Norwegian University
of Life Sciences

Master's Thesis 2023 30 ECTS
Realtek

Load Management and Logging for Stand-Alone Power Systems

Monty J. Hatfield
Maskin, prosess og produktutvikling

Preface

I became passionate about humanitarian work at a very young age. It felt therefore only natural to apply to work for Doctors Without Borders (MSF) at the end of 2008, and consequently, go on my first assignment to a hospital in Sierra Leone in 2009. The next three years I continued working with MSF in various locations across Africa and the Middle East.

During one of these assignments, I had technical responsibility for the four hospitals that MSF was operating in Afghanistan. One night, my phone rang. One of the field hospitals had lost power. I asked what they had gone through the check list and if they had any idea what the problem might be. They responded, “*We don’t have any electricity*”.

As the head of the technical department, it was my responsibility to resolve the problem. I had to evaluate what might have caused the power outage and suggest possible solutions. Whether or not the problem could be resolved over the phone depended, not only on the nature of the problem, but also on the caller’s technical knowledge and the information they had access to. Quite often, I would need to go to the project location myself, involving both flights and car travel. Traveling was quite often difficult, dangerous, and time consuming.

I often encountered challenges with managing the electrical power supply to field hospitals in many countries. I knew there could be a more efficient and effective way to manage the power supplies of field hospitals. I therefore decided to build and test a flexible and easily implementable system to log and manage the electrical power supply to field hospitals, which resulted in the writing of this thesis.

Table of Contents

Abstract

Doctors Without Borders/Medecins Sans Frontieres (MSF), one of the world's largest medical aid organizations, operates field hospitals around the world, providing health care to millions. However, field hospitals are often located in environments where access to a quality electrical power supply is precarious, and MSF must often self-supply or supplement their electrical power needs. Thus, the management of the electrical power supply presents challenges to field technicians. In this thesis, a proof-of-concept system was designed to monitor, analyze, and control the electrical demands, using various sensors and inexpensive micro controllers. After building a replica electrical hospital network, a micro grid analyzer was developed which logged and calculated various real-time electrical values. Next, a wireless mesh system was built to connect or disconnect loads based on a collection of variables. This thesis demonstrates the possibility of using affordable off-the-shelf equipment to build a logging and control system for electrical power supply management for field technicians. Even though these systems will need to be further tested in the field, this thesis proves the concept and shows the potential for simple and affordable solutions to electrical power supply management for field technicians. Implementing such systems in field hospitals will provide more electrical stability in otherwise unstable environments, ultimately serving patients dependent on hospital care.

Abbreviations

Genset	Generator
HV	High Voltage
LCD	Liquid Crystal Display
LMG	Local Micro Grid
MCB	Main Circuit Board
TAPS	Total Active Power Supplied
MGA	Micro Grid Analyzer
MSF	Medecins Sans Frontieres (Doctors Without Borders)
NGO	Non-Governmental Organization
I	Current in Amperes
U	Voltage
R	Resistance in Ohms
Pf	Power Factor
PV	Photovoltaic
RSS	Received Signal Strength
SCADA	Supervisory control and data acquisition
Handshake	Initiation signal between two electronic devices
VA	Volt-amperes
WMLC	Wireless Mesh Load Control
YHDC	Beijing Yaohuadechang Electronic Co
UPS	Uninterrupted Power Supply
AVR	Automatic Voltage Regulator
Node	One device in a larger network
Busbar	Metallic strip used for electrical distribution in a circuit board
µF	Microfarad

1. Introduction

Health care is a fundamental human right. However, almost 9 million people die each year because of insufficient health care. According to Dr. Margaret Kruk, "quality care should not be the purview of the elite, or an aspiration for some distant future; it should be the DNA of all health systems" (HealthDay News, 2018, para. 3). Yet, annually, in middle and lower-income countries, 5 million people die from poor quality health care, and another 3.6 million people die because they lack access to health care (Kruk et al., 2018). Many aid and development organizations have made it their mandate to reduce this number. One of the largest aid organizations is Doctors Without Borders, hereafter referred to as MSF (French: Medecins Sans Frontieres). As an aid organization, MSF works to enhance the quality of and access to health care by building and running hospitals in areas where the in-need population resides. These hospitals are referred to as “field hospitals[1]”.

All field hospitals need medical staff, medicine, and biomedical equipment, but there is also a magnitude of logistical and technical support required for a hospital to function properly. This can include water and food supply, wastewater management, refrigeration, transportation, ventilation, and the maintenance of physical structures (Medecins San Frontieres, n.d. a). These examples of logistical and technical support are not exhaustive, and more subcategories could be included. However, one increasingly critical aspect of running a field hospital is the electrical power supply. This can be partly attributed to the increased sophistication of biomedical equipment, but also a consequence of the general digitalization of today’s world. In addition, inpatient hospitals, which require 24-hour care and 24-hour electrical power, are increasing in number and their infrastructures are becoming more advanced.

Yet, as reliance on electricity increases, a stable electrical supply can be challenging to maintain in field hospitals (Ten-Palomares & Motard, 2019). Many field hospitals are located in areas that are or have been affected by war, natural disasters, long term poverty, poor infrastructure, restricted and/or difficult access, and corruption. Often there is insufficient local electrical power

[1] The terms “Western” and “field” are used often across master's theses. However, these terms can be controversial. Although the author would prefer to omit them, they are so widely used that omitting them became difficult for the purpose of this thesis. In this document, a field hospital is nothing more than the local hospital for a given population.

and/or quality. Therefore, MSF must implement their own power supply solutions, often relying heavily on diesel generators. However, running generators comes with its own set of issues, including poor quality fuel, challenges in finding quality parts, a lack of qualified service agents, extreme temperatures, and even high altitudes. Each of these challenges require specific considerations when setting up a generator.

The electrical loading for a hospital is also dynamic and often unforeseeable. This adds a further set of challenges to the above-mentioned. One solution for these challenges would be to have a person or system to constantly monitor a field hospital's power needs and act based on those needs. For example, a reliable person or system would ensure that each generator does not run for too long with a high load, loads that are no longer needed are shut off, heating or pumping of water happens during low power-demand periods, and the parameters of the power consumption are logged for future reference. Attempting to do this with human resources is neither practical nor economical. Therefore, there exists a need for developing a system that can monitor and log all power consumption within a field hospital and intervene when necessary. This type of system would allow for the disconnecting of lower-critical loads in an attempt to continue electrical supply to high-critical loads in the event of a total system overload. In addition, relevant data on the electrical system will be logged for later review.

The goals for the system were to reduce the number of unplanned power cuts and "waste" of electrical power in MSF field hospitals, to gain a better understanding of power consumption trends within existing facilities, and to enable the use of large-scale data collection to improve current and future electrical installations.

The objectives of this thesis are:

1. To assess the capacity for monitoring the electrical supply for field hospitals using simple, affordable, and easily accessible technologies/equipment.
2. To design and test a proof of concept that can log and control some electrical loads.

2. Background

2.1 Electrical supply systems

Large-scale electrical grids are a network of cables and electrical components that allow the transfer and delivery of electrical power to the end user. They can also be referred to as power grids, and in some countries, national grids. To reduce $I^2 R$ losses (heat losses) in transfer lines, the grid is often divided into segments with different voltage levels. Transformers are used throughout the grid to increase or decrease this voltage.

One large electrical grid can be understood to be many smaller, individual electrical grids or supply systems joined together. Smaller electrical grids can also be referred to as micro grids. Another common term when referring to these systems is islanding. Islanding refers to a smaller independent grid or a section of a main grid that has been separated from the main grid for some period of time. This grid section is then supplied with power sources that already exist within the separated section or temporary power sources that are installed within the grid. Typically, this temporary power generation is from diesel generators.

All electrical grids need to be managed and monitored to ensure that they are operating as intended. Overloading spinning-based power production will result in a decrease in frequency, whereas rapid de-loading can result in an increase in frequency. Ultimately both scenarios could lead to a blackout. To avoid this, large grids have networks of sensors and monitoring systems which follow the real-time values of the grid to ensure that power stations compensate for fluctuating loads (Van der Veen, 2016). Thus, sensors and monitoring systems help to ensure a stable supply of electricity. This is called power system balancing (Van der Veen, 2016).

One tool for managing overload in electrical grids is load shedding, meaning that one or more loads are quickly disengaged from the grid. The practice is used by system operators to match demand with their power station's current *intended* output (Rudez & Mihalic, 2009). It is normally a last resort option but has fewer negative consequences than a total blackout and has an almost instant response time, making it attractive from a technical standpoint (EEP, n.d.).

In all but very small (<10-12kW) electrical systems, 3-phase production and distribution is the most common form of production and distribution. It is always desirable to have the loading divergence of the three phases as low as possible. This helps to reduce the negative sequence component, keeps neutral line currents low and gives a more stable/continuous loading for the diesel engine.

As the majority of loads within most electrical networks are single phase there is always some degree of unbalanced loading. Below is a graph displaying how much these loads can vary in a micro grid setting over a 12hr period, both in their instantaneous values but also in their average trend value.

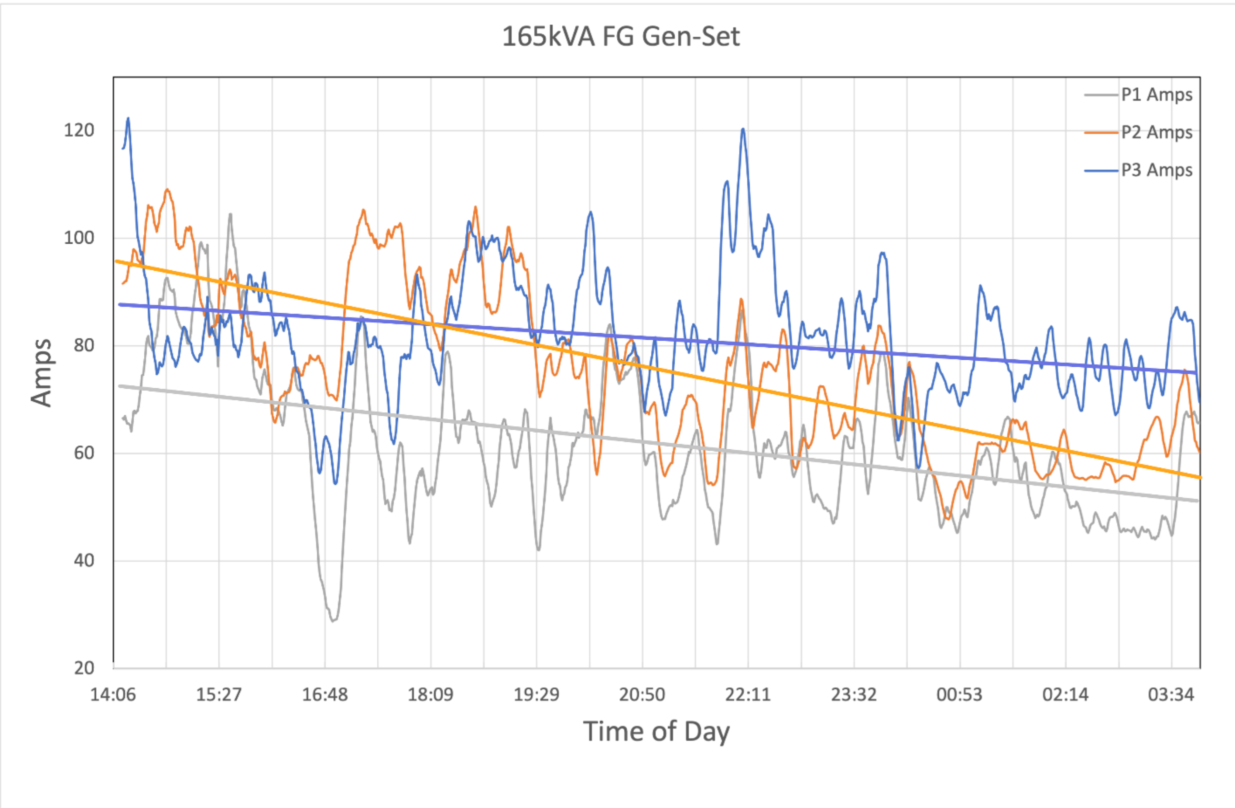


Figure 1: Line currents for a 165kVA FG Wilson generator located at an MSF hospital in Afghanistan between 14:06 and 03:34. The graph shows both the instantaneous values and the linear regression line for the period. Figure made by author.

In recent years, the term Smart Grid has become more common, and refers to the digital technology that is used to monitor and manage electricity in a network or a grid (Tuballa & Abundo, 2015). To achieve this, data needs to be collected and sent from different locations to allow for accurate decisions to be made. This can include the use of fiber optic cables that allow for a signal to arrive a few milli seconds before a change in current demand arrives at a generation station. It could also include the use of Big Data where a central control location could learn what is likely to happen to the loading in part or all the grid based on data from previous periods. Trying to run a country-wide smart grid of today's standards without this data and the technologies associated would be impossible.

While power is distributed through cables, data can be sent wirelessly. When dealing with the transmission of data, senders and receivers can be set up wirelessly, such as in a mesh system. A mesh system or mesh network is a lattice-type formation of three or more transceivers (nodes) that can relay information and allow for good signal coverage without the need for very powerful transmitters or very high towers. “A wide service area is divided into many small cells and the frequency spectrum is reused among areas that are separated from each other” (Yamao, et al. 2002, p.61). Mesh systems were first used on a large scale in the 1970s by the US military (Ellis, 2020), and the concept has since been used for countless applications from satellites to mobile phone towers to Wi-Fi networks.

2.2 MSF

MSF was started by a group of 12 doctors and journalists in 1971 (Medecins Sans Frontieres, n.d. a). MSF was awarded the Nobel Peace Prize in 1999 in recognition of the organization’s pioneering humanitarian work on several continents and operates in more than 70 countries worldwide. MSF has an annual budget of over 1.6 billion USD, of which more than 95% comes from private donors. They only use 4.5% of their funding on management and general administration, and in 2019, they treated over 10 million patients (Medecins San Frontieres, n.d. b). At its core, MSF is a medical organization, which strongly influences the way it operates in the field. While the strong medical focus is beneficial to MSF’s activities, technicians can occasionally have difficulty being heard when it comes to equipment needs or technical improvements.

Field hospitals are often chaotic places, where priorities constantly change, and areas of activity are always moving. Directly implementing western equipment and systems in such environments can be difficult, especially with the wide variety of cultures, traditions, and work ethics. For example, implementing a roster program can be a hurdle, since weekends are defined differently around the world. In Iraq, the weekend is Friday to Saturday, in Afghanistan the weekend is Thursday and Friday. Additionally, the physical environment can be unfavorable to sensitive medical equipment, as most medical equipment anticipates a certain level of stability and agreeable conditions.

As field hospitals are highly dynamic places, electrical power demands continually fluctuate both within sections of the hospital and across the whole hospital. Load variations may result from something as simple as the sun shining on one section of the hospital resulting in a need for cooling that area or because one type of machine is used more at a certain time of the day. In addition, emergencies such as mass casualty events can result in sudden load increases in the emergency department and operating theater. A typical MSF hospital ranges in size from 20 beds to 500 beds. Yet, the electrical power consumption does not always correlate to the bed capacity of the hospital. The electrical power needs are often more dependent on the type of hospital services and the local climate, but a typical range is from 15kVA to 500kVA.

As most loads are single phase in field hospitals, phase balancing is often a problem, and having phases out of balance can lead to electrical shutdowns. Due to the size of a micro grid each load represents a much higher percentage, per phase, of the total load than would be normal in a national grid setting. Moreover, it is not uncommon for the electrical network to be modified during or directly after mass casualties, external attacks, fires/floods, or other emergency events. Due to the severity and urgency of these situations, very little planning is given to what loads are put onto what phase. Having statistical data about the electrical system would allow easier identification of which phases are loaded higher or lower at what times of the day, which in turn would help to solve this problem.

Electrical power is sometimes available from a national grid, but often this electricity is unstable and of poor quality. If a hospital in a Western country lost power for more than 10 seconds, this would be considered unacceptable. Losing power, however, happens daily in many field hospitals. The staff in field hospitals are quite used to this scenario and have systems in place to continue working while the power supply is out for a few minutes. However, the procedures for working without power can only last so long, and eventually everything will come to a stop. One major way MSF tries to correct for unstable and poor electricity is to self-supply or at least supplement. Therefore, MSF is heavily reliant on diesel generators for their field operations. Most hospitals run more on generators than on grid electricity, and sometimes only on generators.

Three phase gensets have been around since the 1890s and can be found in most corners of the world. If a genset is available on the local market there is a good chance that the fuel it uses, the spare parts it needs, and the service technicians can also easily be found locally. The combination of these factors makes them a high contender for electrical supply needs. The biggest advantage of using gensets is their response time. In acute situations, such as a natural disaster, sudden outbreak, or escalation of a conflict, a stable electricity source can be ready within 10-60 minutes of getting a genset on the ground (Boldea, 2017).

In situations where there is little or no available electrical power from the grid, MSF implements their standard setup of two large and two small generators (Figure 2). One large generator is capable of supplying all the needs of the hospital in the peak time of day or peak season. One small generator is sufficient to supply all the needs of the hospital in the off-peak times of the day or in the off-peak season. With this set up, there is always an equally sized backup generator for the one that is currently running.

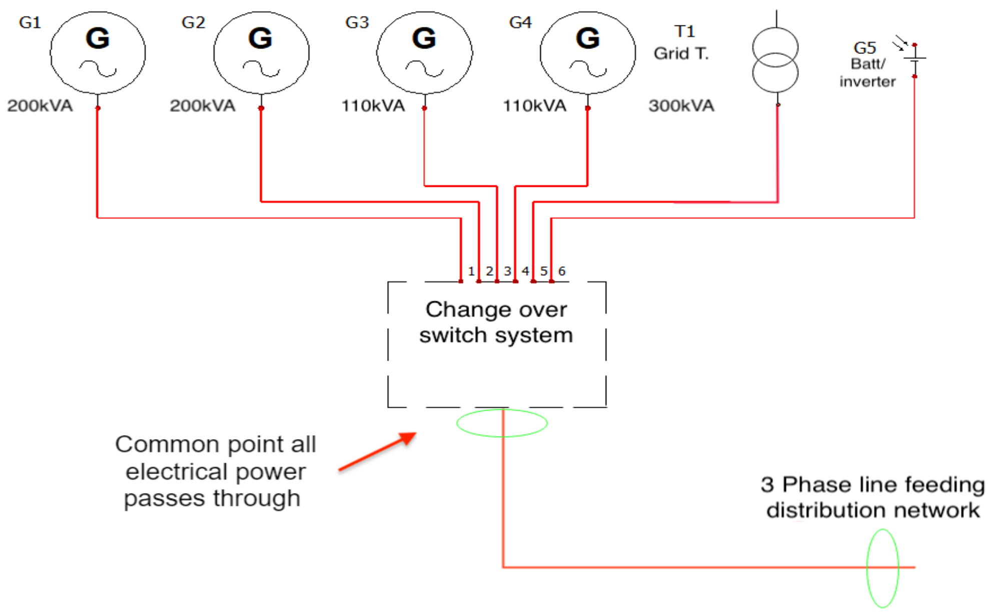


Figure 2. The figure shows one configuration of a field hospital power supply, including the 4 standard generators, one transformer, and PV/battery option. Single lines and single-phase symbols have been used before the changeover switches to maintain an easy overview.

Instead of having only one generator running all loads at once, synchronization of two or more generators is gradually becoming more common within MSF but is still quite rare. These systems often need to be purchased internationally and it is not always easy to find service/installation personnel.

Depending on the loading conditions, quality of service/parts, and fuel quality, a 3-phase diesel generator should last somewhere between 12,000hr to 20,000hr (Worldwide Power Products, n.d.). Unfortunately, they often last a lot less than this in field settings. The MSF standard is to replace any generator requiring significant repairs if it has accumulated more than 10,000 running hours (Goicolea, I, personal communication). They are also expensive to run with some MSF locations paying in excess of 0.41 USD per hour per kW.

The MSF guideline for generator running time is eight hours before the generator is given a period of rest. This lets it cool down and allows the technicians to check various fluid levels, and generally inspect the genset. As well-intentioned as this guideline might be, there are many factors it does not take into account. For instance, there is no allowance for the loading, air-temperature, altitude, or condition of the generator made with this model. All these factors can significantly affect the capable running time of the generator, especially if it is running close to its maximum output. Employing local technicians to monitor these variables and calculate running hours based on them would be a solution, but this is prone to human error and would also require a level of math seldom found in many of the context's MSF works.

Supervisory control and data acquisition (SCADA) devices/systems already exist on the market and can monitor/log most of these parameters, but as mentioned earlier implementing western systems in field settings is often problematic. Additionally, these systems tend to be costly and lack flexibility (AEMC Instruments, n.d.; Data Centre Safety, n.d.).

In addition to gensets, hybrid battery/generator and PV/battery systems are sometimes utilized. Solar systems are generally less used as the short-term planning and budget cycles within MSF, and humanitarian actors in general, limit opportunities for longer-term solutions that require higher initial investments. While these set-ups are slowly becoming more popular within MSF, they are often more complex to install, more expensive and it is harder to find qualified local technicians for installation and servicing. Also, these pieces of equipment are smaller and lighter and often more susceptible to theft, but generator fuel is also prone to theft. For these reasons, their incorporation into the MSF electrical supply system has been slow and the need for gensets will endure for some time (M. Ten-Palomares, personal communication).

3. Methods

The problem being addressed in this project was identified through the author's personal and professional experiences working as a technician for MSF. Much of the brainstorming was done during field work with MSF, however, an initial research phase was done to identify what technologies and components were available to build the solution.

Firstly, the solution was designed around tools and software that MSF already uses in the field, and sensor equipment that minimized invasion into the existing electrical setup. It was important to keep the cost as low as possible, as MSF always strives to prioritize funding their medical activities (Ten-Palomares & Motard, 2019).

Next, the solution should be resilient and flexible, characteristic to make sure the solution could be easily implemented and practically feasible in often challenging field environments. Therefore, the solution included inexpensive and readily available components that were modular based, allowing components to be easily replaced if needed.

Construction and testing was performed at the Norwegian University of Life Sciences (NMBU) in Ås, Norway.

REPLICA FIELD HOSPITAL:

Initially, a replica field hospital was constructed to enable the testing of the data logger (MGA). This 3-phase electrical network replica of a typical field hospital was created using the following equipment:

- 12 - Relay 5V/230V 1 CH Relay Module
- 2 - Arduino Uno R3 AtmelATmega328 Micro controller Board
- 30 - 5 Watt (5W) Ceramic Cement Power Resistor (varying Ohms values)
- 3 - Toroidal transformer 220/48VAC
- 1 - Access to a 3-phase outlet

Six sets of three main resistors (Figure 3) were connected in wye formation to represent three single loads fed by one 3-phase distribution line. A total of 12 extra resistors (Figure 3) were connected via the relay enabling the resistor to be randomly bypassed or engaged by the Arduino. For safety reasons the 3-phase power supply to this circuit was reduced to 48VAC using three Toroidal Transformers. Even though this setup would only give resistive loading it was deemed adequate for testing purposes.

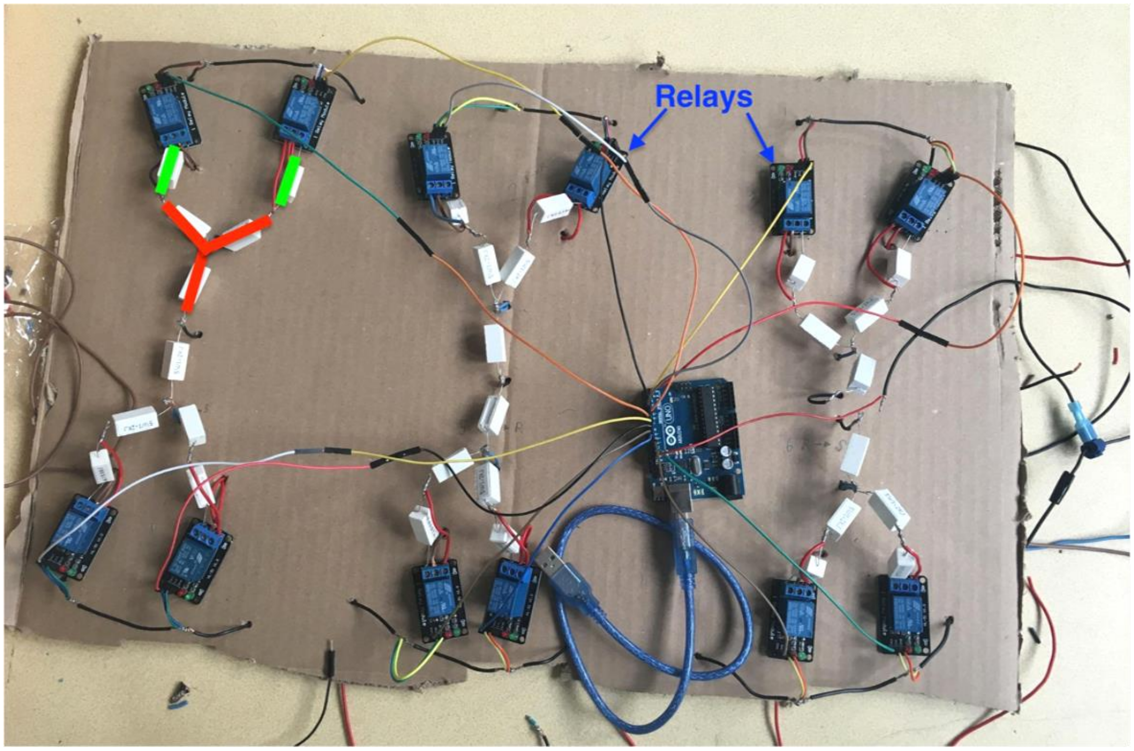


Figure 3: Here the electrical network replica of a typical field hospital is shown. One of the 3 phase wye connections is indicated in red, and the two green lines indicate two of the resistors that can be either bypassed or engaged by the Arduino.

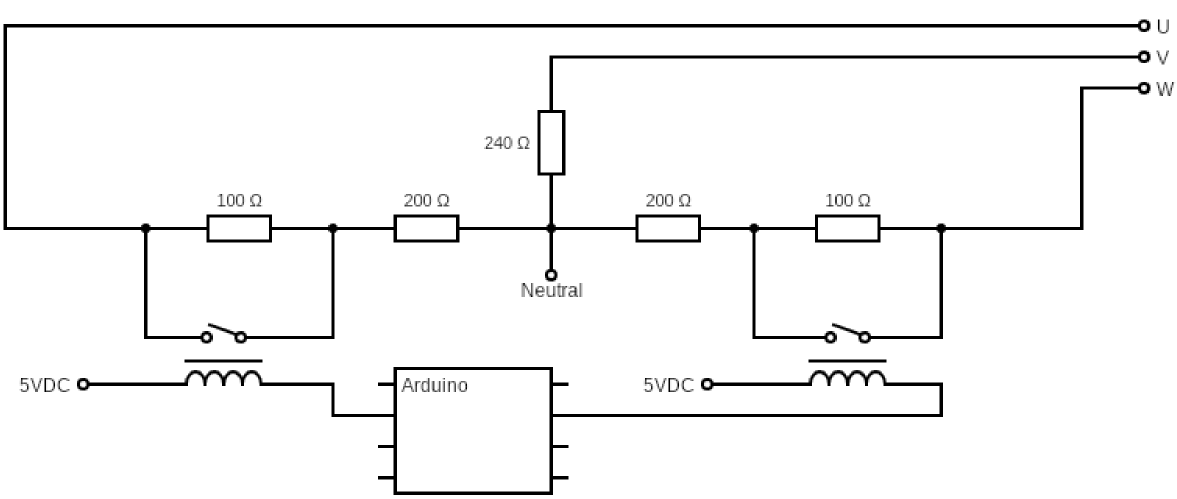


Figure 4: Schematic diagram for a wye connection represented in part of the replica hospital.

MICRO GRID ANALYSER:

After the replica hospital was built and functioning, work could start on the monitoring system which was given the name Micro Grid Analyzer (MGA). The MGA obtained data from the replica hospital. The parameters of interest to obtain were current and voltage readings for each phase plus a current reading from the neutral line, a frequency reading, and a power source indicator to show which power supply was being used. The ambient temperature was also logged for use in the run-time calculations as well as a time stamp. The following equipment was used:

Figure 5 Many turns of enamelled copper wire were wrapped around 50-amp sensors to give a measurable current reading.

- 4 - YHDC Non-invasive AC Sensor Split 0-50A (Core Current Transformer)
- 3 - Single Phase Voltage Transformer Module Sensor Amplifier ZMPT101
- 1 - I2C Logic Level Converter
- 1 - SanDisk 8GB C4 SD SDHC Standard Class 4
- 1 - DS3231 AT24C32 Memory Module for Arduino IIC Precision RTC
- 1 - SD Card Module Reader for Arduino ARM MCU Read and Write 2x
- 1 - Arduino Mega2560 R3 Compatible Board with CH340G
- 1 - 1602 LCD I2C 16x2 Display Module

The MGA needed to have a quick startup time due to the anticipated power cuts experienced throughout a normal working day. On a full-scale version visual and audible alarms would be required to signal sensor values that were out of range. Data retention was set to a minimum of two years with a maximum of one second between each data point.

To ensure the MGA encroached as little as possible on the existing LMG, non-invasive AC current sensors were used thus circumventing the need for cutting/disconnecting supply cables.

For the data logging to have a useful effect on protecting the accumulative loading of the generator, a series of assumptions were made and are listed below.

- There are no synchronous capabilities between the hospital’s potential power sources and therefore a maximum of one power source at a time.
- Standard generator running time is 8 hours.
- Non-critical loads do not use the same supply lines as critical loads.
- There is one single 3-phase connection point where all power is passing through, enabling the collection of data at that point as seen in Figure 2.
- There is someone on site with the knowledge needed to remove an SD-card and transfer the needed files to a computer as well as sending them via email if needed.

WIRELESS MESH LOAD CONTROLLER:

The wireless mesh control system, referred to as the Wireless Mesh Load Controller (WMLC) from here, allows for the disconnecting and reconnecting of loads throughout the hospital without the need for running control lines to each load. The following equipment was used:

- 30 - 433Mhz HC-12 SI4463 Wireless Serial Port Module 1000m
- 30 - Arduino Nano ATmega 328 V3.2 Board CH340
- 1 - I2C Logic Level Converter
- 1 - SanDisk 8GB C4 SD SDHC Standard Class 4
- 1 - DS3231 AT24C32 Module for Arduino IIC Precision RTC Real Time Clock
- 1 - SD Card Module Slot Reader for Arduino ARM MCU
- 1 - Arduino Mega2560 R3 Compatible Board with CH340G USB
- 1 - 1602 LCD I2C 16x2 Display Module

Originally two transceivers were tested, the HC12 433MHz and the XBee 2.4GHz. Both units performed well but have several differences which are displayed below (Table 1.).

Table 1: Technical comparison between XBee and HC12.

	Xbee	HC12
Base frequency	2.4GHz	433MHz
Line of sight range	1300m	850m
Number of 25cm concrete walls penetrated (bypassed)	1-2	3-4
Mesh protocol software	Yes	No
Received Signal Strength	Yes	No
Plug and play	Yes	No
RSS function	Yes	No
Price	700kr	45kr

The XBee was the more user-friendly unit to work with, as it had an impressive range and software, but its cost was its biggest downfall. The HC12 also displayed impressive signal strength and stability, especially when it came to obstacles, but because of its lack of preloaded software it required a lot more programing to be suitable for this project. It was also ca. 10 times cheaper. However, the HC12 has no inbuilt RSS (Received Signal Strength) indicator and each HC12 needs its own dedicated micro controller (Arduino) adding another 30-40 NOK to the price.

All in all, the HC12 was selected because of its price, simplicity, and signal range. The HC12 is a half-duplex, 100mW wireless transceiver with 100 channels operating in the 433.4 to 473.0 MHz range. It also has eight different power settings with 100mW being the maximum. It comes with its default set to maximum power, which gives a line of sight signal up to 850m and an indoor signal range of about 100m depending on the environment. The default channel for all HC12s used was changed to channel 17 to reduce the likelihood of interference from other users.

The following assumptions were made when designing the WMLC:

- That permission would be granted to use the 433MHz bandwidth in the country of installation.
- Installing a wireless system would be cheaper, easier, and more flexible than installing a wired system.

- Someone on site needs to have a basic understanding of radio signals and what can block them.

The WMLC was designed to be installed in electrical networks where there was a need for controlling certain loads. The Arduino family of micro controllers and compatible sensors were selected because of the price, modular design, and open-source software.

Within this design, the system proposed does not offer the ability to monitor distribution lines, rather the only data produced will be based on/relevant for the total electrical power used by the hospital. Additionally, any existing system that requires the inline insertion of new components, for example contactors, into a power fed line will come with added risks.

The final prototype allowed for the logging and processing of data as well as running calculations based on the outside air temperature, total power supplied, and power factor. In addition, values would be stored for later reference. Figure 6 displays a full visualization of the system where the total load on the running generator is within its limits and therefore the risk of an overload shutdown is low. It also displays that all contactors for non-critical loads are closed.

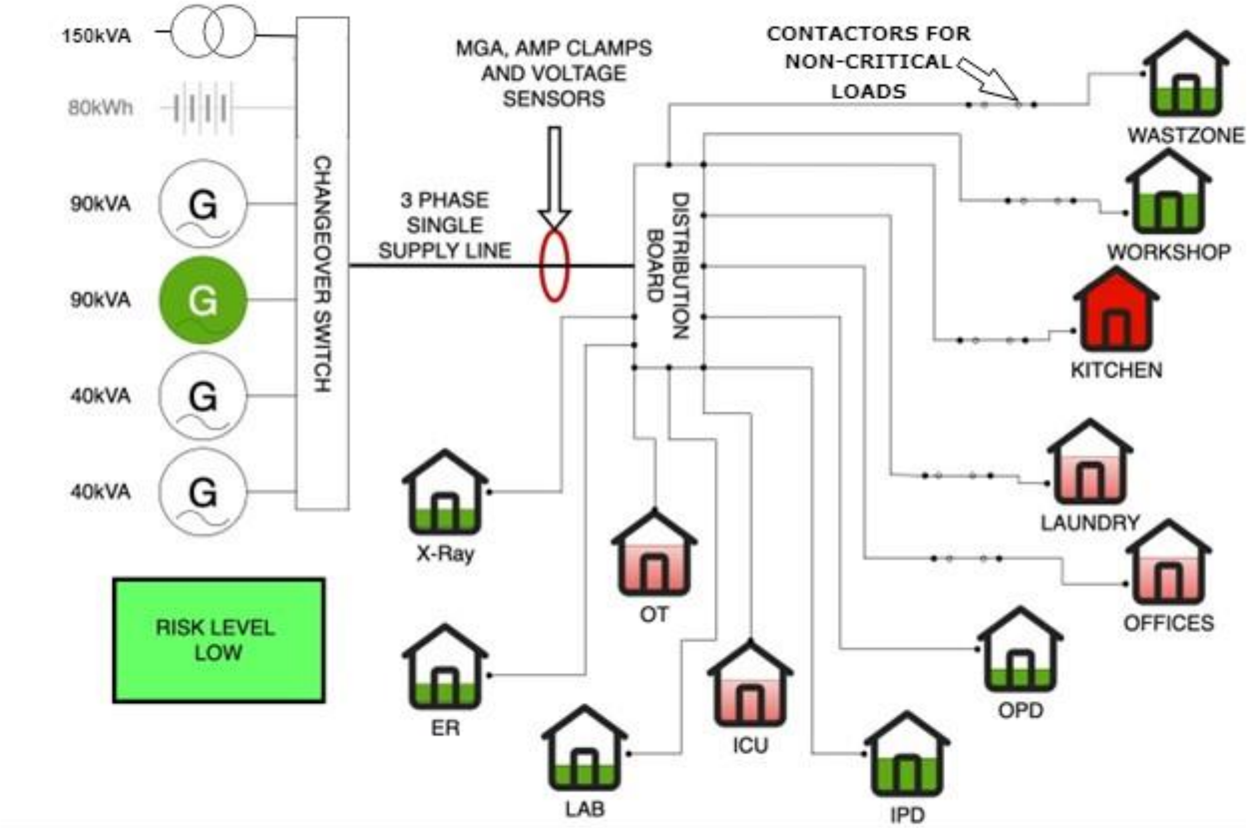


Figure 6: visualization of full system with a potential of six different power supplies as well as critical and non-critical loads.

4. Results

The goal for this project was to design and test a proof of concept that could be used to improve the electrical stability, loading, and fuel consumption for the generators and manage loading by connecting and disconnecting loads in MSF field hospitals.

4.1. Micro Grid Analyzer (MGA)

Programing the MGA included designing an interface so that data could be entered for the hospital that would be monitored. When starting to program the MGA, an excel file was made to store all the information about the simulated LMG (Local Micro Grid). This excel file was named infoFile. The infoFile is the only file that needs to be filled out before monitoring can begin. The file was kept as simple as possible, and warnings were added for possible user errors that could occur (Figure 7). After the parameters were entered into infoFile, it was saved as a .csv file. The .csv file was saved onto an SD card to be read by the MGA (Micro Grid Analyzer). InfoFile.csv was opened by MGA and used to define the limitations for each power source during the power source's run time.

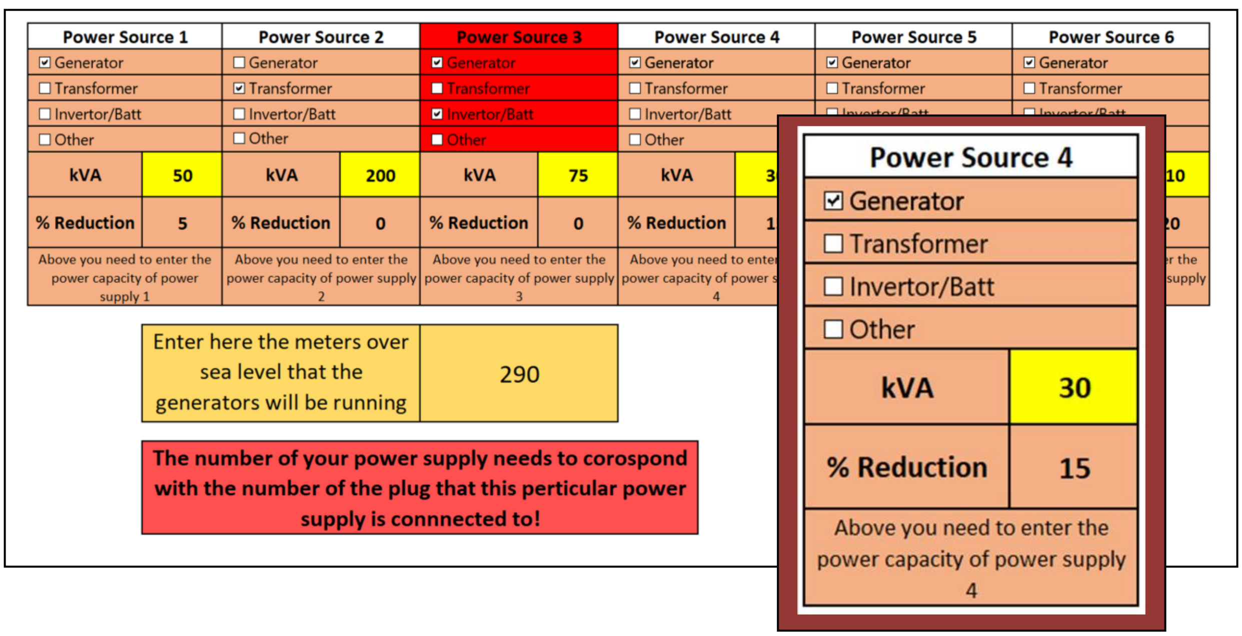


Figure 7. Demonstration of a built-in fail safe: The MGA is programed to default to the setting of generator if more than one power supply is selected in one of the Power Sources. The red column indicates to the user that two power sources were entered into "Power Source 3" and the user has made a mistake.

The MGA was programed to create a folder structure as shown in Fig. 8.

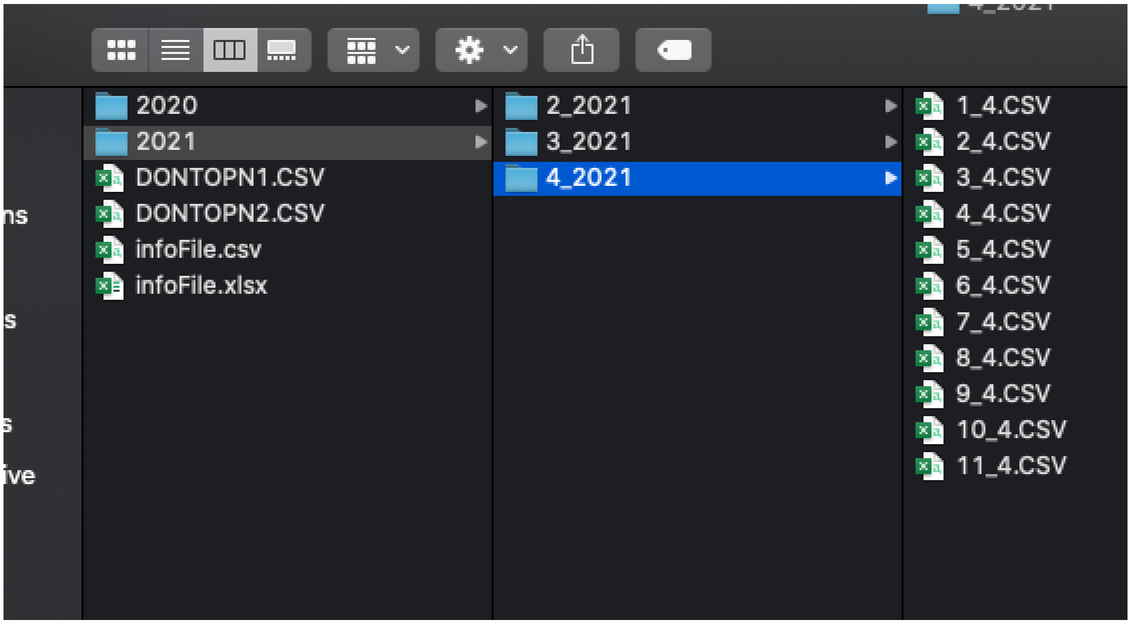


Figure 8. This figure displays the normal folder structure that is found on each SD card. The only two files that were present when this card was first installed in the MGA were the two infoFile's, while all other files were created by the system.

The MGA was programmed to make a folder for the year and then for the month when it starts. It then makes a .csv file for the day which results in a folder/file structure as shown in Fig. 8. It also places headings at the top of each column in the .csv file indicating what the below data represents.

It was necessary to incorporate a runtime log into the MGA because, as mentioned in the background section, to accurately know when one generator should be changed over to another requires some calculations. The runtime log was programmed to keep track of all the individual generators' runtimes. Calculations for how long a generator should run before it requires a break are made by taking into consideration the percentage loading, outside air temperature, altitude, and percentage reduction that is shown in Fig. 7 all of these values are saved to the SD card.

Once a genset is stopped the runtime counter for that genset will start to reduce the accumulated runtime based on the outside air temperature. This will continue to happen until the runtime counter is back to zero or until the genset is restarted and the counter starts to accumulate again.

Run times for each power source were logged in two .csv files called DONTOPN1 and DONTOPN2. These files are created by the MGA and are not meant to be used or opened by the user. The reason there are two files is because they are sequentially being overwritten and if power is suddenly lost while writing to one of them, a backup is available. DONTOPN1 is checked on startup and if it is corrupt then DONTOPN2 is used.

Further testing was done with the MGA on a load bank (12kW/20kVAR) which gave the opportunity for more realistic current readings (Fig. 9). The rig was made up of 12 halogen flood lights with an effect of 1.0 kW each which gave a total resistive load of 12.0 kW. In addition, the rig had 12 capacitors at 100 µF, each giving a total potential reactive load of 20.0kVAR at 230V.

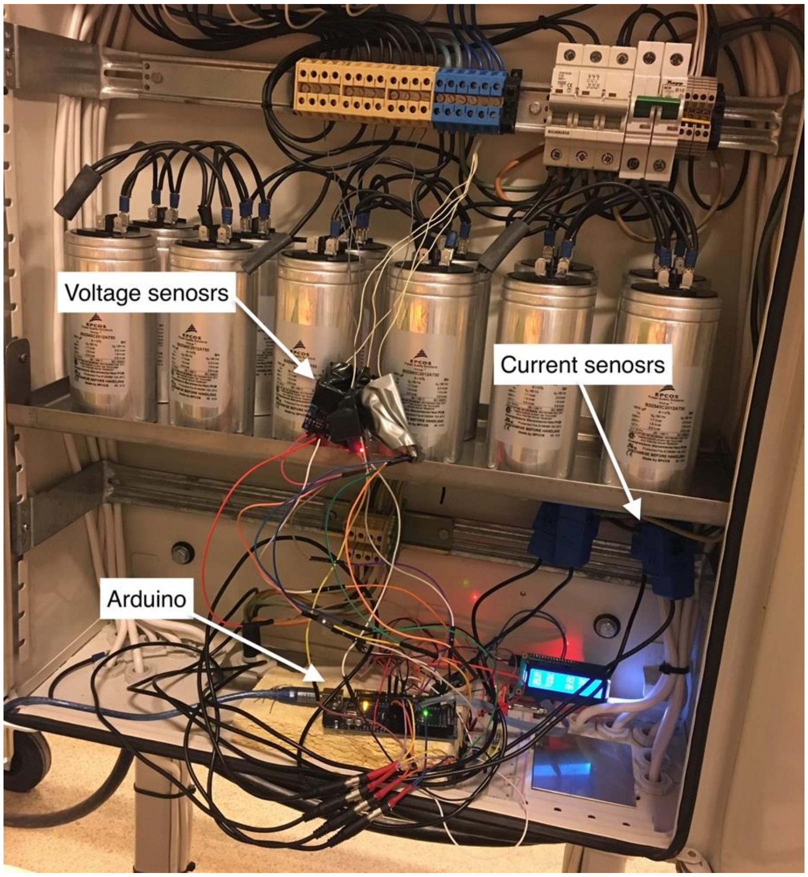


Figure 9. This image shows the MGA connected to the test rig.

$$Q = C \bullet 2\pi \bullet f \bullet V^2 \tag{1}$$

$$= 100 \bullet 10^{-6} F \bullet 2\pi \bullet 50Hz \bullet (230V)^2 = 20.0kVAR$$

The rig made it possible to test the MGA against theoretical values in a real-life simulation.

The Arduino used in this project had a clock frequency of 16 MHz. Yet, it was able to log four current values, three voltage values, one frequency value, one temperature value, a timestamp and the power supply source. In addition, it performed three power factor calculations and the accumulated consumption/overload calculation. All of this was done three times every second.

Having access to quality test equipment through NMBU allowed for the verification of these values.

Obtaining the data needed for the power factor calculations for each of the 3-phases proved to be more problematic than anticipated. Running tests using both the inflection point/zero crossing and the max/min of the sinusoidal wave continued to give sporadic inconsonances for roughly 1 in 150 measurements. Further testing needs to be done to rectify this problem but there are indications it may be linked to the choice/quality of the voltage and current sensors.

Fig. 10 shows that TAPS (Total Active Power Supplied) has reached a value of 87 kWh for the PowerS (genset no 4), based on the calculated capacity of PowerS 4.

Because 87 kWh is the maximum that this generator can deliver with the given variables, it should be taken offline. As indicated in red*, the overload indicator has been activated and, therefore, the PowerS has been changed from four to two (indicated in blue). As the test uses a simulated power supply, this change happened within a second, but in a field setting this would be done manually and would probably take several minutes. *Overload is still one in the next row because this is still in the same second and the Arduino does not update it before a new second has started. In real life this Power Source change would obviously not happen within one second but in most cases would take less than 5 minutes.

1	Time	Hz	Amps 1	Amps 2	Amps 3	Amps N	Volts 1	Volts 2	Volts 3	pf1	pf2	pf3	Temp	PowerS	TAPS kWh	OverLoad
9222	22:14:05	49,96	0	4,06	4,06	4,06	236	238	235	0,84	0,89	0,88	23	4	86	0
9223	22:14:05	49,32	0	3	3,88	3,88	236	238	235	0,84	0,89	0,83	23	4	86	0
9224	22:14:06	49,9	0	8,47	8,11	7,94	235	236	233	0,83	0,88	0,87	23	4	86	0
9225	22:14:06	50,48	3,7	11,99	16,4	11,43	235	232	232	0,89	0,93	0,92	23	4	86	0
9226	22:14:06	49,92	3,88	16,4	19,22	13,9	235	232	232	0,86	0,94	0,91	23	4	86	0
9227	22:14:07	49,92	4,41	16,23	18,52	13,9	235	233	229	0,85	0,93	0,89	23	4	86	0
9228	22:14:07	49,92	3,7	10,58	16,4	11,43	235	232	232	0,83	0,93	0,88	23	4	86	0
9229	22:14:07	49,92	3,88	12,52	16,4	11,43	235	232	231	0,88	0,88	0,88	23	4	86	0
9230	22:14:08	50,52	3,7	11,99	16,23	11,25	235	232	232	0,89	0,88	0,93	23	4	86	0
9231	22:14:08	50,52	3,7	12,7	15,87	11,25	233	232	231	0,84	0,87	0,93	23	4	86	0
9232	22:14:08	50,52	3,53	12,7	16,4	11,43	233	233	229	0,83	0,93	0,92	23	4	86	0
9233	22:14:09	49,92	3,7	12,52	16,58	10,9	233	233	232	0,84	0,88	0,88	24	4	86	0
9234	22:14:09	49,92	3,7	12,52	16,58	11,08	235	232	231	0,84	0,88	0,89	24	4	86	0
9235	22:14:09	49,88	3,7	12,7	16,58	11,25	235	233	229	0,83	0,93	0,88	24	4	86	0
9236	22:14:10	50,52	3,7	11,99	16,23	11,25	233	233	232	0,89	0,93	0,92	24	4	86	0
9237	22:14:10	50,52	3,7	12,35	16,4	11,43	233	233	232	0,88	0,88	0,93	24	4	87	1
9238	22:14:10	50,48	3,7	12,7	15,87	11,08	233	232	232	0,82	0,88	0,92	24	2	0	1
9239	22:14:11	49,96	3,7	11,64	16,05	11,25	233	233	231	0,82	0,88	0,89	24	2	0	0
9240	22:14:11	49,92	3,7	12,52	16,58	11,08	235	232	231	0,89	0,92	0,88	24	2	0	0
9241	22:14:11	49,92	3,35	12,7	16,58	11,25	235	233	231	0,83	0,88	0,87	24	2	0	0
9242	22:14:12	49,92	3,7	12,7	16,58	11,25	235	232	229	0,83	0,92	0,87	24	2	0	0
9243	22:14:12	49,93	3,7	11,11	16,58	10,02	233	232	232	0,83	0,92	0,87	24	2	0	0
9244	22:14:12	50,52	3,7	12,7	16,58	11,08	235	232	231	0,82	0,88	0,92	24	2	0	0
9245	22:14:13	50,48	3,7	12,7	16,58	11,25	235	233	229	0,88	0,88	0,92	24	2	0	0
9246	22:14:13	49,98	3,7	12,7	16,4	11,08	235	232	229	0,84	0,89	0,88	24	2	0	0
9247	22:14:13	50,52	3,7	12,35	16,4	10,73	235	232	229	0,89	0,88	0,92	24	2	0	0
9248	22:14:14	49,96	3,7	12,7	16,23	9,84	235	233	229	0,83	0,88	0,88	24	2	0	0
9249	22:14:14	49,88	3,53	12,7	16,4	10,73	235	232	231	0,83	0,88	0,86	24	2	0	0
9250	22:14:14	50,48	3,7	12,7	16,4	10,9	235	232	231	0,83	0,88	0,93	24	2	0	0
9251	22:14:15	50,48	3,53	12,52	16,4	11,43	235	233	232	0,84	0,93	0,93	24	2	0	0
9252	22:14:15	49,92	3,7	12,7	16,58	11,25	235	232	231	0,88	0,87	0,88	24	2	0	0

Figure 10. This table shows a portion of the collected and calculated data, 3 times every second. Column headings represent time, hertz, and the amps and volts per each line. The power factor for each line is represented by pf1, pf2, and pf3, respectively, and PowerS indicates the power source. Finally, TAPS is the total active power supplied.

4.2. WMLC - Wireless Mesh Load Control

The WMLC had one micro controller (Arduino) as the central controller and then up to a maximum of 30 receivers[2], however this could be increased if needed with some extra coding. Not having any preprogrammed mesh system for the HC12 meant the central control unit had to locate and identify each receiver unit it had contact with. After this was done, each of the found receivers were asked to identify which other receivers they could communicate with. This was continued until all findable receivers were found. This information was loaded into a matrix, which was then used to identify the five shortest routes for communication between the central unit and each of the receivers.

Having a matrix with the five shortest routes allowed for a “self-healing” system in the WMLC. If contact was lost with one of the receivers, then the second fastest route would be tried and so

[2] While the terms “Master” and “Slave” have been commonly used in the fields of electrical engineering and electronics, recent efforts have been made to change this terminology. For this thesis, I will instead use “sender” and “receiver”, respectively. I find this to work quite well as the receiver unit never sends out any signal without it being asked to do so by the sender.

on. This system was then tested with 30 receiver units covering an area of about 1 square kilometer. The receiver units were placed in different buildings around the university and surrounding houses, including basements and labs with a high volume of electronic equipment.

Once this was completed it was possible to use this network to turn on and off indicator lights on each of the micro controllers from a designated location. Testing the self-healing was also achieved by removing several of the receiver units to observe the change in path.

A test was also run where two new receivers were installed within the range of previously registered receivers. As they were not present when the WMLC was started they played no role in any communication, however once the WMLC was asked to run a new search (taking about 15 minutes) they were also added into the mesh.

4.3 Error factors

One of the down sides of using cheaper components is the higher chance of inaccuracies. In this project, the two most critical sensors were the voltage and current sensors.

The voltage transformer used was a ZMPT 101B. This transformer has an accuracy class of 0.2, giving it an accuracy of $\pm 0.2\%$ at $100\% - 120\%$ loading, but an accuracy of only $\pm 0.35\%\ at\ 20\%$* loading. This error continues to increase as the loading gets lower. However, as this sensor is measuring voltage and a voltage reading below 210V or above 250V would be considered critical, $\pm 0.25\%$ was used for the calculations.

Unfortunately, the same is not applicable to the YHDC current transformers as they have an accuracy of around $\pm 3\%$, and they are also not IEC Standard 60044-8 approved. Finding alternatives to these sensors with a lower error factor could be advisable, however this will likely result in an increase in cost.

To calculate the total accuracy when using these two sensors on one phase, the following independent random errors formula (Taylor, 1997) was used:

$$s_P = |P|\sqrt{\left(\frac{s_i}{i}\right)^2 + \left(\frac{s_u}{u}\right)^2} \qquad (2)$$

Where the total error is s_P and the values of 230 volts and 60 amperes were used on a pure resistive load was used.

Firstly, the kW calculation without errors $P = U \bullet I$

$$= 230 \bullet 60 \quad = 13.8kW$$

$$s_P = |13.8|\sqrt{\left(\frac{3}{100}\right)^2 + \left(\frac{0.25}{230}\right)^2} \qquad = \pm 0.414kW$$

This gives a variation of $\pm$ 3% using these values.

The value of $\pm$ 3% is relatively small and is within the safety margins in use, if however, this value was shown to be higher in further physical testing it would be possible add a *base* reduction to all power sources, like the one used in Fig. 7 this would help mitigate the error.

5. Discussion

5.1 Micro Grid Analyzer

Based on the work on the MGA, there are considerations that should be taken into account, both when it comes to the actual system, but also the system's potential use in the field.

Basing the data storage on an SD card platform allowed for simple and efficient downloading of data. Further enhancing the ease of use is the filing system. For this filing system, each day is created as a file and months and years are created as folders, which means that it is easy to navigate to the needed data. A compiled overview of the week/month/quarter period is not prioritized as this would take up both capacity on the SD card and the processing power of the Arduino. If this is desired, however, it can be done once the raw data is downloaded from the SD card.

Having access to the variable values of the LMG in an organized structure as mentioned above would help local technicians gain better insight into the electrical system and assist with solving LMG issues that arise. It would also allow different field hospitals to compare their data files, which could help foster a better general understanding of the hospital power systems and how to improve them.

Not all faults are electrical, some may be mechanical or even chemical (batteries). For example, a fault could be an intermittent problem with the fuel supply to one of the gensets. In this case, the MGA would still assist by recording data in the run-up to an involuntary shutdown and show there were no unexpected electrical occurrences preceding it.

One weakness with the MGA becomes apparent when the SD card is to be removed for downloading saved data. If the LMG is running, then data produced in this period will not be recorded. Values can, however, still be read from the LCD screen or a second card could be installed to reduce the amount of unrecorded data.

As stated above, the instantaneous values can be read from the LCD display on the MGA unit, also when the SD card is in place. In many cases, this will not be needed as most modern generators and inverters have a screen that displays this information. But for older generators and transformers this information is quite handy to have quick access to in one central location.

Not only would the MGA help in situations where someone is looking for a problem, it would also help when planning the activities for the daily operations of the hospital. For example, if there is a significant increase in the consumption of electrical power at a given time of the day, due to daily routines such as food preparations, then other routines like water pumping could be scheduled to fill the reservoir tank before this period. Another example could be to adjust the opening hours of the out-patient department because of extra loading on the LMG from the first load of washing.

The MGA would also prove beneficial for calculating the power and energy needs for future expansions of the hospital facilities and/or deciding whether to change the size of a generator when it is time for replacement. In both cases, it is a huge advantage to be able to go back and see the power needs throughout the year.

Having a warning system for when a power supply is overloaded based on relevant data is much better than having an eight hour “rule of thumb”. However, it is only better if action is taken based on the warning that is given. Such a warning system should first have a visual warning (blinking light) and if no one is responding, then an audible warning (siren). If there is still no response, the WMLC could be used to disconnect low priority loads to save the whole system from crashing. Having an SMS warning message would also be great, but it should not be relied upon as mobile phone networks in many of the places MSF works can be very unpredictable.

5.2 Wireless Mesh Load Control (WMLC)

There are many advantages with having a wireless system for controlling the non-critical loads. First, it is not necessary to run control lines out to each non-critical load making the installation process much simpler and less expensive. Secondly, working wirelessly drastically improves the flexibility of the system because adding or moving a disconnection point only requires the removal and installment of a contactor.

Making the mesh system required trial and error, especially when figuring out how each receiver was going to discover which other receivers it could communicate with. A better approach would be to exploit the fact that the power output of the HC12 is adjustable. It would have been possible to start with all the receiver units at the maximum power setting and the sender unit at the minimum power setting. A minimum strength signal would be sent out from the sender unit to see which (if any) receiver units could be contacted. The signal strength would be incrementally increased, and the process repeated. Entering this information into a matrix and then repeating this process for each new receiver found by giving it a temporary status of sender unit. On completion of this process, a matrix containing the 4-5 most secure pathways for data transfer for each receiver would be saved for later use.

The default channel of the HC12 is channel 1 out of the 100 possible channels, as mentioned this was changed to channel 17. It would have been good to have an option to change the channel across the board from the sending unit. This would have required some extra programming, as you would need to start at the outermost receiver units as well as making sure that you had contact with all receiver units before beginning. But it would provide the big advantage of being able to move all units quickly and easily to another channel if there was interference on the first channel.

Cyber security should be considered when doing further work on this project. The way in which the WMLC operates requires a signal to be sent three times before an action is taken, first from the sender to the end receiver and then back to the sender where it is checked to make sure it matches with the signal that was sent. After this check is done a confirmation signal is sent to the end receiver and the load is connected/disconnected.

Many of the structures MSF uses were existing structures, old hospitals or structures that have been modified/expanded many times, and it is often difficult to run extra cables if you want to have a tighter control on what loads have power at what time. The benefit of a wireless system would be much tighter control of non-critical loads as well as loads that can be selectively intermittent.

The sorts of loads that would typically be controlled with a wireless system like this would be heavier loads that are non-critical and maybe only needed during certain times of the day. But it could also include sections of a building that are not used on the weekends or nights. It would also provide the option to cut noncritical loads in an overload situation, if requested by the MGA. It would be advantageous to have a screen displaying the main values of the LMG in the technical office of the hospital. A screen would allow a technician to quickly observe the system in the event of lights flickering or the change in tone of a generator. If further investigation is needed, having access to the SD card from the MGA would allow a technician to review the latest data.

5.3. Other Power Analyzers

During the late stages of writing this thesis, the product Emonio was launched by a German company (Emonio, n.d.). This product has a lot of similarities with the unit that has been developed in this thesis. This could be interpreted as an indicator that there is a need for this type of device and MSF has already bought over 40 of them (Goicolea, I, personal communication).

Emonio has some extra features that are not offered with the proposed solution in this thesis. These include, a well-equipped interface and app, Wi-Fi connection, and encryption of the data. However, it still suffers from a lack of flexibility, inputs, and some critical options, it also cost 475 Euro for the base model setup.

Although there is some flexibility in the software of the system, it is very limited when it comes to hardware. Apart from the voltage and ampere inputs there are no other standard inputs or outputs apart from a Wi-Fi connection. There is however an optional temperature sensor that can be purchased, but this then eliminates the possibility of having extra data storage. Having limited inputs means the unit cannot take an active role in the electrical network unless it would be through some secondary device after the data has been processed coming from the Wi-Fi connection.

When the data is being recorded on to the Emonios internal storage, it is all dumped into one file until that file reaches a size of 64kB, then a new file is created. As this file will be created at some random point in time and because the file will be spread over several days without the start date logged in the file name it will make it quite difficult to find information from a specific day. It also stops logging data once the SD card is full whereas the MGA starts deleting the oldest data to make space for the new data.

In addition, the Emonio unit itself receives power directly from the network and it is also indicated that it has a maximum variation in the supply voltage of +-10%. Using this unit in locations where you are wanting to log grid power would most likely cause problems as voltage fluctuations can be much greater than +-10%. This is not as much of a problem with the MGA as power to the MGA first runs through a 5V DC power supply, this will help to stabilize the power, but it also makes it possible to power the MGA from another source than the network being monitored.

The Emonio unit does not have any form of warning system, or output. It is worth noting again that it would be possible to do this after the information is passed on via a Wi-Fi link, but that requires more hardware and software. Not having this function means that if a current, voltage, or frequency was going out of range it would not indicate this or disconnect the load.

There are however many advantages with the Emonio product. It was developed by a team of engineers with relevant experience within this field. It has also been on the market for over two years, giving the company both the experience and opportunities to iron out many of the early bugs in the system.

6. Conclusion

An LMG is critical to any field hospital; it could mean the difference between life and death. This thesis, therefore, set out to test a proof-of-concept for the monitoring and controlling of an electrical supply network to field hospitals in the MSF network. To achieve this, an MGA and WMLC were built to log all the supply variables within the electrical system and enable the wireless connecting and disconnecting of certain non-critical loads.

Problems cannot be solved, or improvements made in any complex system without having reliable data relating to that system. The tests performed in this thesis demonstrate the possibility to obtain this data while using inexpensive equipment in a non-intrusive manner. It also demonstrated the possibility of using inexpensive equipment in a mesh configuration to wirelessly connect and disconnect various loads throughout a small-scale electrical network/micro grid.

Having access to this data would give operators a better chance at running an efficient and more secure and continual electrical supply system. The data would help with finding faults in the LMG as well as support decisions on future changes or expansion of the LMG. These types of data can also be used to take immediate action based on real-time values, which make it possible to manipulate the system to improve electricity supply and stability. In this thesis, the MGA successfully monitored and logged electrical data from the replica hospital and NMBU's testing equipment.

7. Further Work

Both systems were designed and built in a Norwegian laboratory with a stable electrical supply and favorable environmental conditions. Even though the concept proved to be successful in a stable lab environment, more lab tests could be done with a rig that was designed to create unstable load and/or supply environments as well as possible user error situations. After this field testing could be done with even harsher conditions and environments as well as testing the user experience.

As mentioned in the Discussion, a more robust and reliable way to log the viability of each receiver would be to incrementally adjust the signal strength of each receiver during the initial search process. This would give a much better picture of the weak areas in the mesh system and allow for the addition of a repeater/dummy receiver to be installed.

External communication from the MGA and WMLC have not been covered in this thesis, the reasoning behind this is based on the writer’s field experiences. Very often if MSF tries to join many individual systems together to share information which almost never works well.

References

AEMC Instruments. (n.d.). Power and energy logger model PEL 103. Retrieved from https://www.aemc.com/products/power-analyzers/power-pel103

Boldea, I. (2017). Electric generators and motors: an overview. *DES transactions on electrical machines and systems, 1*(1). 3-14

Data Centre Safety. (n.d.). Fluke 1742 three-phase power quality logger. Retrieved from https://datacentresafety.com/product/fluke-1742-three-phase-power-quality-loggers/?gclid=CjwKCAjwtpGGBhBJEiwAyRZX2qu_IOtyFVISAxfbqoJexAQri3aR0mqw3e8QprGSYqjySzVk_paZ1RoCJjwQAvD_BwE

EEP. (n.d.). Load shedding for utility and industrial power system reliability. Retrieved from https://electrical-engineering-portal.com/download-center/books-and-guides/power-substations/load-shedding-power-system-reliability

Ellis, B. (July 30, 2020). How the US military helped develop mobile mesh networking. The Last Mile. Retrieved from https://thelastmile.gotennapro.com/how-the-u-s-military-helped-develop-mobile-mesh-networking/

Emonio. (n.d.). Emonio P3. Retrieved from https://www.emonio.de/en/content/10-emonio-p3

HealthDay. (September 7, 2018). Poor health care linked to 5 million deaths worldwide a year. Retrieved from https://consumer.healthday.com/public-health-information-30/health-care-access-and-disparities-news-752/poor-health-care-linked-to-5-million-deaths-worldwide-a-year-737440.html

Kruk, M., Gage, A., Joseph, N., Danaei, G., Garcia-Saiso, S., & Salomon, J. (2018). Mortality due to low-quality health systems in the universal health coverage era: a systematic analysis of amenable deaths in 137 countries. *The Lancet, 392*(10160), 2203-2212.

Medecins San Frontieres. (n.d. a). We are Medecins San Frontieres. Retrieved from https://www.msf.org/who-we-are

Medecins San Frontieres. (n.d. b). Financial independence and accountability. Retrieved from https://www.msf.org/reports-and-finances

Rudez, U. & Mihalic, R. (2009). Analysis of underfrequency load shedding using a frequency gradient. *IEEE Transactions on Power Delivery, 26*(2). 565-575.

Taylor, J. (1997). An Introduction To Error Analysis: The Study Of Uncertainties In Physical Measurements Second Edition - University Science Books

Ten-Palomares, M. & Motard, E. (2019). Challenging traditional energy settings in the humanitarian aid: experiences from Doctors Without Borders. The European Journal of Social Science Research. DOI: 10.1080/13511610.2019.1594718

Tuballa, M.L. & Abundo M.L. (2015). A review of the development of Smart Grid technologies. *Renewable and Sustainable Energy Reviews*, *59*. 710-725.

Van der Veen, R. & Hakvoort, R.A. (2016). The electricity balancing market: Exploring the design challenges. *Utilities Policy, 43*. 186-194.

Worldwide Power Products. (n.d.) How long do diesel generators last? Retrieved from https://www.wpowerproducts.com/news/diesel-engine-life-expectancy/

Yamao, Y., Otsu, T., Fujiwara, A., Murata, H. & Yoshida, S. (2002). Multi-hop radio access cellular concept for fourth-generation mobile communications system. *IEEE*. NTT DoCoMo. Kyoto University. P. 60-63

Appendix 1

Micro Grid Analyzer (MGA), price per unit				
	QTY	UNIT PRICE Kr	TOTAL NOK	TOTAL EURO
Arduino Mega	1	65	65	6,66
SD Card Holder	1	10	10	1,02
SD Card	1	40	40	4,10
AMP Clamp	4	50	200	20,48
Voltmeter	3	19	57	5,84
Clock	1	16	16	1,64
Clock Battery	1	20	20	2,05
Box	1	45	45	4,61
Phone charger	1	50	50	5,12
Wire, Plugs,	1	50	50	5,12
		Grand total	553	56,64

Wireless system, price per sender unit				
	QTY	UNIT PRICE Kr	TOTAL NOK	TOTAL EURO
HC-12	1	65	65	6,66
Arduino Mega	1	65	65	6,66
5VDC relay	1	18	18	1,84
Phone charger	1	50	50	5,12
Box	1	60	60	6,14
Other	1	60	60	6,14
		Grand total	318	32,56

Wireless system, price per receiver unit				
	QTY	**UNIT PRICE Kr**	**TOTAL NOK**	**TOTAL EURO**
HC-12	**1**	**35**	**35**	**3,58**
Arduino NANO	**1**	**28**	**28**	**2,87**
5VDC relay	**1**	**18**	**18**	**1,84**
Phone charger	**1**	**50**	**50**	**5,12**
Box	**1**	**50**	**50**	**5,12**
Other	**1**	**60**	**60**	**6,14**
		Grand total	**241**	**24,67**

The price for 3-phase contactors has not been included here as they would normally be locally purchased.

Appendix 2

Split core current transformer

Model: SCT-013 **Rated input current: 5A/100A**

Characteristics: Openning size: 13mm*13mm,

Non-linerity±3% (10%—120% of rated input current)

1m leading wire, standard Φ3.5 three core plug output.

Current output type and voltage output type (voltage output type built-in sampling resistor)

Purpose: Used for current measurement, monitor and protection for AC motor, lighting equipment, air compressor etc

Core material: ferrite

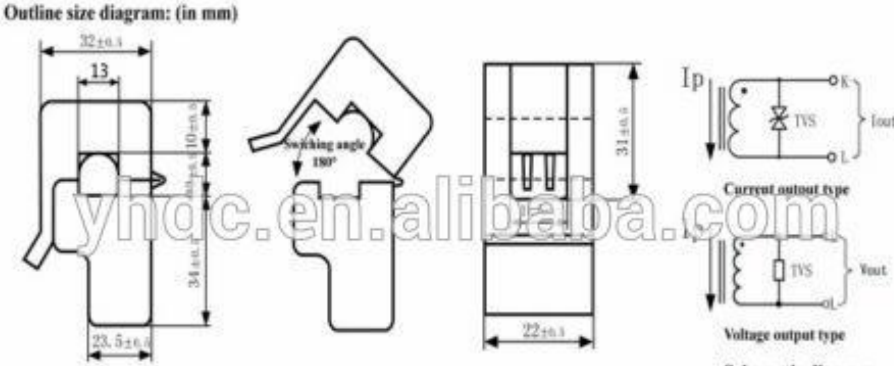
Mechanical strength: the number of switching is not less than 1000 times(test at 25℃)

Safty index: Dielectric strength(between shell and output)1000V AC/1min

Fire resistance property: In accordance with UL94-Vo

Work temperature: -25℃~+70℃

Outline size diagram: (in mm)



Front View

Side View

Schematic diagram

Three-core plug size

	X	Y	select
2.5mm Audio Plug	11.9	2.5	and use
3.5mm Audio Plug	15.0	3.5	standard

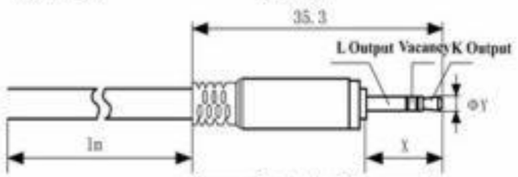


Diagram for standard three-core plug

Table of technical parameter:

Model	SCT-013-000	SCT-013-005	SCT-013-010	SCT-013-015	SCT-013-020
Input current	0-100A	0-5A	0-10A	0-15A	0-20A
Output type	0-50mA	0-1V	0-1V	0-1V	0-1V
Model	SCT-013-025	SCT-013-030	SCT-013-050	SCT-013-060	SCT-013-000V
Input current	0-25A	0-30A	0-50A	0-60A	0-100A
Output type	0-1V	0-1V	0-1V	0-1V	0-1V

※ Output type: voltage output type built-in sampling resistor, current output type built-in protective diode.

Beijing Yaohuadechang Electronic Co., Ltd

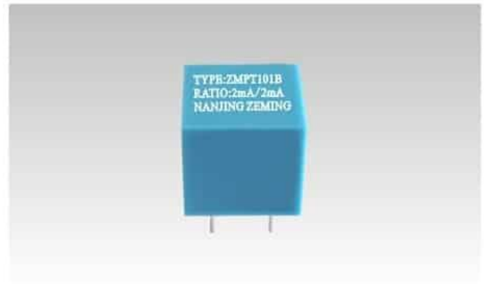
Web (China): www.yhdc.com Web (Latvia): www.yhdc.lv

Appendix 3

ZMPT101B VOLTAGE TRANSFORMER

Applications

* Sensing Overload Current
* Ground fault detection
* Metering
* Analog to Digital Circuits



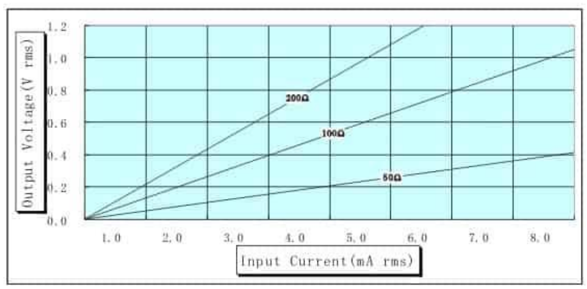
Product Illustration

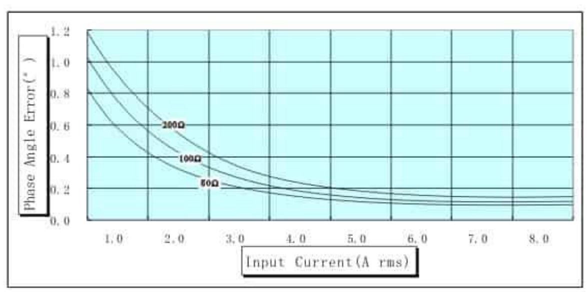
Electrical Specification	
Primary Current	2mA
Secondary Current	2mA
Turns Ratio	1000:1000
Phase Angle Error	≤20'(50Ω)
Current Range	0 ~ 3mA
Linearity	0.1%
Accuracy Class	0.2
Rated Burden	≤200 Ω
Frequency Range	50 ~ 60Hz
Dielectric Level	3000VAC/min
DC Resistance at 20℃	110 Ω

Mechanical Specification	
Cup	PBT
Encapsulant	Epoxy
Terminals	Pin ϕ0.80mm
Tolerance	±0.2 mm
Approx.Weight	13g
Case	Carton

Environment Specification	
Storage Temperature	-40℃ ~ +130℃
Insulation Resistance	>100 MΩ

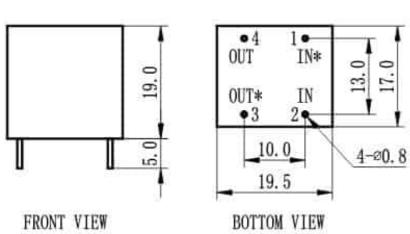
Output Characteristic





Dimensions(mm)

Same Polarity *



Label

TYPE:ZMPT101B
RATIO:2mA/2mA
NANJING ZEMING

Description: Micro Precision Voltage Transformers, with low price, small size and easy PCB mounting, are mainly used in electrical energy meters, household electrical equipment, industrial apparatuses, electrical testing equipment and relay protection, widely acclaimed as well.

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway