solar power

This option includes a UPS system that is centralized and not primarily located close to the loads. The system is dimensioned to supply all loads on one phase. Separation can be made between critical and non-critical load by connecting all critical loads to one phase. The UPS system uses one phase power as input and output power. Rewiring may be needed in order to collect all the critical loads on one phase. If the hospital uses a one phase system already no rewiring needs to be done. A separate solar inverter is used to utilize solar power. The solar inverter is connected between the UPS system and the main incoming feeding utility.

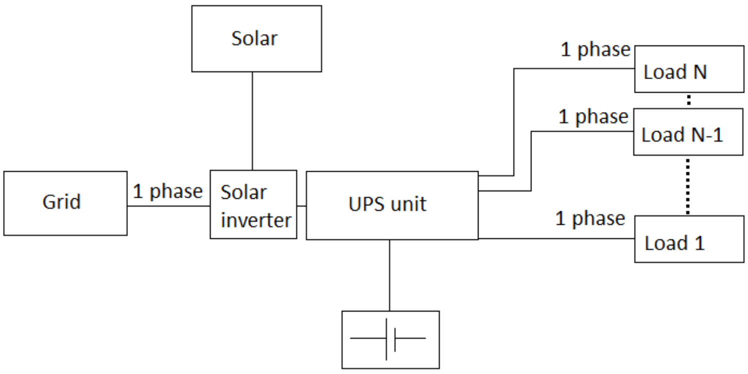

Figure 5.8: Centralized single phase UPS with separate solar power

3C - Decentralized single phase UPS with separate solar power
The options include one or multiple UPS systems that is located close to the loads. The systems are dimensioned to supply the loads that is connected to each individual UPS system. Separation between critical and non-critical loads can be made by only connecting the critical load at the load location. The individual uses primarily one phase power as input and output but three phase power solutions may be required in special cases if three phase equipment is considered critical. Rewiring may be needed to separate critical loads from the non-critical. A separate solar inverter is used to utilize solar power. The solar inverter is connected between the UPS systems and the main incoming feeding utility.

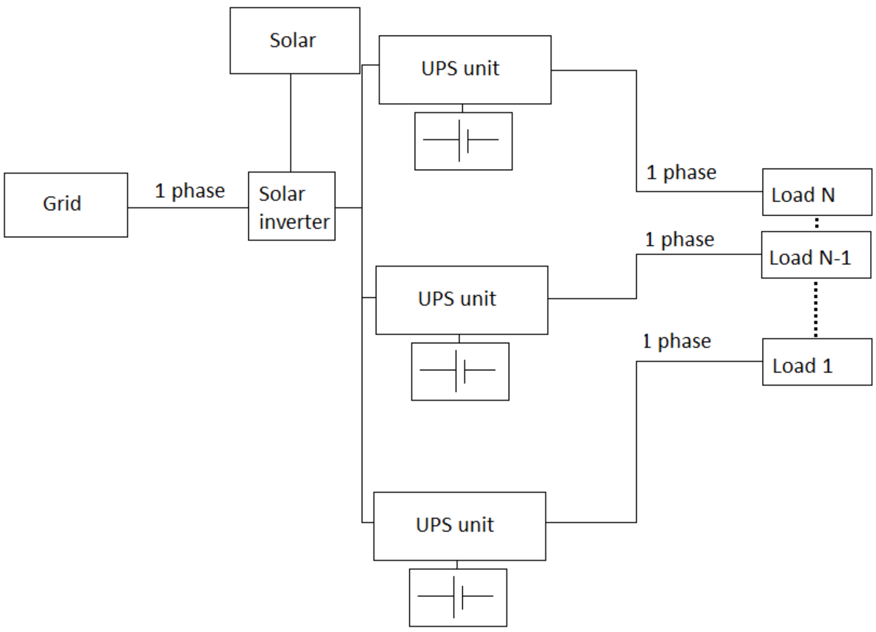

Figure 5.9: Decentralized single phase UPS with separate solar power

5.3 Design decision

In this chapter the processes of determine what UPS system to choose is described. In figure 5.10 a map including four binary options are disclosed together with nine resulting UPS systems to follow. The outlining map guides in deciding upon a suitable system design for an individual purpose with particular conditions. The resulting nine UPS system are disclosed in subchapter 5.2 and the decision making of the four binary options are advised in the following paragraphs.

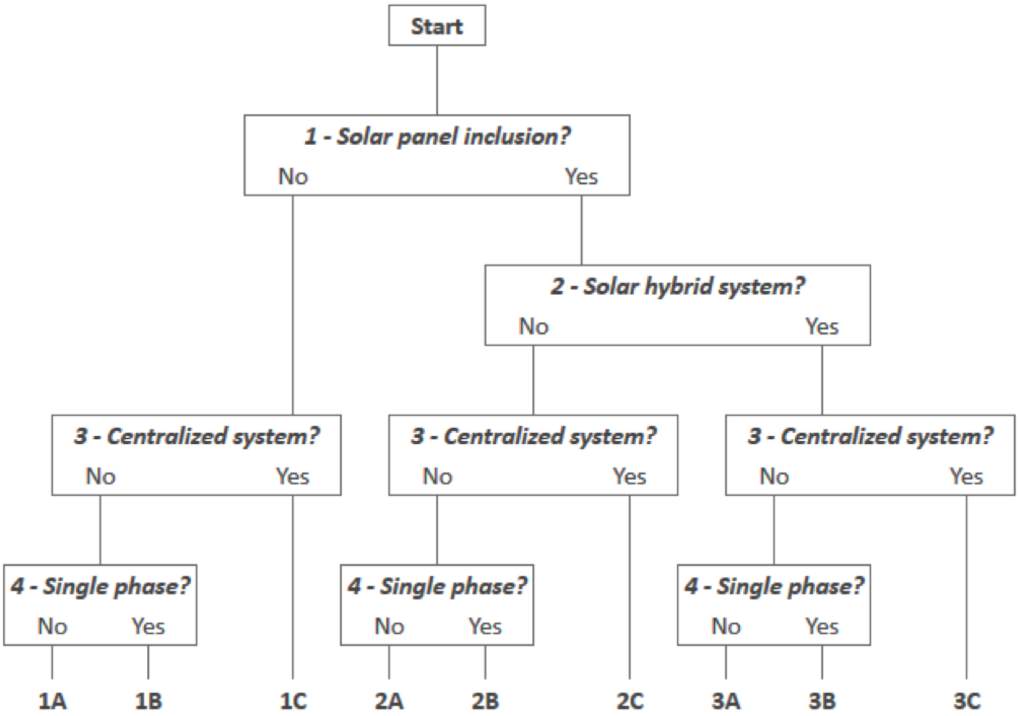

Figure 5.10: Orientation map for design alternatives

1 - Solar inclusion vs. solar exclusion
Including a solar panel in a UPS system is generally a beneficial measure to adopt for the sake of having the system further vigorous. The system will hence lengthen its duration during a power outage as the stress and discharge rate of the battery bank is decreased. An inclusion of solar panels in the UPS system could furthermore be beneficial economical vice as the power consumption from the main utility is lowered, which is the case either if the solar panels are integrated separately into the hospital or integrated through a hybrid system.

The first step into making a decision of whether or not to include solar panels is to investigate the physical constraints of the hospital site. It is hence decisive to locate a proper place on the hospital site that can support the solar panels and which can provide a sufficient cardinal orientation along with an efficient tilt. The process of exploring the feasibility is described in section 5.1.3. The next step is to set at classification of the feasibility (which is described subchapter 4.3). If the physical constraints are negligent and the classification is appointed to be 3A solar panels should be included in the system. If the classification were to be 3B the advice would pursue to be to include solar but with the recommendation to utilize the feasibility if future expansion of solar panels were to be considered. If the classification were to become 3C however, solar panels should not be included in the system. The physical constraints would then be too substantial to comprehend and could possibly drive the focus from the UPS system installation as a whole to instead focus on dealing with solar arrangement obstacles.

2 - Solar hybrid system vs. separate units
The question lays in the decision making of either having the solar panels included in the UPS system, by hence forging a solar hybrid system, or integrating the solar panels separately into the hospital electrical system. Having the solar panels separated and thereby using a separated inverter is advantageous since it gives the possibility of distributing the power to a specific area of the hospital where it is needed. With the solar hybrid system the solar panels is however restrained to only feed loads which are supported by the UPS functionality of the system. By having a hybrid solar system the potential of further not consuming all produced energy is possible, this since the s are only directed to specific loads. By determining what option to go forth with the concentrations of the hospital loads and their critical level needs to be investigated. The process of collecting necessary information to classify different parts of the hospital is described in sector 5.1.5 and the actual procedure for classification is described in subchapter 4.5. When the different parts of the hospital has been classified the determination of what out of the two solar power integration models can be realized.

The intention of the UPS is to mainly feed the locations of the hospital which is classified as 5A. If the classification of 5A is widely spread across the hospital separated solar panel integration option should be adopted. This in order to benefit as much as possible from the solar panels. If the classification of 5A however is concentrated to one or a few areas and the rest of the hospital is classified as 5B or 5C the hybrid option should be chosen. This in order to ensure that all generated solar power is used as close to the maximum capacity as possible

3 - Centralized system vs. decentralized system
A centralized UPS system is a solution where a single UPS is installed in the pursuance of feeding larger or all parts of the hospital from preferably a centralized location or close to the incoming feeding utility. All the critical loads are hence fed by one single UPS unit. The centralized system has the benefit of lowering the necessity of being precautious when adding loads to the system. This as the there will not be any sockets intended for specific loads exclusively as all loads are fed by the UPS.

The opposite of a centralized UPS system is the decentralized UPS system. The decentralized UPS system is a solutions where one or several UPS units is placed near a load location. The individual UPS units are dimensioned to support the loads that are connected to it. It is therefore possible to have different ratings on the units depending on the size of the connected loads. A decentralized system requires users to have provision when to connecting additional loads to the UPS. Sockets connected to the UPS should therefore be marked accordingly to lower the risk of confusion.

The first step to decide whether to use a centralized UPS system or a decentralized UPS system is to first look at the distribution and the critical level of the loads at the hospital. The practical manner of collecting essential information to classify different parts of the hospital is described in sector 5.1.5. The actual procedure for classification is then described in subchapter 4.5. If a majority of the hospital is of the same load classification (5A, 5B or 5C) and there is a low number of areas with classifications that diverge from the rest of the hospital areas a centralized UPS system should be chosen. If however there is a high diversity of load classifications throughout the hospital a decentralized system should be chosen. Decentralized UPS systems are hence preferred when areas with classification 5A is spread out.

4 - Single phase vs. three phase
The deciding of whether or not to go with a single phase UPS system or three phase UPS system is heavily depending on the formation of the current electrical system. If the current electrical system is one phase then the UPS should be a one phase UPS and the same goes for three phase. A three phase UPS system could be considered if the hospital are planning to in the near future to upgrade to a three phase system. This does however requires the feasibility to access a three phase junction for input of the UPS even though the electrical system of the hospital is using only one phase.

5.4 System dimensioning and optimization

In subchapter 5.3 the guidance of selecting a UPS system design was deliberated and in this chapter the design will further be refined through dimensions and optimizations. Featuring this subchapter is the determination process of what components of the UPS system to choose. The purpose of this subchapter is hence to highlight the important design decisions which has to be made to achieve a fulfilling UPS system. To facilitate the dimensioning and optimization process the appliances for classifications, described in chapter 4, are presumed to have been resolved. There are essentially three dimensions which has to be carried out; the UPS unit, the battery bank, the solar panel along with their inverter. In addition to the dimensions there are two optimizations which might need to be considered; cooling and installation.

5.4.1 UPS unit

As there are several UPS technologies to chose among it is essential to acknowledge their differences and learn when to use what technology. The following paragraphs aims to described this but also how to set the sizing of the UPS among with extra functionalities which might be included in the UPS.

Topology
There are several different UPS topologies which all have different properties and functionalities. All of the topologies provides a basic protection against power outages but also have specific properties that enable specialized solutions during deficient power quality. The main parameter to comprehend is the load requirement for power quality stabilization. Depending on the objectives of the UPS installation the demand for power quality stabilization will vary. It is then imperative

to examine the power quality prior to appointing a topology. The classification of the power quality is detailed in subchapter 4.6 and the complementary procedure of determining the power quality is addressed in section 5.1.6. The three types of UPS topologies are delimited to static topologies exclusively and are described in subchapter 2.1. In addition to the these is the possible incorporation of solar power integration to the UPS. The UPS topology will hence be chosen in accordance to the classification of need for power quality stabilization and the UPS system design alternatives from subchapter 5.4.

The non-solar hybrid UPS systems includes the design alternatives 1A-1C and 2A-2C. If the classification of 6A is given to the need for power quality stabilization the offline UPS unit should be adopted. This since there are no obvious demand for stabilization of the power quality in which the offline UPS topology could not handle regardless. If the classification is 6B however the line interactive UPS should be chosen. This is essentially recommended since this topology provides a moderate voltage level control and can suppress frequency deviations. When classification 6C is given the Online UPS is recommended since it can handle voltage deviations of greater magnitude than the line interactive UPS. By having a line interactive UPS when the classification is 6C could lead to the UPS switching to battery mode to frequently and thus degrading the battery lifespan. The Online UPS topology would further be preferred for this classification when the frequency deviations is too great since it has a better control for the output frequency that neither the offline nor the line interactive UPS unit has.

The hybrid solar UPS systems includes the design alternative 3A-3C. The correlation between the UPS topologies and the classifications follows the same reasoning as for the design alternatives 1A-1C and 2A-2C. There is however an additional aspect to account for when deciding topology for the hybrid solar UPS systems, the usage of the loads. If the loads are used often and on a daily basis the Online UPS topology should be adopted nevertheless.

Sizing

When sizing the UPS unit the same principle of sizing can be adopted for all topologies. The essentials lays in the connected loads and their ratings. It is hence necessary to recognize the power consumption of the loads. There are two practical methods which may be utilized for obtaining information about the load consumption.

The first method is the most comprehensive one. It required a review of the load's nameplates or documentation in order to find the consumption rating. The rating found on the nameplates or in the documentation is the rated power and not the actual consumed power. Sizing the UPS after the rated power consumption is not optimal but is an adequate measure to take in order to lessen the risk of overloading.

The second method requires measuring instruments and gives a more precise description of the power consumption of the loads. The measuring instruments will illustrate the real power, instead as for the first method where the apparent power is given. In order to reassure a margin for eventual overloads the UPS unit should, as a rule of thumb, be sized to be 40% greater than the measured real power.

5.4.2 Batteries

There are several types of battery technologies used for backup energy storage. For static UPS however there are essentially three technologies which are widely used. The technologies are widely used for hospital UPS usage, the most commonly used technology for hospitals in Eastern Africa is however the VRLA battery. This is mainly due to its less advanced maintenance requirement and cost advantages. These technologies will in furtherance be deliberated below on how they are differing from each other and also also how to size them accordingly. The choosing of technology does not rely on a specific as cooling provided of the batteries is presumed. The cooling and ventilation is described in section 5.4.4.

Technology
The three most commonly used battery technologies for UPS applications are the valve-regulated lead-acid (VRLA) battery, the vented lead-acid (VLA) battery and the nickel-cadmium (Ni-Cd) battery. The different functionalities and constraints for the technologies does differ which is why they are important to acknowledge prior to appointing a specific battery technology.

The vented lead-acid (VLA) batteries has a high reliability and lifetime when being maintained properly. The requirement for proper storing is nevertheless decisive for the battery's features. The battery primary calls for storage location with good ventilation and stable temperature of around 25 °C. This technology does in furtherance require some technical knowledgeable personnel at the hospital which can perform the maintenance.

The valve-regulated lead-acid (VRLA) batteries has a shorter lifetime and has fewer discharge cycles than the VLA batteries. The need for maintenance is minimal and the emissions from the batteries are low. These batteries are recommended if the maintenance of a VLA battery can not be ensured or if the batteries will be housed in rooms without good ventilation.

Nickel-cadmium batteries has the longest lifetime of the three battery technologies which is made possible due to its rugged construction. Similar to the VRLA batteries nickel cadmium batteries has minimal emissions and small need for maintenance. One of the most beneficial aspects of these batteries when used in eastern Africa is that the temperature tolerance is much higher than for the lead acid batteries. These batteries is recommended if the rooms where the batteries is going to be housed has low ventilation and a high temperature and if the higher purchase cost can be accepted.

The battery technologies does demonstrably have different features in terms of lifetime, maintenance requirement and climate withholds. In easter Africa, as for today, the range of available technologies for batteries can be limited to one or a few technologies. These often being the VLA- or the VRLA battery technology. If the UPS system calls upon a Ni-Cd battery technology due to temperature conditions, the VRLA battery should be adopted in the case of unavailability as both has low maintenance and emission.

Sizing

The sizing of the batteries are heavily dependant on the discharge rate and discharge prevalence. It is then desired to determine the classification of the power outage regularity. The classifications are described in subchapter 4.4 and how to determine what classification to set is defined in section 5.1.4. The reason for embracing the need for classification lays in the gravity of the wearing effect the frequency of discharges and the depth of each discharge (DOD) has on the batteries. The recommendations given in accordance to the classifications presumes other surrounding obstacles already being settled, such as cooling (described in 5.4.4) and placement.

In addition to the classification it is further necessary to settled the desired protection time of the battery bank. To ensure an optimal performance the discharge voltage of the batteries should be greater than the input system voltage of the inverter. To compensate for an eventual decrement of the batteries it is then recommended to have the end discharge voltage to be at least 25-30% greater. The fundamental understandings of sizing of the batteries is to first acknowledge how large the load is and also for how long the desired back-up time should be. It is also important to recognize the conversion losses along with wiring losses when dimensioning the battery pack.

If classification 4A is given, meaning that there are less than four outages annually with each outage average interruption duration being less than 12 minutes, the battery technology of choice is of little importance to the overall functionality of the battery system. Assuming that the batteries are designed to fulfill a backup time of less than 12 minutes. If the classification were to be 4B then a more cautions should be given into choosing a battery technology. The classification basically states a more frequent use of the battery along with deeper discharges. As these are two parameters with great effect on the battery life time, a battery with more robust should be chosen. If the power outage regularity should be classified as 4C then the Nickel-Cadmium battery technology should, for most cases, be adopted as this battery technology and its electrochemical capability calls for better proof against deeper discharges and intermittent use of the battery.

5.4.3 Solar panel and inverter

When installing solar power feedings there is a handful of essentials to bare in mind. The number of solar panels is decisive to resolve but also the size of the inverter along with the practice of mounting is important. This section aims to provide the different aspects to approach obstacles to conquer in order to fulfill a successful solar PV system.

Technology
The factual principal is more or less the same for all types of solar modules. The aspects of mounting could however differentiate, solar panels can either be installed on the ground or on a roof top. If the solar panels are installed on the ground ensuring that the fundament is reliable is key for a safe installation. Advised is to have the fundament being concrete along with the metal structure being extra reinforced. The reason for this is the additional impact wind does have on a ground mounted solar pv system. A swift wind can potentially jolt the structure of the ground if the mounting system is not properly arranged. If decision has been made to install the arrays on a roof there are essentially two ways of approaching a roof top installment of solar panels. The panels could either be rack mounted or stand-off mounted. The rack mounting procedure aspire the panel to be mounted on a pre-built metal framework which could either be placed in parallel to the roof or directly on top of the ridge of the roof. The positive effect of this is the flexibility to place the panel in the most suited cardinal direction as possible and the extra cooling that the spacings between the panel and the roof provides. The adverse consequence of this is yet again the exposure to heavy wind. The stand-off mounted solution is a mounting structure which can only be installed in parallel with the roof, though some modules has the opportunity to change the angular position once installed. This solution does nonetheless give the ventilation and neither the cooling ability that the rack mounted solution gives as the air gap is far from efficient. The solution does in contradiction instead increase the heat development beneath the panel which in furtherance decreases the efficiency of the solar panels.

Sizing
If a UPS system with solar power feedings has been chosen and a feasible location for placing the solar panels is available, then the next step is to decide upon how large the solar system should be. What limits the size of the solar feeding is the inverter, which is why it is suggested to not only decide upon the size of the system being built at the particular instant but also to establish as sense of what the future prospects of the system might be. The reason for this being that the inverter, as of today, is the most cost intensive equipment contributing to the solar pv system. If the objective system is to precisely fulfill a certain amount of feeding then there is no reason to over dimension the inverter. If the system objectives however is further to lay ground for a future expandability then there are reasons to have the initial inverter to be capable of converting more energy than the installed capacity. Though it is not crucial to construct in this matter it is however suggested. Some inverters are capable of being coupled in parallel to increase the size of the conversion potential.

5.4.4 Cooling

In the region the temperature may rise well beyond optimal range of VRA and VRLA batteries and therefore severely decrease the lifetime of the batteries. Even other components such as the UPS unit may be negatively affected by high temperatures but not to the same extent as the batteries. It may therefore be necessary to include a cooling system to increase the lifetime of the batteries. The cooling system that is recommended to be used is air conditioning since it will both control temperature and airflow.

If the classification for climate sensitive equipment is 2A no cooling system is required since the conditions in the room is of such a good quality that a stable temperature in an acceptable range can the ensured at all times. If the classification of the room is 2B or 2C measures to increase conditions in the room has to be performed. If the classification is 2B an air conditioning system is recommended since it will increase the ventilation in the room and allow the temperature to be controlled so it is in a range so that the lifetime of the batteries would not be affected negatively. If the classification of the room is 2C an air conditioning unit is recommended as well as improvements to the build quality of the room. This will both ensure that the climate in the room as well that the isolation and protection of water intrusion is acceptable.

The need for improvement of the cooling in the room may however purely economical and in these cases the cost of replacing batteries should be compared to the cost of purchase of an air conditioning unit, the cost of running the air conditioning unit and the cost of improving the build quality of the room. If the combined cost of all of these expenses over the desired time period are higher than the cost would be to replace the batteries more often the installation of a cooling system is not recommended in an economical perspective. The difference in cost of purchasing batteries with or without a cooling system can be estimated by estimating the lifetime to be halved every 8.5 degrees Celsius over 25 degrees Celsius.

When dimensioning an air conditioning system for the UPS room the BTU rating of the air conditioning unit is the main value to examine. The BTU rating need should be calculated using formulas or premade calculation sheets. Since the exact heat development of the UPS units and other equipment that may be present in the room as well as the lack of knowledge regarding the isolation properties of the room a completely accurate BTU value may be hard to find. Therefore, it is acceptable to use values that may not be completely accurate for the dimensioning of the air conditioning unit as long as the value is reasonable. If the need for improvements of the build quality of the room is present, the goal is to ensure that the insulating properties of the room is increased. This can be done by covering holes in the walls or in the ceiling, increasing the thickness of walls or covering windows.

5.4.5 Installation

The two main goals during the installation of all equipment is to ensure that the functionality of the system is as wanted and that the safety is adequate. The functionality can be compromised if the voltage drop is too high and therefor cable dimensioning needs to be addressed carefully. The safety of the system needs to be so that no harm can be done to either person or property. Wiring needs to be made properly with correct cable dimensioning so that circuit breakers functions properly and that the heat development in the cable is controlled. The installation is described in three parts, installation of UPS equipment, installation of solar equipment and installation of wiring to loads.

When installing the UPS unit it should be mounted so that there is enough space between the unit and the ceiling and floor so that sufficient airflow is meet. The required space should be written in the documentation for the unit. There can be great variety in how the connection to the unit from solar panel and to the loads should be made so the installation guides in the documentation should be read and followed carefully. It is recommended that a changeover-switch is installed so that UPS unit can be bypassed during malfunctions and during service. The changeover-switch should function so that when need all loads can be powered directly from the grid. The batteries should be placed so that they are level and standing stable. The nodes of the batteries should be covered so that accidents may be prevented.

The solar panel should be placed only where the strength of the structure can be ensured too be high enough so that it can support the solar panels. The solar panels should be secured in place so that they can endure strong wind from all directions. The direction and angle of the solar panels should be so that the most radiation hits the solar panels, this can be done in most cases by modifying the mounts so that the angle and direction can be correct even thou the mounting surface is not. The solar panels should be connected so that a correct voltage level is obtained suitable to inverter.

When connecting the equipment to the loads it is necessary to ensure that the safety of the system and all connections included is high enough so that no harm to person or property is possible. Therefore, it may be needed to make alterations to the existing installation or to make a new installation. If the classification of the electrical system is 1A no alterations is required and all parts of the new system can be directly connected to the existing electrical system. If the classification is 1B the parts of the systems can be connected to the existing electrical system but modifications to the systems is required to increase the safety. The modifications can vary between different cases so the guideline is to increase the level of safety so that a 1A classification is meet. This can include changing parts of wiring, installing earth leakage circuit breakers, changing wall sockets or replacing faulty components of the electrical system such as circuit breakers, switches etc. One of the more common issues is cable dimensioning and therefore it is recommended to pay extra attention to this issue since to small cable dimensioning may reduce the short circuit currents so that circuit breakers won't function properly. If the classification is 1C the condition of the existing electrical system is of such a poor quality that a completely new electrical system is recommended. The new system should be of such quality that a 1A classification is meet.

5.5 Testing

System testing is expectantly the closing activity carried out during the UPS system installation. The reason for testing the system is to assure that the system function is as specified and that all electrical equipments are intact. There are several verifications which should be fulfilled after the UPS installment is initially considered as complete.

Testings to verify the functionality of the solar modules is carried out by measuring the open circuit voltage and the short circuit current. The testing have to be carried during hours of sunlight. The open circuit voltage and short circuit current should match the stated values in the datasheet for the solar panels. The open circuit voltage is measured by connecting a multimeter to the positive- and negative lead on the terminal on the back of the solar panels. The should then be pointed directly towards the sun. The voltage on the multimeter should then be the same as the voltage stated in the datasheet. The same procedure is then carried out to acquire the short circuit current, thus the current on the multimeter should match the manufacture specification. This test is preferred to be done on all modules before the mounting. When the is mounted it might be difficult to connect the multimeter to the terminal on the back of the modules. The reason for doing this test on the modules individually is that when the modules are installed they are either connected in series or in parallel, making it harder to determine which on is might be defected.

There are several methods for how to perform battery testing. Seldom is one method enough to draw any conclusions, it is then recommended to perform several tests. One of these tests are the float test, where the float voltage and float current is measured. This test is first carried out by measuring the voltage over the pools of the battery when it is fully charged. If the float voltage is less than the factorial specified float voltage, it might be and indication that at least one cell within the battery is not working properly. If the float voltage is greater than the specified it is an indication that the battery is being overcharged. Overcharging batteries will drastically limit the lifetime of the battery as the temperature will rise within the cells and eventually cause early on grid corrosion. A high float voltage is often an indication that the float current is high, which eventually might cause a thermal breakdown. A high float current could also be a result of a short circuit within a cell. Another test is the internal resistance test which is performed in the same manner as the float voltage- and current test. The internal resistance should align with the values in the datasheets. Important to acknowledge is that an eventual decreased internal resistance might not be an indication to a damaged battery, this as the it will naturally decrement as the battery gets older. Sudden decrements of internal resistance might point to the battery being defected.

The final test which should be carried out is a full system test. The intention of the test is to simulate a power outage and stress the UPS with a full load capacity. This test is essential to perform in order to see if the system can provide power to the critical load for the intended period. If the UPS system has a solar panel directly integrated to the UPS, this test should be performed twice. Once during night time when there is no solar power generation and once during day time. This since the system will perform differently for the different times of the day. The night time test could possible be done by disconnecting the panel and is done in order to examine the durability of the batteries.

5.6 Expandability

That the option to upgrade the system is available regarded as important. Every type of system recommended by the strategy presented has ways of upgrading both the backup time and power rating is the need is presented and the funds is available. Strategies for upgrading aspects will therefore be presented.

The need to increase the power rating of the UPS system may be a result a small increase in load such as a single new critical equipment in an operation theatre or an extensive increase such as a new department with a high number of critical loads. Therefore, options for upgrading the UPS system for both small and extensive changes is needed. When upgrading the size of the system it is preferable to utilize as much as possible of the current system since it will lower the cost of the upgrade. When increasing the backup time, it is in most cases sufficient to add additional batteries. An increase in batteries will increase the amount of energy being stored and the backup time will be increased. When adding additional batteries, it is important that batteries are connected so that the rated voltage of the UPS unit is meet.

When increasing the power rating of the UPS system it is necessary to review both the current UPS system and the new load situation. The recommended expanded UPS system may be different depending if the current UPS system is either centralised or decentralised, if the new load is small or extensive and if the new load is located near a current load location or not.

If the current UPS system is a centralised system, there are two options for upgrading the system. One is to switch to a decentralised system by adding a new UPS unit that supplies the new load separately, one is to increase the power rating of the centralised system by adding a new UPS unit and connecting the new load to the centralised system. If the new load is located far from the existing loads and/or if power rating of the new load is under half of the rating of the current UPS unit, it is recommended to switch to a decentralised system by adding a new UPS unit that supplies the new loads separately. This solution is recommended when the load is far from the since the cost of wiring decreases significantly if the UPS unit can be located close to the loads. It is recommended for small increases in loads since the cost of upgrading a centralised system by purchasing a new UPS unit with the same rating as the current would be too high in comparison with purchasing a smaller UPS unit for the new load.

If the size of the new loads is higher than half of the rating of the current UPS unit an upgrade of the centralised system is recommended. The upgrade should be conducted by adding a new UPS unit of the same rating as the current UPS unit. It is important that the effect rating of each UPS unit is higher the total effect of the loads divided by the number of UPS units. This is to ensure that none of the UPS units are overloaded during full load situations. To reduce the risk of damages from overloading the UPS units should if possible share the same battery pack instead of each unit having a separate battery pack. If each UPS unit has a separate battery pack, there is a risk of overloading if one of the battery pack is depleted or malfunctioning resulting in a situation there the all of the load is supplied by one less UPS unit than intended. If the UPS units share a battery pack this will not occur but it is instead important to ensure that the batteries are dimensioned to deliver the amount of power needed. As additional protection it is also recommended to add additional overloading protection to each UPS unit if the units do not already have this feature, this is to protect the UPS units from overloading if one of them malfunctions.

If the current UPS is a decentralised system, there also two options for upgrading the system. One is to collect all or parts the current UPS units and forming a full or partial centralised UPS system to supply parts or all of the loads. The other solution is to maintain a decentralised UPS by adding a new UPS unit that solely supplies the new loads. If the new load is of a small size or is located far from any load currently protected by any UPS unit it is recommended to add a new UPS unit that solely supplies the new loads. The new UPS units should be dimensioned using the same principles as any other UPS unit for a decentralised system. This solution will maintain the decentralised status of the UPS system.

If the new load is located close to a load currently supplied by a UPS unit and is of a size higher than half of the effect rating of the current UPS unit a partial centralised UPS system solution is recommended. This solution is based on the same concept as the solution for upgrading a centralised UPS system by adding additional UPS units with the same effect rating. All precautions mentioned to avoid overloading should be followed for this solution as well. This solution will result in a situation where parts of the decentralised UPS system consists of UPS configurations that resembles a centralised UPS system. It is possible to transform from a decentralised system to a centralised system if the new loads are located so that the density of critical loads are high enough to promote a centralised system. The transformation can be performed by collecting all UPS units and connecting them to supply all loads.

5.7 Economical framework

The economical aspect of any project is key to comprehend in order to fully success with the project. A correct balance between number of solar modules, size of inverter and battery storage is important and since the cost and system size does not correlate linearly it is especially important to settle the framework for the system in advance. The presented strategy does however not account for project with budgets which are to build systems which is built for expandability but instead for system which are to operate as backup systems for the current critical loads. There will always be economical trade offs to be made when building solar powered UPS systems. There are no general guideline to purse when deciding what technology or what size the system should be. The primary objective should be to meet the initial requirement of the system first before extending the system into e.g having more robust battery system or expanding the capability for solar modules.

Up to this point the technological specifics has been presented but not the economical. In terms of cost there are some understandings which are important to recognize. The following orders are made with information available up to the point of the authoring of this strategy. In times like these it is far from easy to forecast technological upraised or commodity price (which prices of electrical equipments are heavily dependant on).

The strategy substantially consists of three different UPS topologies. The topologies are roughly given the order of Online UPS, line interactive UPS to offline UPS from being most expensive to cheapest. Keeping in mind that different manufactures offers different functionalities for their UPS units which can drive up the price having a offline UPS being more expensive than a line interactive UPS for some cases. If the UPS unit should be accustomed for a hybrid solar system it usually also drives up the price of the UPS as the complexity of the UPS is then increased. The different battery technologies does also separate themselves in accordance to cost. Within a UPS solar system, the battery is the equipment which depends uttermost on the price of the commodity composing the battery. As of today the lead-acid batteries are cheaper than the nickel-cadmium batteries but there are no warranty that may change in the future. This as new electrochemical capabilities might be derived from other materials and the physical extraction of raw material might gets easier. The solar panel is the part of the system where cost have minor impact on its objective function. The solar panels available in the market for commercial use, of 200 W (rated) per solar panel, usually offers an efficiency of in between 13-16 %.

6
Result - Kolandoto

The case study of Kolandoto hospital filled the purpose of applying the described strategy and examine its capability. Some of the appliances were incorporated into the strategy after the case study which meant some classifications were not carried out as the formed strategy suggests. The reason for this being the realization of the need for additional appliances after the case study was finalized, one of these being the classification of need for power quality stabilization. Some inputs into the strategy were developed after the case study was executed which meant that some measures which are described in the strategy was not carried out during the case study. The strategy was however applied for as much as possible and the case study came to fill a substantial role in the formation of the strategy.

6.1 Classifications

The initial action that was carried out were the classifications. These were essential in order to navigate through the formed strategy in a comprehensive way. The classifications were determined with the best intentions and with the knowledge available at the time.

6.1.1 Electrical system

Determination of the condition of the hospitals electrical system was made accordingly to the description in subchapter 5.1.1. Unfortunately there were no documented electrical schematics available of the Kolandoto hospital which lead to the investigation being pursued as an visual investigation. The visual inspection was conducted on the electrical installation and its protection systems. The investigation showed several unpleasant installations with cables wrapped around sharp metal objects and poor cable connections in general. The extensive part of the hospital were hence classified as 1B thus the electrical system in these areas could possible cause injuries in the future but are not constituting an immediate threat. In the sterilization building there were signs of small burn marks on the sockets which indicates scanty connection, if these damages were to be worsen before any improvements are made this area could be downgraded to class 1C.

The operation theatres were all classified as 1A thus the cabling and connections were installed with better precautions. It was obvious that more attention had been given to these areas when the electrical system was initially installed. All theatres, including the dental clinic and except the maternity theatre, had electrical systems with a voltage regulator installed. The voltage regulator is used to ensure a stable disturbance free voltage which may harm sensitive machines and equipments. Other buildings and areas which were also classified as 1A were the care treatment clinic and the family planning building.

The outdoor waiting area at the eye ward are the only area which were classified as least favourable class 1C. The installation in this area were carried out with no respect to outdoor environmental stresses like rain and other induced contamination. Due to the high risk of short circuits and direct hazardous threat.

Circuit breakers with acceptable ratings and functioning earth leakage current circuit breakers were installed in all buildings. In figure 6.1 an overview of the hospital area and each area's classification is presented.

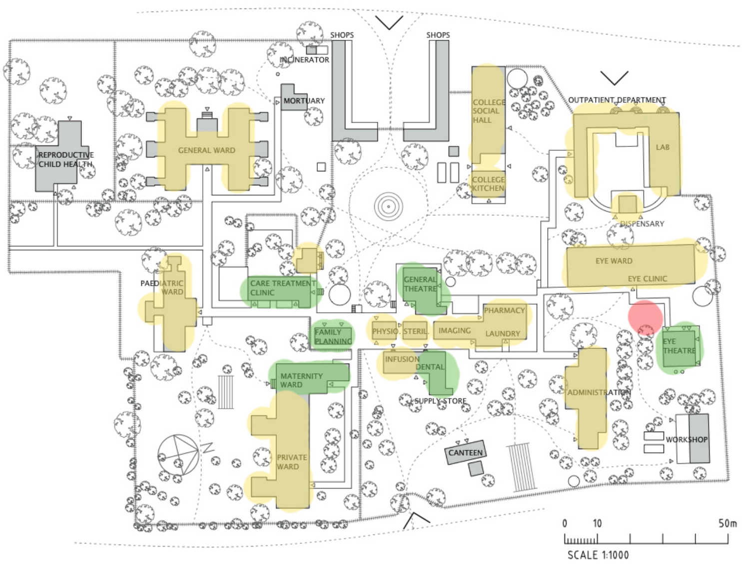

Figure 6.1: Electrical system classifications with green indication being classification 1A, yellow being 1B and red being 1C

6.1.2 Surroundings of climate sensitive equipments

Finding satisfying places for locating the UPS systems were rather easy at Kolandoto hospital. Finding places which could be isolated from the normal activities at the hospital were more difficult and especially as the location needed to be in satisfactory condition for the UPS. There were especially three different locations which came down to be the best suited locations to put the UPS system. The rooms were however in different conditions and all had their individual demand for reinforcement.

The first room, which got to house the UPS for the eye theatre, were the location out of the three in best shape. The room was closely located to the junction box and was well separated from the daily activities ongoing in the rest of the building. The doors and walls were in good shape and in no need for upgrade. Even though the room was in satisfying shape it was classified as 2B due to the temperature variations and lack of airflow. From measurements carried out every hours for ten days showed an average temperature of 28,4 °C. There were no particular reinforcement of this room other than an installation of an AC in order to raise the airflow and keep the temperature down over the day.

The second room was the room that got to house the UPS for the general theatre. This location differed from the first room, firstly in terms of location to the junction box of the theatre but also in terms of heat radiation. The room had a window, which were not exposed to the sun but still let in a heat. The room had high ceilings which is good for air countervailing. The temperature was not measured in this room, it was however unlikely that this room could have been cooler than the first room. This determination was carried out by visiting the room during different hours of the day and getting a sense. This room also got the mediocre classification of 2B. The room was eventually enhances by shutting the window close and installing an AC for the same reason as in the first room.

The last and third room was the most problematic room for UPS installation. The room had holes in the ceiling caused by damp and two windows which were directly exposed to the sun. Due to the placements of the windows it was also possible for rain to reach in. The junction box was however in close distance to the UPS location which came down to be single good thing about this location. This room eventually got the 2C classification due to the many improvements which needed to be done before hosting sensitive electrical equipments. The windows were shut to reduce heat exposure and risk of rain intake. As for the other rooms an AC was installed here also in order to keep the temperature stable throughout the day and increasing the airflow. It is favourable to have a good air flow in furtherance of reducing the sediments on the equipment.

6.1.3 Solar power arrangement

Kolandoto hospital came to be an exceptional hospital to arrange a solar panel at. The hospital had plenty of roof capacity for placements and which also could provide a favorable orientation. As Kolandoto is in the southern hemisphere the best orientation is having the panel facing north, which was also how the panels were eventually placed. By having the panel placed on the roof, the risk of theft were drastically decreased. The placement of the panel were further excellent due to the viability to be installed close to the UPS. The only insufficient specification of the solar power arrangement were the slightly deficient roof standards which made the panel structure slightly difficult to attach. The placement did moreover not include any type of shading throughout the day. Considering all the positive conditions for a successful arrangement the classification came down to be of 3A.

6.1.4 Power outage regularity

The determination of regularity of power outages and length were carried out by interviewing managing personnel at the hospital. The power providing company were unable to arrange these number for the investigation which lead to de facto. The hearings showed that the average outages per week was approximately 2 times/week and the average length was 20 minutes. This lead to the classification to be 4C.

6.1.5 Load

The procedures described in section 5.1.5 were not followed in the case study for Kolandoto since a complete list of critical loads had been realized prior to the start of the case study. The list of critical loads was made by students from Chalmers in collaboration with the hospital management. The procedure that was used to obtain the load information was mainly through discussions with the hospital management. This was essential to do in order to study what load the hospital saw as critical and non-critical. Unfortunately no semi-critical loads were investigated. The list of loads was later handed over for use in this case study.

The list was revised with the intention to eliminate any non-critical loads or semi-critical loads from the list. A microscope that is used in the laboratory was stated as critical in the load list, this load was later removed due to its semi-critical nature and due to the impracticality to feed this load as it was to external to the critical loads and would impose an inefficient use of the budget. The removal of the microscope was the only change made in the list during this step of the procedure.

Lastly a final re-visitation was made of the list by investigating the operations theatres and the wards to see that the list was correct. All equipment that was present in the list was confirmed to be existing in the operation theatres with the exception of the general operation theatre. During the investigation it was noticed that only one anaesthesia machine was mentioned in the general operation theatre when there was infact two present during the investigation. The second anaesthesia machine was confirmed by the hospital management to be critical for any ongoing surgery and were therefore included in the critical load list.

The only critical loads in the wards, stated in the list, was lightning and oxygen machines. During the investigation it was noticed that there were two oxygen machines in one ward and not one in each ward. The oxygen machines are always repositioned according to where they are needed at the time. The critical load list was changed so that the power required from the UPS system would considered two oxygen machines and not one in each ward. A notice was made so that it was clear that installation should be made so that each ward should have the possibility to use one oxygen machine during an power outage. With these two changes being made the final load list was made and is presented in appendix A.

Even though the classifications of loads were not made precisely in accordance to how the strategy suggested some conclusions could be drawn as the strategy was formed. Looking at the load list and the hospital area it is safe to say that the general theatre, the eye theatre and the maternity ward were classified as 5A. The pediatric ward and general ward were classified as 5B and the rest of the hospital were classified as 5C. Figure 6.2 gives a pictorial description of the hospital area and each buildings classification.

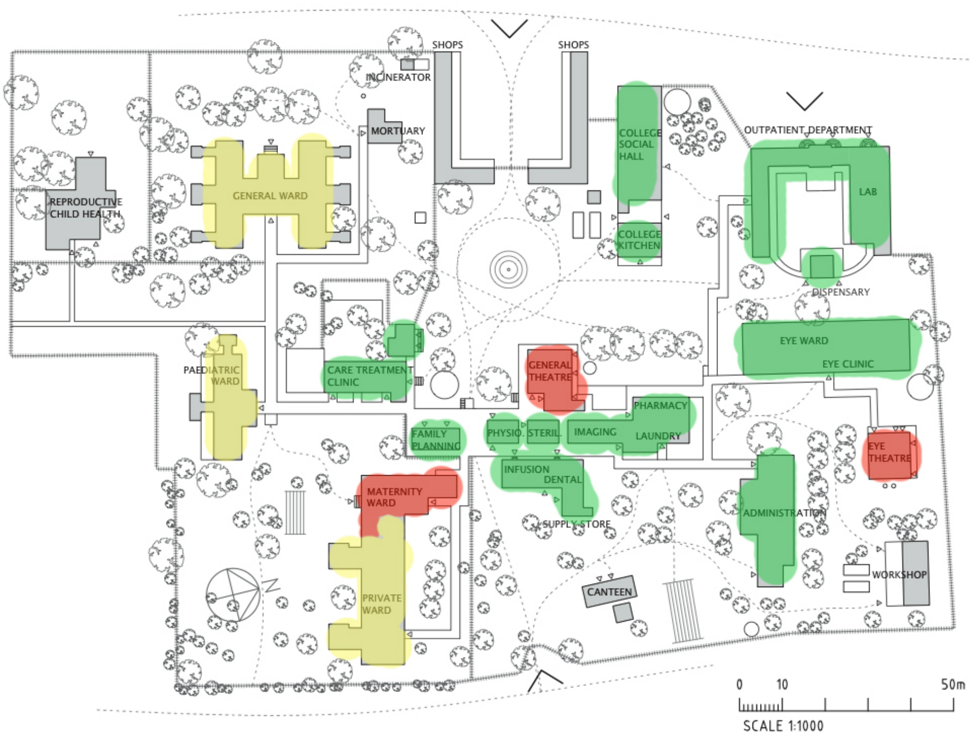

Figure 6.2: Hospital area with the classification of 5A being red, 5B being yellow and 5C being green

6.1.6 Need for power quality stabilization

As no measuring tools were incorporated in the case study a thorough examination of voltage irregularity nor frequency variation could be conducted. This essentially meant that the stated manner of classifying the need for power quality could not be realised. There were however some indications which pointed to the power quality sometimes being substandard in the region. There were voltage stabilization units installed in the General theatre and the Maternity ward. The reason for having these units installed was not evident upon detection but were most likely done in precaution to the expensive equipments placed in these areas.

6.2 Design and dimensions

The design alternative which was chosen for this case study was 3B, hence a design with including a solar panel and a single phase hybrid UPS system. In subchapter 5.3 a orientation plan (figure 5.10) was settled, this plan was used in this case study to scope the final design. In figure 6.3 the actual navigation through the design orientation map is presented.

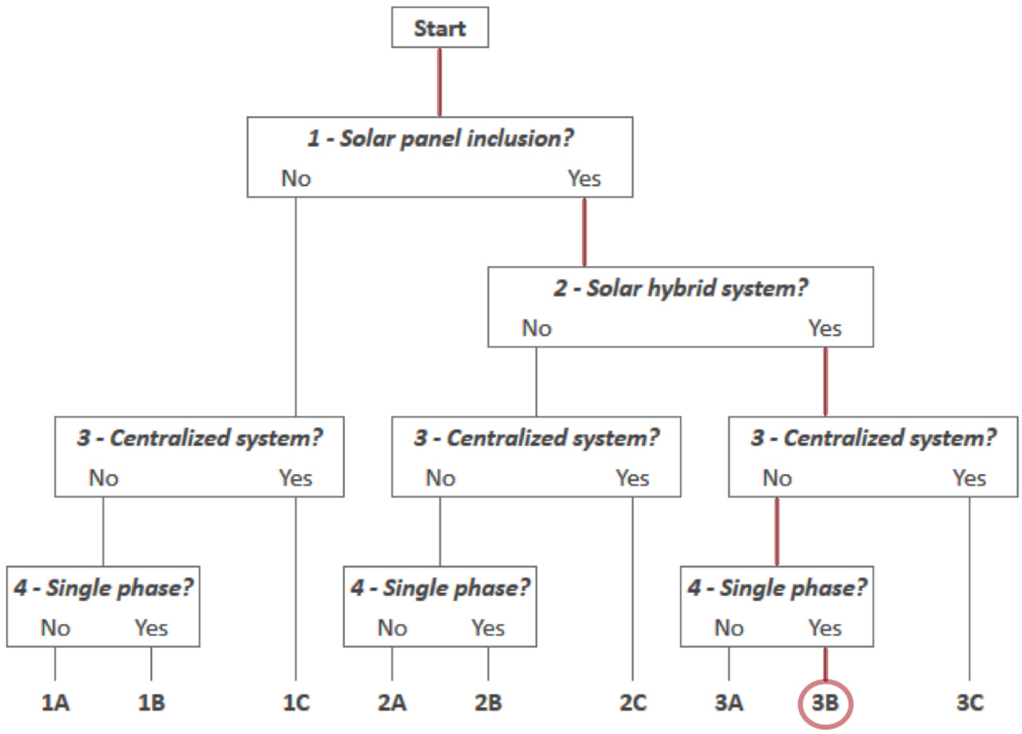

Figure 6.3: The navigation through the design orientation map of the strategy for the case study at Kolandoto Hospital

The first inquiry in the orientation map treated the options of whether or not to include a solar panel in the system. The classification of solar power arrangement was 3A which gave good incentives to include a solar panel in the UPS system. The argumentation for the classification of 3A is given in section 6.1.3. 18 solar modules á 195 W contributing to a total capacity of 3510 W were installed. Even though the roofs at Kolandoto Hospital were recognized as to be slightly deficient the panels were rack mounted. The rack mountings do impose unnecessary stress on roofs but as no other option for mounting was available, this came to be the adopted solution.

The second inquiry treated the choice of either having the solar panels included in the UPS system (hence a solar hybrid UPS system) or having the panels separately integrated in the hospital. Looking at figure 6.2 in section 6.1.5 it is shown that the classification of 5A was only concentrated to a few locations around the hospital and the majority of the hospital area was classified as 5C. This lead to the decision of having the solar panels directly integrated into the UPS system since then the generated power is directed to where the essential need is. The 18 modules were distributed in accordance to the eventual placements of the UPS units and their specific sized. The eye theatre were given two modules and the general theatre and maternity ward were each given eight modules. The following pictures (figure **??**) shows the resulting installation of the solar panels.

The third inquiry dealt with the decision of either having the system centralized or decentralized. The UPS system at Kolandoto hospital was selected to be decentralized. The reason for this decision was mainly due to the distribution of the loads and the diversification of their classification throughout the hospital area. The critical loads did further only contribute to a small portion of the total load of the hospital. If a centralized system would have been adopted, the UPS dimension would not have fitted in to the framework and constraints of the project.

The decentralized UPS system consisted of three UPS units. One at each of the Eye theatre, the General theatre and the Maternity ward. The size of the units were chosen in accordance to the size of the critical loads and were 2.4 kW / 24 V, 6 kW / 48 V and 6 kW / 48 V respectively. These dimensions were chosen in pursuant to the critical loads but as the number of available sizes were limited some UPS systems prevailed to be both over dimensioned and under dimensioned. One of the over dimensioned UPS units was the UPS installed in the Eye theatre. The total load fed by this UPS is 962 W which accounts for almost 1.5 kW in over dimensioning. The UPS system which featured an over dimensioning was the UPS at the Maternity ward where the total fed load was 7.5 kW. In table 6.1 below are the over/under dimensionings displayed and the critical load for each UPS system is obtained in Appendix A.

Table 6.1: Difference in rated critical load and UPS dimension for the three UPS systems

	UPS dimension	**Rated critical load**	**Difference**
Eye theatre	2400 W	962 W	+1438 W
General theatre	6000 W	4868 W	+1132 W
Maternity ward	6000 W	7500 W	-1500 W

The last inquiry treated the option of either having the system in single phase or three phase. Due to the design of the electrical system at Kolandoto hospital the choice of having the UPS system in single phase was chosen. The hospital main feeding is a three phase 400 V line which stretches over the main parts of the hospital. The three phase line is then separated into single phases prior to feeding of the different buildings. The choice of having the system in single phase was therefore convenient and installing a three phase UPS system would hence have been impractical. The electrical grid network, for Kolandoto hospital, is disclosed in figure 6.4 below.

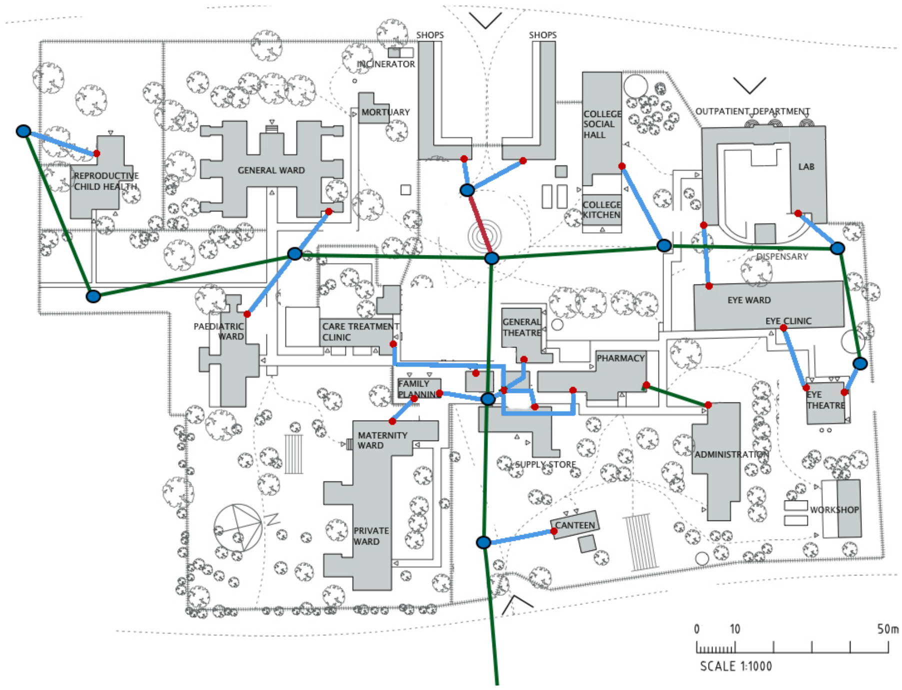

Figure 6.4: The electrical grid network at Kolandoto hospital with blue lines being single phases and green lines being three phases.

When the design alternative 3B, hence a solar hybrid UPS system was chosen the next step was to set the UPS topology. This decision was according to the strategy dependant on the classification of need for power quality stabilization, but as it was not possible to carry out a proper classification extra precautions were instead taken. The solar hybrid UPS got to be an Online UPS. The incoming feeding for the solar panel and the battery were 24 V DC respectively.

The final step in the UPS installation was to decide on the battery technology and the size of the battery bank. The technology chosen was the valve-regulated lead-acid (VRLA) battery. As the power outage regularity was classified as 4C (determined from hearings and described in section 6.1.4) the battery technology had to be robust. The best fitted technology for Kolandoto hospital would have been the Ni-Cd battery, mainly due to classification being 2C for the surroundings of climate sensitive equipments. But as economical constraints limited this option the VRLA technology was adopted instead. The VRLA technology was however beneficial for the purpose of this project due to the low maintenance requirement. The temperature conditions in the storage rooms for the batteries were as previously described (section 6.1.2) enhanced which made the installment of the VRLA batteries more justified. The sizing of the batteries were done accordingly to the load being able to be fed for two hours. The initial calculation were carried out theoretically resulting in a needed capacity of 160.3 Ah for the eye theatre, 811.3 Ah for the general theatre and 1250 Ah for the maternity ward.

These calculations were done to get sense of the required size of the battery. Practically parameters like inverter efficiency and power factor of the load needs to taking into account. Due to this the resulting sizes of the battery were dimensioned considerably greater than the calculated. The eventual battery capacity installed was 400 Ah for the Eye theatre and 1600 Ah for the General theatre and Maternity ward respectively.

6.3 Testing

The testings of the finalized UPS system at Kolandoto hospital were not executed precisely in the stated manner as described in section 5.5. The important procedure of testing the batteries was not done. The reason for this was due to the lacking knowledge of the importance of the test at the time. The testing of the solar modules were however carried out as intended. The test of checking the open circuit voltage and the short circuit current performed during sunlight. Out of the 18 modules, none gave indication of defects as the measured values were for most parts exactly the same as the rated values or very close to.

The full system test was however carried out as described. As the UPS system included solar power two tests should have been executed. The night time test was however the only test which was done. The objective of the test was to see for how long the system would last without solar power and only battery capacity. All systems were designed to last at least two hours with only battery power. The test was realized three times, one for each UPS system. In table 6.2 below are the results of the night time test.

Table 6.2: Measured battery discharge time for the three UPS systems at Kolandoto hospital during night time

	Rated load	**Battery capacity**	**Inverter size**	**Average inverter load**	**Time**
Eye theatre	962 W	400 Ah	2400 W	30%	4.25 h
General theatre	4868 W	1600 Ah	6000 W	60%	3.25 h
Maternity ward	7500 W	1600 Ah	6000 W	85%	2.75 h

6.4 Expandability

Since there are no developed plans for expansions at the hospital it is not possible to present any plans for expanding the installed backup system. If any expansions are to be made in the future the guidelines regarding expandability in section 5.6 should be followed.

There is however room for some increases in loads due to the over dimensioning of the systems in the eye theatre and the general theatre. Based on the night time test the amount of load could if needed be increased so that an 85% inverter load is meet. A higher load amount is not recommended due to the chance of overloading. This would result in a possible load increase of 1320 W in the eye theatre and an increase of 1500 W in the general theatre. This would decrease the backup time to 1.5 h for the eye theatre and 2.29 h for the general theatre. Since this would result in a to low backup time for the eye theatre the increase of load should be limited to 1130 W resulting in a backup of 2 h.

7
Analysis

In this section the result sections will be analysed. Weaknesses will be discussed as well as possible effect of differences that could be made in the strategy. Ethical and environmental aspect will be discussed.

7.1 Appliances

For the section 4. Appliances many of the different classification systems share the same weaknesses, namely there to make the division between different classifications. The specific criterions for a certain classifications needed to be set so that they had a meaningful impact on the strategies presented in section 5 and therefore clear criterions had to be set. Since the strategy hade to be applicable for many different situations generic criterions had to be found that would give accurate guidelines for the strategy presented. This may however result in some cases where the specific classification for a situation may not result in the most beneficial solutions in the strategies due to inherent differences. The classification system is however designed to give the most accurate representations and result in the most beneficial solutions for the majority of cases.

For the classification of present electrical system, the criterions resulting in a specific classification may be slightly ambiguous. A more detailed classification system on this topic may have been counterproductive since the parts of the intended audience for this strategy may not have sufficient knowledge in electrical installations to follow a more detailed system with more technical descriptions.

The classification of surroundings of climate sensitive equipment mainly revolves around the need to improve the area that will house the batteries. The main issue is here to improve the temperature so that the lifetime of the batteries isn't affected negatively and for most cases this classification should be accurate and give enough information to make correct decisions. This is since the main parameters affecting the temperature is sufficiently treated and explained so that untrained personnel should be able to follow the instructions.

The classification of solar panel arrangement is similarly to other classification in the matter that the criterions may be slightly ambiguous. The prominent lack of accurate measuring equipment in the area would have made more detailed criterions regarding orientation and levels of radiation abundant. The ambiguous criterions may in some cases lead to faulty classification but in most cases the level of information should be suitable to make correct classifications.

The classification of power outage regularity should be the most easily followed due to the numerical values given for each aspect as long as those values could be obtained. The values used may be discussed be in order to be able to make the classification useful in the strategy exact values had to be set and the values chooses gave the most meaningful impact to the strategy.

The classification of load should give a clear indication of what kind of equipment should be prioritized and seen as critical. There will be situations where equipment may be hard to categorize but these situations are unfortunately inevitable.

The classification of need for power quality stabilization is the most problematic when following since the values of frequency and voltage may be hard to obtain due to lack of measuring equipment and lack of data to be gained from grid operators. Without proper knowledge of the needed values the classification of a specific case may be hard to obtain and incorrect actions may be taken when following the strategy.

7.2 General

In chapter 5 there the general strategy is presented ethical and environmental aspect become important and will be discussed in this section. The first topic of the chapter is how the necessary data for the appliances should be gathered. This sections of the chapter serves as a guide and therefore it has no impact on the actual outcome of the strategy but is more of a help on how to use it. No variations on how to present this section differently that would give an improvement or meaningful difference is therefore apparent.

The nine different design alternatives that are presented is intended to provide suitable alternatives to the majority of cases that may be presented in the region. Additional alternatives may have been possible to present that would improve the final result of any project following the strategy. The additional alternatives would however have been similar to the ones presented with few alterations and therefore the number of alternatives was limited to nine. With these nine alternatives and when implementing the succeeding design choices in this strategy an optimal design should be possible for most possible cases.

In section 5.3 the design decisions are described and the specific design alternative for a specific case should be found. When following the instructions in the section it should be easy to find the most suitable alternative if the all necessary classifications presented in chapter 4 is obtained. It may have been favourable to recommend solar power inclusion for more cases even thou it may not be optimal in some cases. The recommendations in this strategy is mainly based on finding the most optimal solution in regards to functionality. Environmental aspects are taken in to concern only after functionality and therefore solar power inclusion in mainly based on whether it improves the functionality of the UPS system. It could be argued that solar power should be included for more cases than recommended with the benefit of lowering emissions and leaving a smaller environmental footprint.

In section 5.4.5 the installation of the system is discussed. In the strategy a high level of safety is recommended and the different options regarding improvements of the electrical system reflects this. The high level of safety may be questioned since the general state of the electrical systems I generally lower in this region compared to what may be expected in western country. Installing a system that is in much better condition than what surrounding electrical system is may be question by the hospital staff since they may perceive the cost of obtaining a high level of safety to be hard to motivate. It may also prove difficult to find electricians that are trained in installing system with the level of safety that is recommended, this may be due to a lack of guidelines and laws regulating the installations. The motivation for only recommending solutions that don't compromises the safety of the system is since the reduced work and cost needed to install a system with lower safety can't be motivated if there is any chance that someone may be harmed by the system. The strategy is developed in Sweden and only a level of safety that would be acceptable in Sweden is recommended. The Swedish level of safety was chosen because it is of such a high level that when followed properly the risk of harm to person or property is low.

In section 5.6 the options for expanding a UPS system is discussed with a focus on utilizing the current UPS system to as a high degree as possible. For most situations a solution is presented that integrates parts of the current system into the new expanded UPS system. The degree of how optimally the parts of the current system is integrated varies between the different current systems and the specifics of the new load. It may be favoured to have one system configuration that is the most ideal for any situation and that all upgrades to a system should move the entire system this ideal system, resulting in a linear path of development. This strategy however does not promote a linear path of development since the difference between how the loads are positioned, sized and used in combination with varied conditions of the feeding grid it is not viable to try to find a solution that should fit all hospitals. The strategy presented instead aims to provide a flexible system that can develop with the development of the hospital and that efficient solutions should be found each time a new load is introduced that requires an expansion in the UPS system. It is however recommended to in an as high degree as possible try to foresee any expansions in the future when designing an upgrade.

7.3 Kolandoto

In chapter 6 the case study in Kolandoto is discussed. The strategy was tested and adjusted according to findings at Kolandoto. The results from the final system tests should that the desired functionality was meet and the electrical supply to the critical loads was secured. The system was however slightly oversized which is apparent when reviewing the results from the final full system test, the times that the system could maintain electrification to the loads was longer than was originally desired. This was mainly due to the use of the rated effect being used for dimensioning and not the actual effect consumed. The reason for this was that it was desired that the UPS system should be functional for two hours during heavy loading. When the test was performed the load situation was that of a normal operation and not during the most intense load situation that may occur. There is therefore a difference between the situation that the system was designed for and how the system was finally tested. A clearer intention of how the system was supposed to be used would have been usefully and would most likely have improved the outcome.

The decision to include solar power was easy to make since the condition for solar power inclusion was good. The way the solar power was integrated in the system may have been improved if the aspect of utilizing the solar power the most efficient was of higher priority. The solar power was dimensioned with the rated effect of the loads and this value proved to be further away from the actual effect of the loads than was expected. This resulted in a situation where the solar panels provided enough power during sunny occasions to supply all of the loads for each UPS system. Since the panels provided enough and in some cases more than the loads consumed there was a waste of energy that could have been used elsewhere.

The fact that the system installed at Kolandoto was slightly oversized was seen to the whole project a minor issue. If the opposite would have been the reality with a undersized system the functionality of critical equipment could have been compromised and in the worst cases resulting in harm to patients. The overdimensioning of the system is therefore viewed as a major fault, it could even be argued that it may have been good since the hospital may in the future start making small expansions in some areas of the wards. The hospital staff expressed a great thankfulness over the system and said that it functioned beyond their expectations.

8
Discussion

Conducting projects like these could be somewhat challenging. The presented strategy is far from perfected and could well be refined several times before it would fit every possible UPS installation on hospitals in East Africa, if it ever will. Starting with the core essence of the strategy, where the factual design was chosen. The strategy itself is concrete and distinct in its modelling and leaves little room for soft interpretations. What that implicates is a strategy where the decision making relies on there always being a right decision and a wrong decision. An example to this is the decision of having the solar panels either being integrated directly to the UPS or the entire hospital. The strategy presents a proceeding which does not consider the fact that a critical load is not labeled likewise for everyone. What is more critical, a baby warmer or an anaesthesia machine?

The economical dilemmas which are featured in projects like these are far from easy to comprehend. An investment in an UPS system is a capital intense investment and the question of using the funds elsewhere is not brought about in the strategy. The strategy does not look into a possible utilization factor which would have been interesting to consider. At what point is funds spent on another investment, that can increase the quality of the hospital, more evident? An halving of number of batteries will for most cases release a great amount of funds from the project as the cost for batteries constitute a great share of the overall cost. These funds could possible be used elsewhere and in a more efficient manner in order to increase the hospitals quality of activities.

The strategy eventually became a plan for courses of action which fully discounted any ethical dilemmas and instead only accounted for technical aspects. This was however the initial concept of the strategy. The intention of the strategy was hence to give the most perfect solution in terms of technical challenges and in some extent environmental challenges, but unfortunately not ethical nor economical. A desire for a strategy is evidently needed, so the encouragement of hospitals in East Africa to engage in UPS installments needs to continue. If hospitals in East Africa wants to develop into higher end technically advanced health care institutions, a UPS technology needs be in order.

The case study fulfilled an important role in the formation of the strategy. Instead of presuming on-site-conditions the case study provided genuine inputs to the strategy. The importance of talking and interacting with personnel whom will operate close to the technology is important, unfortunately it was not brought in to the strategy in the extent that it might have should. The strategy is explicitly pointing to solar power being the best alternative of source of energy, but what makes solar power better than diesel power? A diesel machine is by far more cost effective than a solar panel but the option is still neglected. Here is probably where the strategy has its most evident world view clash.

9
Conclusion

A strategy for designing UPS systems for hospitals in Eastern Africa is presented a case study to verify and point out improvement to the strategy. First the necessary tools needed to perform the process of designing a UPS system using the strategy is presented followed by the actual strategy. A UPS system at Kolandoto hospital in Tanzania was designed and installed as a case study. The case study provided a high volume of important information to the strategy.

How to integrate the new UPS system with the current electrical system is also described. The electrical system should if needed be upgraded so that a sufficient level of safety is meet so that the risk of harm to person or property is minimal. The choosing of all important components is discussed with a focus on the UPS unit, the solar panels and the batteries. The choice of what UPS topology to use is mainly a matter of how big the need for power quality stabilization is. The solar panels should be dimensioned in accordance to the size of the load and the desired output from solar power. The type of battery to use is mainly influenced by the temperature of the room and the need for maintenance. If an expansion of load is to be conducted the current UPS system should be utilized to as a high degree as possible. This can be done by either connecting new UPS units to feed the loads or to expand current UPS units by running them in parallel with new UPS units.

9.1 Future work

How to expand a UPS system the most efficient is a topic of great value since many hospitals in the region is in a continuous state of expansion and as a result the electrical system needs to be able to expand as well. In this strategy solutions on how to expand a system is given but no testing on the solutions has been made. If any of the solutions for expanding a UPS system could be tried with a case study it would give a great amount of information on the efficiency and viability of the solutions proposed.

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A
Appendix

Critical loads at Kolandoto Hospital				
General Operation Theater (System 1)				
#	**Items**	**Quantity**	**Load [W]**	**Total Load [w]**
1	lighting tubes	23	36	828
2	Operation light (Small theartre)	1	300	300
3	Operation light (Large theatre)	1	400	400
4	Operation bed (Small theatre)	1	240	240
5	Operation bed (Large theatre)	1	240	240
6	Electrosurgical machine (large theatre)	1	1000	1000
7	Electrosurgical machine (small theatre)	1	1000	1000
8	Anaesthesia machine (small theatre)	1	320	320
9	Anaesthesia machine (large theatre)	1	320	320
10	Suction machine (large theatre)	1	220	220
		Total	4076	4868
Maternity theater (System 2)				
#	**Items**	**Quantity**	**Load [W]**	**Total Load [w]**
1	Lighting tubes	6	36	216
2	Operation light	1	300	300
3	Operation bed	1	240	240
4	Electro surgery machine	1	1000	1000
5	Anaesthesia machine	1	320	320
6	Suction machine	1	90	90
		Total	1986	2166
Maternity ward (System 2)				
#	**Items**	**Quantity**	**Load [W]**	**Total Load [w]**
1	Lighting tubes	8	36	288
2	Energy server bulbs	8	18	144
3	Suction pump machine	1	120	120
4	Baby warm air machine (In operation room)	1	800	800
5	Baby warm air machine (In premature room)	1	800	800
6	Oxygen machine	1	320	320
		Total	2094	2472
Private ward (System 2)				
#	**Items**	**Quantity**	**Load [W]**	**Total Load [w]**
1	Lighting tubes	17	36	612
2	Energy server bulbles	1	18	18
3	Oxygen machine	1	320	320
		Total	54	630
General ward (System 2)				
#	**Items**	**Quantity**	**Load [W]**	**Total Load [w]**

#	Items	Quantity	Load [W]	Total Load [w]
1	Lighting tubes	45	36	1620
		Total	36	1620
Paediatrics (System 2)				
#	Items	Quantity	Load [W]	Total Load [w]
1	Lighting tubes	17	36	612
		Total	36	612
Eye theater (System 3)				
#	Items	Quantity	Load [W]	Total Load [w]
1	Lighting tubes	8	36	288
2	Energy server bulbles	3	18	54
3	Microscopy machine	1	40	40
5	Operation lights	1	300	300
6	Anaesthesia machine	1	280	280
		Total	674	962

Overall total critical load	
System	Load [w]
1	4868
2	7500
3	962
Total (1+2+3)	12368