BRNO UNIVERSITY OF TECHNOLOGY
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
FAKULTA ELEKTROTECHNIKY
A KOMUNIKAČNÍCH TECHNOLOGIÍ

DEPARTMENT OF FOREIGN LANGUAGES
ÚSTAV JAZYKŮ

THE BENEFITS AND PITFALLS OF SMART METER DATA COLLECTION

VYUŽITÍ DAT ZE SMART METERINGU

BACHELOR'S THESIS
BAKALÁŘSKÁ PRÁCE

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BRNO 2019

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ

Bakalářská práce

bakalářský studijní obor **Angličtina v elektrotechnice a informatice**

Ústav jazyků

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Ročník: 3 ***Akademický rok:*** 2018/19

NÁZEV TÉMATU:

Využití dat ze smart meteringu

POKYNY PRO VYPRACOVÁNÍ:

1. Vysvětlete pojem smartmetering.
2. Na základě rešerše identifikujte sledované veličiny a popište současný stav využití dat ze smartmeteringu ve světě a ČR.
3. Uveďte hlavní přínosy analýzy dat ze smartmetering
4. Analyzujte možná rizika, která smartmetering přináší

DOPORUČENÁ LITERATURA:

Dle doporučení odborného konzultanta

Termín zadání: 4.2.2019 ***Termín odevzdání:*** 28.5.2019

Vedoucí práce: Mgr. Magdalena Šedrlová

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předseda oborové rady

Abstract

In recent years, the demand for electricity has been increasing in households because various appliances and newest technologies have been used on an everyday basis. This raises concerns about the lack of electricity production around the globe. There is also a need for people to track their daily power usage in houses. The aim of this thesis is to explain the term smart metering and its benefits for both people that might use this technology in their households, and for companies. Smart meters allow people to track and control their energy consumption and eventually it might result in cheaper costs of the resources. What is more, the smart meters help consumers to know specific information about the consumption of electricity for appliances. In a global scale, the smart metering technology is used in smart grids which are more environmentally friendly power grids with higher efficiency and greater energy production. This work also focuses on the overall distribution of smart meters both in the Czech Republic and in the world. Nowadays, there are many projects in progress that are trying to switch from traditional power plants to smart grids with the intention to increase energy production and to become eco-friendly. The companies behind these projects have already published some of their researches which bring positive information about the energy production. The majority of these projects should be in progress until 2020 and some until 2025. Therefore, the final conclusion whether the smart metering technology will replace the traditional power grids and will be implemented in households cannot be drawn yet. This thesis also contains a practical part in which I create a user interface in Grafana, which is an open-source software for time series analytics. The user interface is created for a Raspberry Pi touch display which has a sensor connected to it that allows us to measure energy consumption of electricity meters. The measured values are then presented in useful graphs and gauges in Grafana, and also on the display itself.

Key words

Smart meters, smart metering, smart grids, power grids, energy management, electricity meter, Grafana, user interface

Abstrakt

V posledních letech, spotřeba elektřiny v domácnostech začala stoupat, kvůli každodennímu používání všelijakých spotřebičů a nejnovějších technologií. To budí znepokojení o nedostatku výroby elektřiny po celém světě. Lidé také potřebují sledovat jejich energetickou spotřebu v domácnostech. Cílem této práce je vysvětlit pojem smart metering a jeho výhody jak pro lidi využívající tuto technologie v jejich domech, tak pro společnosti. Smart meters neboli chytré měřiče, umožňují lidem sledovat a kontrolovat jejich energetickou spotřebu, a nakonec mohou vést ke snížení cen daných energií. A co více, tyto chytré měřiče pomáhají spotřebitelům zjistit přesné informace ohledně spotřeby elektřiny ze spotřebičů. V globálním měřítku je smart metering technologie používána v tzv. smart grids, neboli inteligentních sítích, což jsou v podstatě elektrické sítě, které jsou více přátelské k životnímu prostředí a produkují více energie. Tato práce se také zaměřuje na celkovou implementaci chytrých měřičů jak v České republice, tak i ve světě. V dnešní době lze již najít několik vyvíjejících se projektů, které se snaží přejít z tradičních elektráren na tyto inteligentní sítě za účelem zvýšit produkci energií a být více šetrnější k životnímu prostředí. Společnosti, které stojí za těmito projekty, již publikovaly nějaké jejich studie, které přináší pozitivní informace z hlediska produkce energie. Většina těchto projektů by měla trvat do roku 2020 a některé projekty až do roku 2025. Proto není možné říci finální rozhodnutí, zda tato smart metering technologie nahradí běžné elektrické sítě a zda bude implementována do domácností. Tato práce také obsahuje praktickou část, v které vytvářím uživatelské rozhraní v Grafaně, což je software s otevřeným zdrojovým kódem, který dokáže analyzovat časové řady dat. Uživatelské rozhraní je vytvořeno pro dotykový displej Raspberry Pi, ke kterému je připojený sensor umožňující měření spotřeby elektřiny z elektroměrů. Změřené hodnoty jsou poté vyobrazeny v užitečných grafech a měřidlech v Grafaně, a také na displeji samotném.

Klíčová slova

Smart meters – chytré měřiče, smart metering, Inteligentní sítě, elektrické sítě, hospodaření s energií, elektroměr, Grafana, uživatelské rozhraní

BAZAL, S. *Využití dat ze smart meteringu*. Brno: Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, 2019. 43 s. Vedoucí bakalářské práce Mgr. Magdalena Šedrlová.

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V Brně dne ....

Stanislav Bazal

Acknowledgement

I would like to express my gratitude towards my supervisor Mgr. Magdalena Šedrlová for the support and encouragement that she has provided throughout the period of this thesis. Under her guidance I had a very clear image of what to do, and her opinions and valuable hints helped me to correct the mistakes I have made.

The practical part of this thesis has been done under the guidance of Ing. Michal Vrána to whom I also owe my gratitude. Without his knowledge and pieces of advice, which he has provided throughout our consultations, I would have not been able to finish the practical part.

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1. Introduction

1.1 Background

The world as we know it today has been growing remarkably fast and the technologies that have been developed throughout the history of mankind have changed the way of living. Nowadays, our lives rely on high efficiency of energy usage more than ever before. Energy has become increasingly important in all areas of our society. Efficiency and flexibility are the key ingredients in finding a solution for the usage and production of electricity. The history of electricity meters is well connected to the researchers from the past. The general usage of electricity in the early 1870s is only confined to telegraphs and arc lamps. With the invention of the electric bulb by Thomas Elva Edison, the power energy market became widely opened to the public in the year 1879. Oliver B. Shallenberger introduced his AC ampere hour meter in the year 1888. Eventually, the progressive development in metering technology has effectively improved how effectively people both produce and consume electrical energy.

Nowadays, the power supply infrastructures are facing radical changes by the introduction of so-called Smart Grid technology. Its use is expected to grow exponentially in the coming years. Smart grids modernize electric power delivery systems by using computer-based remote control and automation. The smart meter is an important component in smart grids and is deployed in companies, flats, and individual customers' homes. A smart meter enables the collection of accurate power metering data and transmission of remote commands that trigger different actions (e.g. starting an appliance when energy prices are low). However, ICT (Information and Communication Technologies) systems in general, and therefore also smart grids are subject to cyber-attacks, which can have a disruptive impact on the whole power grid, and put people's safety and business interests at risk.

1.2 Introduction of smart meters

The term smart meter often refers to an environmentally friendly energy meter that is used to measure electrical energy in terms of kilowatt-hours, but also natural gas or water consumption. What makes the smart meters special from common electrical energy meters is the fact that it records the consumption of electrical energy and communicates the information to the electricity supplier for monitoring and billing. This brings direct benefits to the consumers who want to save money on their electricity bill. Smart meters record the consumption on the basis of hourly or less than hourly intervals. They belong to a division of Advanced Meter Infrastructure (AMI) and they are responsible for sending meter readings automatically to the energy supplier. Communications from the meter to the network may be wireless, or via fixed wired connections such as power line carrier (PLC). A simple picture of a smart meter is displayed in a figure 1.

Figure 1 - Smart Meter (Conrad H. Richard)

Smart meters usually involve real-time or near real-time sensors, power outage notification, and power quality monitoring. The implementation of smart meters is claimed to be one of the strategies for saving energy. They have non-volatile data storage, remote connect or disconnect capability, tamper detection, two-way communication facilities and they perform remote reporting of the collected data to the central meter, which controls the functionality of the smart meter.

2. Purpose of smart meters

Non-smart electrical energy meters and gas meters only measure total consumption and they do not provide any information of when the given energy was consumed. Smart meters provide a way of measuring this site-specific information which allows utility companies to charge different prices for consumption according to the time of day and the season. It has been said by the utility companies that smart metering offers potential benefits to householders ("2010 to 2015 government policy: household energy"). These benefits are:

- An end to estimated bills, since they are a major source of complaints by many customers
- A tool to help consumers better manage their energy purchases
- Feature of saving time to the consumers and utility companies for reporting the meter reading back to the energy providers
- Low operational cost
- Feature of automatically terminating the appliances off when they are not used
- Online electricity bill payments are allowed

3. Smart grids

A smart grid is a secure integrated electronically controlled system that is used to deliver electric power that operates in parallel with a traditional power grid. It includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy recourses, and energy efficient resources. Even though most of its components had been developed, and many of them had been implemented during the early 21st century, no smart grid was yet fully completed until 2016 (Amin S. Massoud). The traditional electric power grid can be simply defined as a network of wires, transformers, substations, and machines that connect power plants with customers.

Unfortunately, this traditional type of power grid has one specific disadvantage which is one of the reasons why the smart grids were developed. In this electric power grid, the electricity is distributed in one direction, from the power plant to the customers, through a network that only has a few means of monitoring its transition and delivery. In contrast, the smart power grid would include an array of sensors, communications networks, control systems, and computers which improve the security, efficiency, and reliability of the end-to-end system. What is more, the smart power grid could minimize the impact of unforeseen events, such as power outages, and the utilities would be able to charge customers variable rates based on fluctuations and consumers could adjust their electricity usage with the intention to save more money. This could be done if the consumers shifted their heavy use of electricity to the times of the day when the demand is low, which would result in more efficient energy management and usage.

3.1 Self-healing smart grid

As mentioned before, the smart grid can become a subject to cyber-attacks which could have a devastating impact on the whole power grid. A self-healing grid uses digital components and real-time communications technologies installed throughout the grid to monitor its electrical characteristics at any time. Such technology has the intelligence to constantly look for potential troubles caused by storms, natural disasters, human error or even sabotage. Its reaction to such problems occurs within a fraction of a second. The self-healing grid isolates the problems immediately when they happen before they turn into major blackouts. It also reorganises the grid and reroutes the energy transmissions. This is one of the benefits of self-healing smart grids since the services may continue for all customers while the problem is physically repaired by a technician (Amin S. Massoud).

3.1.1 Benefits of self-healing smart grids

A self-healing smart grid can provide numbers of benefits which eventually result in a more stable and efficient system. Three of its main functions include:

- Real-time monitoring and reaction which allows the system to constantly tune itself to an ideal state
- Anticipation which enables the system to automatically look for any problems that could possibly trigger major disturbances
- Rapid isolation which allows the system to isolate parts of the network that experience failure from the rest of the system to avoid spreading of the problems which might cause even more trouble

As a result of these characteristics, the self-healing smart grid system has the ability to significantly reduce power outages and minimize their length when they occur.

4. Implementation of smart grids

4.1 Overview

North America, which used to be the leader of market for investment in smart metering technology, has not held the top spot since 2013. For the last five years it has been China and Europe who have taken North America’s top spot in smart meter’s marketing. European utilities are planning to install 182 million smart meters over 2016 to 2020, which approximately equals to 37.8 billion dollars of investments. Many other countries have similar plans because the smart metering technology is truly beneficial for them. Japan, for example, wants to install approximately 55 million smart meters from 2016 to 2020, which would roughly cost 16.6 billion dollars. (Frith James).

The global smart meter’s market is expected to launch over 588 million units by 2022. According to GlobalData, the global smart meter’s market volume grew at a compound annual growth rate (CAGR) of 6.8% between the years 2012 and 2017. The market is expected to witness large roll-outs and it is estimated to reach 10.4 billion dollars in 2022. Countries such as the United States of America, South Korea, and Japan aim to invest a lot of their financial resources into the distribution of smart metering technology. (“Global smart meter market expected to see huge rollout”)

4.2 The United Kingdom

The United Kingdom's government is committed to ensuring that every home and small business in the country is offered a smart meter by the end of 2020. The Smart Metering Programme aims to distribute over 50 million smart gas and electricity meters to all houses and companies, and approximately 30 million smart or advanced meters to smaller non-domestic sites in Great Britain. ("Smart Meters", Department for Business, Energy & Industrial Strategy)

4.2.1 The Smart Metering Programme

The Smart Metering Programme consists of two phases. The foundation stage began in March 2011 during which Great Britain's government started to work with the energy industry, consumer groups, and other interested parties to ensure that all the important groundwork is completed before the energy suppliers start the process of distributing smart meters to the majority of their customers. This phase is certainly important to the successful roll-out of smart meters in Great Britain because the government can gather valuable information during this stage, e.g. do all the necessary trial and test systems, learn what works best for consumers, and learn how to help people to get the best from their smart meters.

The second phase, the main installation stage, started in November 2016 and is planned to be run to the end of 2020. During this phase, most of the households and small companies will have the smart meters installed by their energy suppliers. ("Smart Meters – Quarterly Report to end June 2018, Great Britain")

4.2.2 Types of gas and electricity meters being installed

There are a few types of meters that are being installed around the United Kingdom by energy suppliers, i.e. Smart meters, Smart-type meters, Advanced meters, and the traditional meters.

Above in this thesis, we have already deeply described the benefits and usage of smart meters but for further comparison of the different types, it is necessary to mention again that the smart meter is a device with the Smart Meter Equipment Technical Specification (SMETS) and it is capable of transmitting the meter readings to energy suppliers and receive data remotely. Only smart meters that meet the SMETS regulations count towards supplier's obligations for the distribution. Energy suppliers will have to replace other meter types in households with the SMETS meters by the end of 2020 in order to fulfil their licence conditions.

The distribution of smart-type meters has already started by some energy suppliers even though these meters do not possess the full functionalities that are included in SMETS. Smart-type meters are not categorised as "smart meters" and therefore they cannot be installed in households since they do not count towards the supplier's obligations. By the end of 2020, smart-type meters will need to be replaced with smart meters that meet the SMETS regulations. Despite the fact that this type does fulfil the supplier's obligations, it still exceeds the minimum specifications for advanced meters and it will meet the requirements in smaller non-domestic sites which are businesses or public sector customers whose sites use low to medium amounts of electricity or gas.

Advanced meters are only installed in smaller non-domestic sites and they must store at least half-hourly electricity and hourly gas data, to which the customer can have timely access and the supplier has remote access.

The traditional meters are the ones that can be currently found in the majority of households and companies, and not only in the United Kingdom but also in the Czech Republic. Unfortunately, they do not possess any smart capability. Eventually, they will be replaced by smart and advanced meters. ("Smart Meters – Quarterly Report to end June 2018, Great Britain")

4.2.3 Costs and financial benefits

Over the period to 2030, the installation of smart meters in Great Britain will cost approximately 10.9 billion pounds and provide over 17.1 billion pounds in benefits.

A total of 1.24 million smart meters have been installed by energy suppliers in the second quarter of 2018. Approximately 542 000 of them were gas meters and roughly 707 000 were electricity meters. In comparison to the previous quarter, such number represents a slight increase in domestic smart meter installations. By the end of August 2018, around 13.55 million smart and advanced meters have been installed in households and businesses in Great Britain by the energy suppliers. Approximately 12.51 million of these were installed in domestic properties and roughly over one million in smaller non-domestic sites. ("Smart meter roll-out for domestic and small and medium non-domestic sectors in GB").

4.3 Europe

In November 2011, the European Union officially launched a project named Grid4EU that aims at the development of smart grids and so far, it has been the largest demonstration project in power engineering supported by the European Union. It is led by six distribution system operators from Germany (RWE), France (ERDF), Sweden (Vattenfall), Italy (ENEL), Spain (Iberdrola) and the Czech Republic (CEZ).

4.3.1 Grid4EU project

The goal is to implement six large demonstration projects that focus on distribution grids with distributed generation facilities and the active involvement of customers. Each of the projects has its predefined task and will be implemented in a different country and under different conditions. As Richard Vidlicka, the CEO of CEZ says: "*The Grid4EU project significantly aids in the implementation of the energy strategy chosen by the European Union at its beginning and is part of a collection of pilot projects in the EU on the basis of which the future strategy in the area of smart grids will be defined*." (Vidlicka). The Czech Republic's first smart-energy region, the Smart Region Vrchlabí, is undertaken by CEZ Group.

4.3.1.1 Smart Region Vrchlabí

The Smart Region project is part of CEZ Group's FUTUR/E/MOTION framework which focuses on verifying the functionalities of the smart grid concept. This project has three main goals:

1. Low voltage network automation – automatic detection and repair of errors, infrastructure check for low voltage electro mobiles
2. High voltage network automation – automatic detection and repair of errors in new technology networks
3. Standby recovery in case of malfunctions, and usage of local electricity production

Vrchlabí was chosen for this trial project on purpose because the city meets the recommended size, there is the possibility of implementing renewable resources and the location is suitable for the installation of some cogeneration units ("Projekt Smart Region ve Vrchlabí", CEZ). In general, these units use heat engine or power station to generate electricity and useful heat at the same time. They are more efficient in using the fuel because the heat that is wasted from electricity generation is put to a productive use. Conventional power plants usually convert 35-60% of the fuel to useful power. In contrast, the cogeneration plants can reach up to 90% of fuel efficiency. Such improvement means lower costs to produce the same amount of power. This combined heat and power system results in overall reduction of energy costs while simultaneously achieving significant decrease in carbon emissions. What is more, the waste heat produced in plants is utilised in other industrial processes, extracted to cover the heat demand of individual buildings, or exported to a district heating system ("Combined Heat and Power").

4.3.2 Other Grid4EU projects

As stated before in this thesis, the European project Grid4EU consists of six demonstration projects, one for each country and its energy supplier. Each of them has their specific name.

Project Demo 1, which is the name of the RWE's project, takes place in Reken, Germany, and its purpose is to show that autonomous systems, which are using the function of agent technologies for monitoring and control of medium voltage systems, can serve as a solution for better management of such networks.

Project Demo 2 is being realised in Uppsale, Sweden, and it is focused on the development of monitoring systems for low-voltage distribution network with the use of intelligent electrical substations.

Project Demo 3 is held in Castellon, Spain, and its purpose is to improve the automation of medium and low voltage networks and to inform the consumers about their consumption and the situation in the smart grid.

Project Demo 4 takes places in Forli-Cesena, Italy, and is focused on implementation of improved control system that increases the capacity of the grid and also integrates renewable resources and electricity production into the medium voltage network.

Project Demo 5 is the already mentioned Smart Region in Vrchlabí, Czech Republic. As stated before, it is undertaken by the CEZ Group and they cooperate on this project with companies, such as ABB, CISCO, Siemens and Ormazabal Current.

Project Demo 6 is named Nice Grid and is being realised in Carros, France. Its goal is to prove in practice the functionality of the smart grid system with the use of modern devices for communication and control ("Projekt Grid4EU: demonstrační faze úspěšně uzavřena").

If we have a look at figure 2, we can notice the distribution of smart electricity metering systems in the European countries until 2016, their decisions whether they intend to implement the systems, and the cost-benefit analysis for each country. Only by looking at this picture, we may notice that the majority of the European countries, which have decided to roll-out the smart electricity metering systems, express the positive cost-benefit analysis. Therefore, the smart metering technology might be eventually more positive option of energy production that would overcome the traditional power grids.

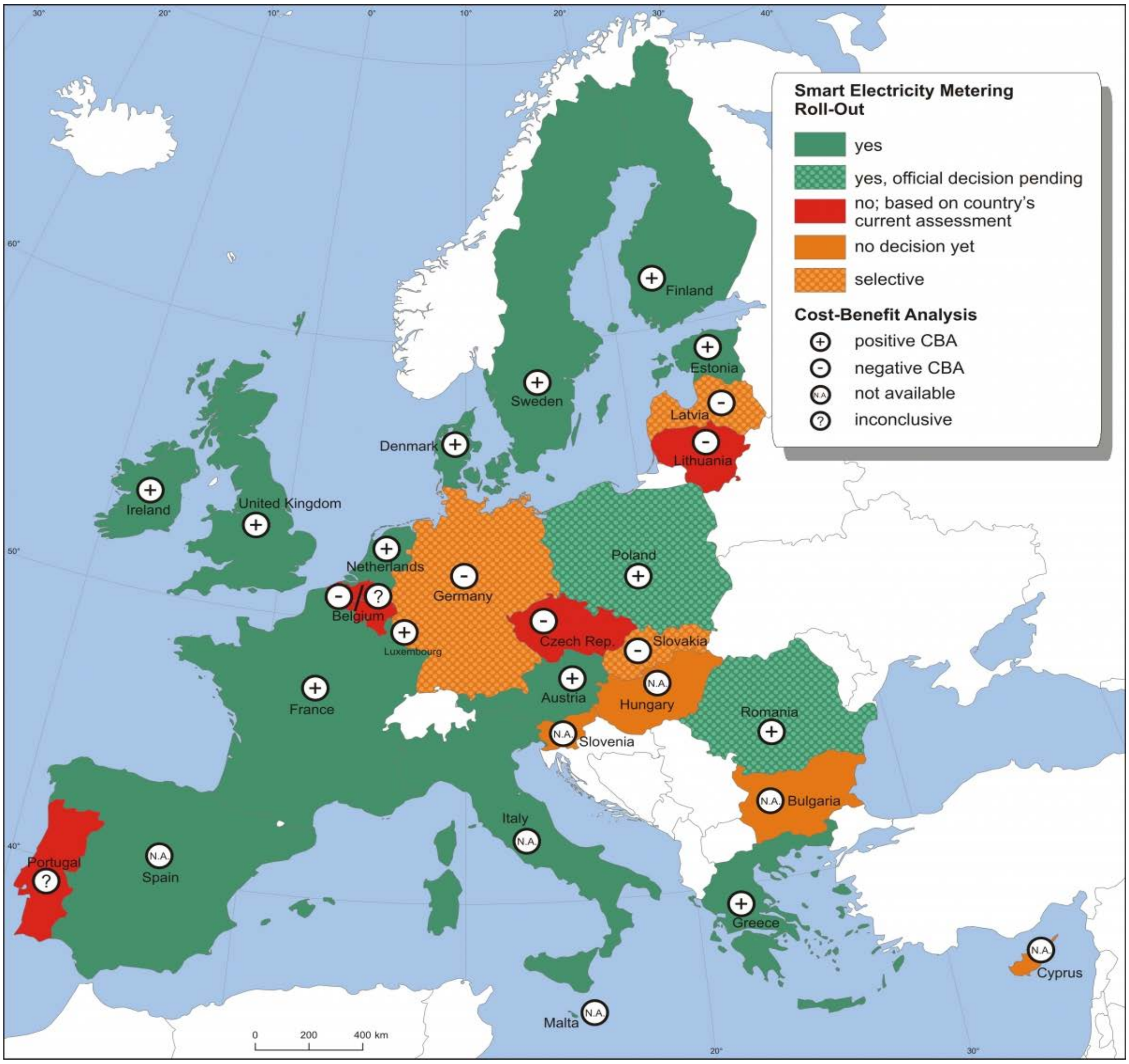

Figure 2 – Smart electricity metering roll-out in European countries (T. AlSkaif and W.G.J.H.M Van Sark)

4.4 Canada and its provinces

In 2012, Canada, and Ontario, in particular, started major policy initiatives that have supported rapid growth in smart grids. Over 2013 to 2014, electric utilities from Ontario, Quebec and New Brunswick, along with industry and provincial government partners, attempted a pilot test to explore how smart grid deployment and its benefits could be measured and presented publicly in Canada. The result of the pilot was a detailed survey of smart grid application and its benefits. Natural Resources Canada (NRCan) signed an agreement with the Canadian Electricity Association (CEA) to complete the survey (Hiscock Jennifer).

4.4.1 Alberta

Alberta happens to be a province with the third-largest total wind capacity and the largest solar resources across Canada. Late in 2014, The Alberta Innovates – Energy and Environment Solutions, which is a lead government agency, started a two-phase request for proposals for next-generation energy storage technologies (Hiscock Jennifer).

4.4.2 British Columbia

British Columbia's smart grid technology goals are clustered around advanced metering infrastructure, microgrids, reliability, and electric vehicle integration. In 2014, there were more than 550 public charging stations, and 350 of those were being monitored by PowerTech labs. During the same year, they reported that the number of charging sessions was twice as big as in the year before. The majority of consumers in British Columbia are served by a Canadian electric utility - BC Hydro, which launched the distribution of smart meters in 2013, and continued with it until 2015 (Hiscock Jennifer).

4.4.3 New Brunswick

The smart grid development in New Brunswick has three main objectives:

- Keeping energy prices low and stable
- Improving electricity system reliability
- Demonstrating environmental responsibility

New Brunswick Power, which is a company that manages the PowerShift Atlantic project, was awarded by the Peak Load Management Alliance for its "Innovative Application of Technology". This project has already won two other awards for its progress toward sustainability and wind integration ("Smart Grid in Canada", 2014).

4.4.4 Ontario

Ontario has always been a province that internationally stood out for its leadership in developing and implementing smart grid technologies. Almost two thirds of Ontario's consumers have access to their electricity data in a standardised format which allows them to better comprehend and control their own consumption. The Advanced Energy Center was launched in Ontario as a public-private partnership with support from the Ontario Ministry of Energy, MaRS Discovery District, Cap Gemini, and Siemens. The Ontario Ministry of Energy's Smart Grid Fund supports the total of 28 projects that are in the area of energy storage, grid automation, microgrids, electric vehicle integration, and meter services (Hiscock Jennifer).

4.5 Asia and Oceania

Smart grid technologies have been brought to a spotlight in the Asia-Pacific region because for the last decade there has been an increasing demand for electricity. During the past few years, many smart metering projects started appearing near Southeast Asia. At present, the utilities are deploying and testing smart meters, demand response, and battery storage in the region ("Asia-Pacific Smart Grid Market").

The total smart grid market in the Asia-Pacific region is expected to grow at a fast pace of 9.1% CAGR (compound annual growth rate) during 2015 to 2020 and the expected revenue will increase from US$9.21 billion in 2015 to US$14.25 billion in 2020. (Avanthika Satheesh)

Unfortunately, in most Asia-Pacific countries, the occurrence of natural disasters such as earthquakes, cyclones or tsunamis is higher than anywhere else. As a result, the central grids have undergone several damages. To overcome this, many facilities have started deploying microgrids backed by battery storage support.

4.5.1 Investments in smart-meter projects

Japan, South Korea, and India have installed more than 17.5 million smart meters in the past years. Japan and South Korea have exact plans for smart-meter implementation. Four utilities in Japan aim to distribute nearly 27 million smart meters by 2024, and Korea Electric Power Corporation (KEPCO) in South Korea has a plan to install approximately 26 million smart meters by 2020. In Southeast Asia, for example, roughly 360 000 meters were installed during 2017, and the number is likely to be twice as big by 2020 ("Asia-Pacific Smart Grid Market").

4.5.2 Japan

As an International Trade Administration claims, "Japan ranks third among Top Markets for near-term smart grid export growth, due in large part to electricity sector reforms, energy efficiency objectives and active technology procurements by utilities. While U.S. suppliers face difficult competition in Japan, important inroads have been made in recent years, and the market is expected to evolve favourably for innovators and entrant to a strong market." ("2016 Top Markets Report Smart Grid, Country Case Study").

4.5.2.1 Japanese marketing

The Tōhoku earthquake, which was the most powerful earthquake ever recorded in Japan, and the fourth most powerful one in the world, has had a serious impact on the Japanese market. At that time, the damage resulting from the earthquake and tsunami forced Japan to shut down approximately 30 percent of their electricity supplies. Such disaster resulted in improving the overall energy security and resiliency through smart grid and energy efficiency technologies.

Since 2012, the need for efficiency and resiliency has eventually forced all Japanese utilities to present plans and ideas for the installation of smart meters into every household across the country which have involved approximately 80 million of them. In 2015, the utilities have already started with the smart meter distribution and according to their plan, the installation process should last until 2025. At that time, Japan surpassed China as the largest smart meter investor (International Trade Administration, “2016 Top Markets Report Smart Grid”).

4.5.3 Singapore

By the year 2016, approximately 1.2 million smart meters were implemented in households and businesses in Singapore (“Asia-Pacific Smart Grid Market”). Energy utility company Singapore Power has started the Singapore Power Centre of Excellence where they test and develop smart grid technologies. The centre has tested the viability of remote sensors and intelligent drones that perform monitoring tasks. The first task of the centre has been the Singapore Power Energy Advanced Research and Development (SPEAR) programme, which has focused on control of grid communications and energy management (Theron-Ord Ashley).

5. Practical part - Introduction

In the second part of this thesis, I am going to describe the device that I have been working on for the last few months under the guidance of my technical consultant. The device we have been working with is a Raspberry Pi touch display (see fig. 3). We have been trying to create a device that would have the capability of collecting data of real-time power consumption of traditional electricity meters, which can be found in almost every house across the globe, and display the values on the device. Since there are only a few methods of tracking the data from electricity meters, we decided to choose the one that could be used by the majority of people and applied on their electricity meters. Usually, electricity suppliers do not like it when some external work has been done on the electricity meters that they provide and especially when it somehow affects the electrical circuit inside the meter. For this reason, we used the method in which we gather the data from the electricity meter without affecting the inner circuit.

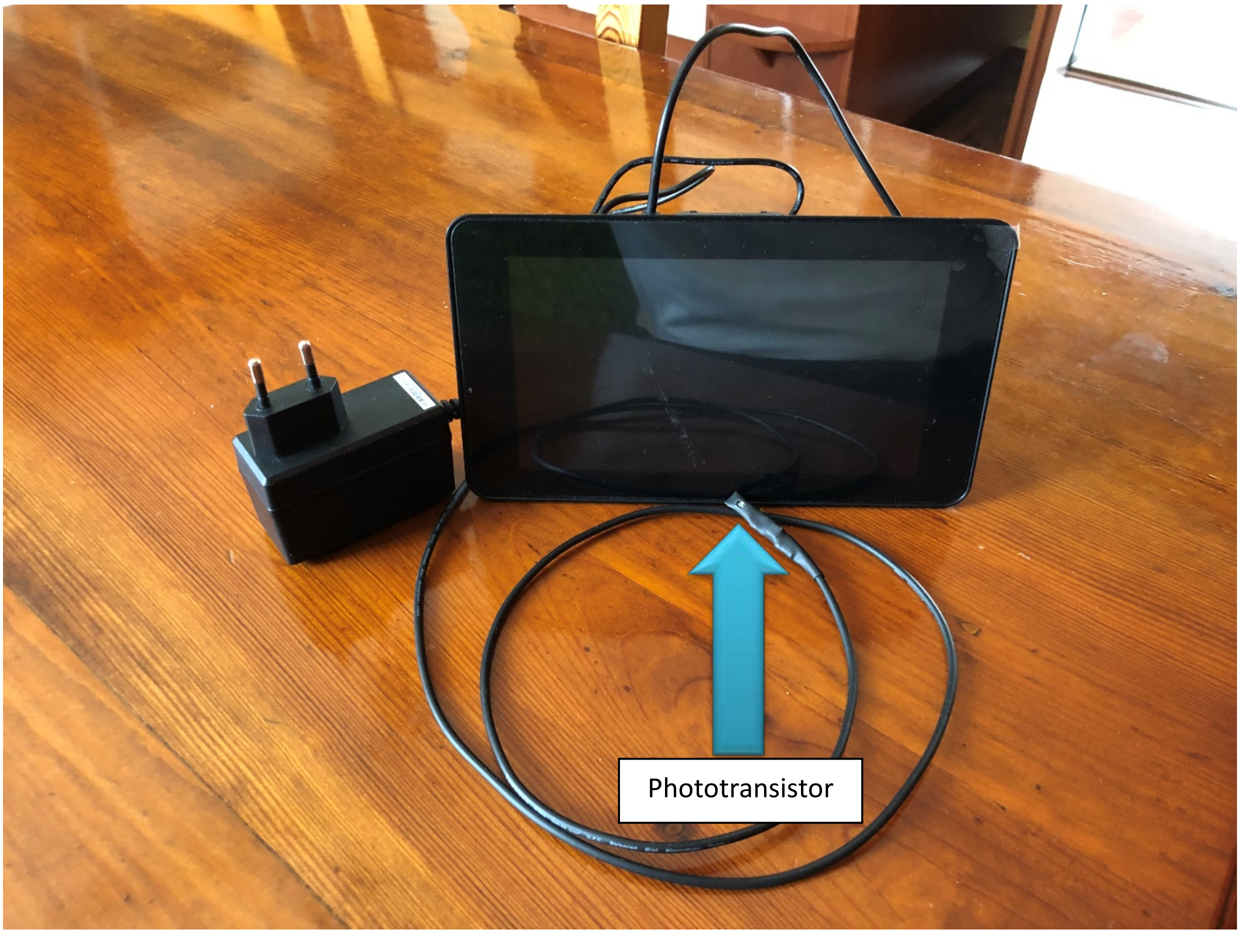

Figure 3 – Raspberry Pi Touch Display with a phototransistor at its end (Bazal Stanislav)

5.1 Insight into the working principle and description of the device

Every electricity meter has a diode which blinks according to energy consumption and production. The specific number of flashes differs among the types of electricity meters but usually this number equals to 500 pulses for 1 kilowatt-hour. Sometimes the values of flashes of the diodes can reach up to 1000, 2000 or even 10 000 pulses for 1 kilowatt-hour. This specific number is used later in a mathematical operation for calculating power consumption. The device consists of two main parts – the Raspberry Pi touch display and a sensor that is attached to the display. This sensor looks like a cable with a small diode at its end. This diode is actually a phototransistor which probably has the most important role in this whole device. Without the phototransistor, we would not have been able to gather any data from electricity meters. To comprehend the principle of how the device works, it is necessary to have a fundamental knowledge of phototransistors.

5.2 Principle of phototransistors

Phototransistors are solid-state light detectors with internal gain and are used to provide analog or digital signals. They detect visible, ultraviolet and near-infrared light from a variety of sources and are more sensitive than photodiodes. Phototransistors can be used in almost all electronic devices that depend on light including optical remote controls, smoke detectors, and other security systems ("Phototransistor Basics, Circuit Diagram, Advantages & Applications").

The main purpose of phototransistors is to detect light pulses and convert them into digital electrical signals, which is exactly what we desire. Phototransistors are transistors with the base terminal exposed. Instead of sending current into the base, the photons from striking light activate the transistor. That is the key difference between phototransistors and regular transistors. In figure 4, we may notice a simplified schematic of how the phototransistor works.

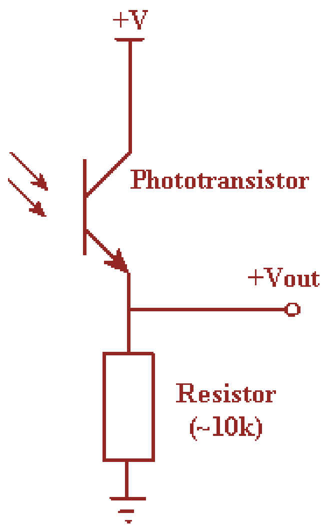

Figure 4 – Simplified circuit diagram of a phototransistor ("Phototransistor Basics, Circuit Diagram, Advantages & Applications")

Some of the benefits of phototransistors are as follows (“Phototransistors Information”):

- 50 to 100 times higher sensitivity compared to photodiodes
- Higher current production than photodiodes
- Nearly instantaneous response
- Relatively low price
- Simple principle
- Size small enough to fit onto integrated computer chips

5.3 Working principle

Now that we understand how the phototransistors work, I can continue explaining the working principle of our device. Using the sensor that is connected to our device, we are able to measure how many times the diode of electricity meter flashes. This particular part had some programming actions involved. This specific task has been done mainly by my technical consultant since my major contribution to this work comes later. It was necessary to create a source code in which the device writes down the number of pulses in one-minute intervals and this value is saved into InfluxDB database and then sent into Grafana, which is an open-source software for time series analytics where I present the gathered data in useful graphs and gauges. Programming language of the InfluxDB is slightly similar to an SQL and the database is optimised for fast storage and retrieval of time series data which perfectly fits our purpose. What is more, it is compatible with the Grafana, in which I later create the user interface for our device. Later, I will look deeper into Grafana, its useful tools, and features, what are its possibilities of use, and mainly I will describe my biggest contribution to this work – the whole dashboard of the user interface.

5.4 Data collection

The overall concept was to create a device that would have the capability of displaying data that were acquired from the electricity meter. To secure the correct functionality of the device, it has been tested on various electricity meters, which are commonly used in Czech Republic, under laboratory conditions at our university under the guidance of my technical consultant. Therefore, in practice, the device that we have created has the capability of displaying data collected from electricity meters. Unfortunately, I was not able to connect it to the electricity meter that my family owns at home. There are two simple reasons for that. Firstly, the place where we keep our electricity meter is poorly located and difficult to access. Secondly, the electricity meter is placed in a small cabinet and there is not enough space where I could place our device for the data monitoring. There was the option of me standing close to the electricity meter and holding the device in my hands, but since I wanted to gather data for at least one whole day, this was not an option. As I was unable to connect the device to the electricity meter, I had to propose a different approach. Therefore, I have decided to simulate the pulses of a diode by simply flashing a light onto the phototransistor by using a regular flashlight and mainly a flashlight application on my mobile phone where we can easily adjust the flashing frequency. Despite the fact that the display is fully capable of collecting the data from electricity meters, I was not able to do so for the reasons stated above and I had to simulate the diode flashes from a different source of light.

In the early stages of the data collection, there have been some unfortunate issues that made the whole process more complicated than I expected it to be. It the beginning, there were only a few instances where the phototransistor did not actually work as intended. It did not give me a single response to the light flashing. Since these instances occurred only at the beginning of the data collection and have not occurred since then, I consider them to no longer be a problem. For the purpose of this thesis, I wanted to gather data for at least one whole day that would be later displayed in Grafana and also on the Raspberry Pi touch display. I wanted the simulated data of energy consumption to represent an approximate average energy consumption in households. For this reason, I had to adjust the frequency of the light flashing onto the phototransistor, which was achieved in the application of my smart phone. With the increasing frequency of the light flashing, the power consumption would also increase. This is due to the fact that we are working with 500 flashes per 1 kilowatt-hour. As I have already mentioned, I strived to collect data that would be similar to the power consumption of a regular household. The average power consumption of households differs among families, their habits, number of people living in the household, number of appliances, which can be turned on, turned off or in a standby mode, and much more. All of these aspects can change the amount of consumed power. I also increased and decreased the frequency of the light flashing according to the time of the day. It is quite obvious that energy consumption overnight is much smaller than during the day and especially during peak hours from 2 P.M. to 7 P.M. Therefore, the resulting graph, which is going to be described later, shows highest (peak) values during this time period.

6. Grafana

Before I fully explain the fundamentals of the user interface that I created in Grafana, I would like to explain the reason for choosing Grafana in the first place and describe its benefits since there are many of them.

As mentioned before, Grafana is an open-source platform for data visualisation, monitoring, and analysis. Grafana supports numbers of data sources, e.g. Prometheus, MySQL, Graphite, CloudWatch, and many more, but I used it primarily with InfluxDB, which is the database for our collected data. For each data source, Grafana has a customised query editor and specific syntax, which is going to be described later when I introduce the user interface I have created ("Grafana Features").

Grafana contains specific terminology that should be explained.

- A **Panel** is a basic visualisation building block that is presented on your dashboards. Grafana supports graphs, tables, heatmaps, singlestats, free-text panels as well as official and community-build plugins, e.g. world map or clock, and apps that could be also visualised on your panel. Each panel can be adjusted in terms of style and format. It is possible to freely change the panel's size, position, colour, etc. What is more, users have the possibility to add annotations into the panels to track specific events and reference to their consequences, e.g. runtime errors. When an annotation is made and a person hovers over it with his mouse, he receives an event description and tags, by which the annotations can be grouped.
- A **Dashboard** is a set of individual panels that can be arranged on a grid with certain sets of variables. Data with different variables can be displayed in the same dashboard, for example, data from two separate servers. Both panels and dashboards are versatile, therefore it is possible to customise their values and aesthetic features for any kind of specific project that some company might require.

What I personally find interesting about Grafana is its large community of contributors and users who develop new panels and share their own dashboards as an inspiration for others. Some users can create really complicated dashboards that contain varieties of panels, graphs and colourful gauges.

I found it truly impressive when I discovered what companies and corporations support and use Grafana ("Grafana Testimonials"). There is a short list of the most known ones:

- **CERN –** Grafana visualises metrics from their infrastructure, accelerators, experiments, and computing infrastructure. What is more, Grafana helps CERN support high energy physics.
- **eBay** uses Grafana to look for anomalies in the experiments they conduct on their website.
- **Energy Weather** uses Grafana to demonstrate weather forecasts, resulting renewable energy production, and price developments.
- **Gameforge –** Grafana displays millions of metrics per minute that their games produce from over 200 servers, and share that data across game teams.
- **New City Energy –** Grafana demonstrates how the entire system delivers values to the City of D.C.
- **PayPal**
- **Redhat**

7. User interface

Since we are already familiar with the fundamental features of Grafana, we can now proceed to describe my main contribution to this work, which is the user interface that I made in Grafana for our device. This part is going to contain a significantly greater number of pictures than before, which is due to the fact that it is necessary to show them for the comprehension of how the panels work. In figure 5, we can see the resulting user interface that I have created. Since the picture is rather wide, we will enlarge the picture of all panels, describe each of them, their purpose, options, and the mathematics behind some calculations.

Figure 5 – Created user interface in Grafana (Bazal Stanislav)

7.1 Graph of energy consumption

In figure 6, we can see the enlarged version of the energy consumption graph. The horizontal axis represents time while the vertical axis represents the consumed power. As I have mentioned before, I strived to collect data for one whole day, while also trying to reflect the energy consumption of a regular household. In the top right corner, we may notice that the values were recorded from midnight of April 10th, 2019 to midnight of April 11th, 2019. From the graph, we can notice that the values of power are rather stable from midnight to 11:45 A.M., while later on the values are increasing till 6 P.M. After that time, the values start to decrease and they eventually become stable at 10 P.M. This has been done by increasing and decreasing the frequency of the light flashing onto the phototransistor.

Figure 6 – Graph of energy consumption (Bazal Stanislav)

7.1.1 Editing section – General tab

We should now have a look at the editing part of the panel because I personally believe it is important to mention at least the fundamental editing features. In figure 7, we can notice that the editing section consists of several tabs, i.e. *General*, *Metrics*, *Axes*, *Legend*, *Display*, *Alert*, and *Time range*. All of these have their specific options. In figure 7, we can observe the *General* tab where it is possible to change the name of the panel, define its description, or make the panel transparent. We can use the *Repeat* feature if we want Grafana to dynamically create new panels based on values that we would select in the tab, but I personally have not used it in my work.

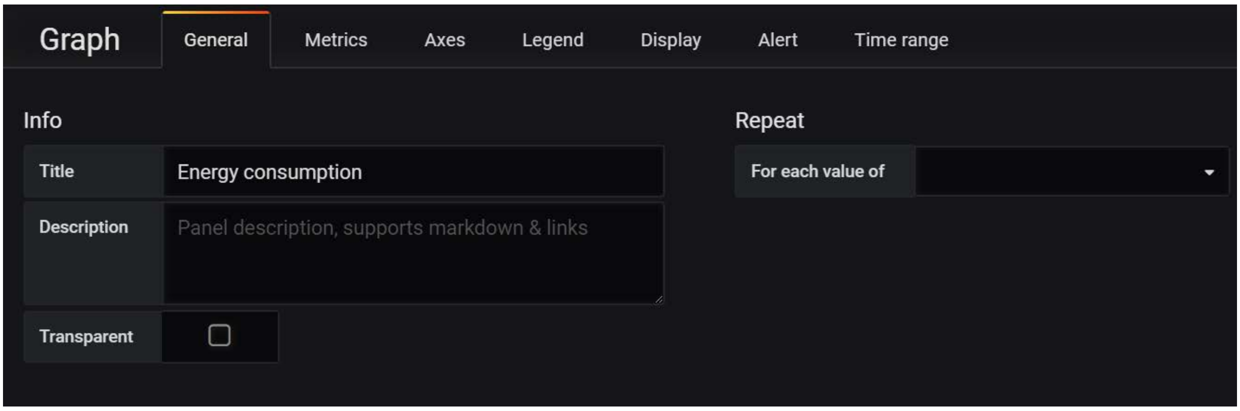

Figure 7 – General tab of the editing section (Bazal Stanislav)

7.1.2 Editing section – Metrics tab

In figure 8, we proceed to the *Metrics* tab, where we can choose among different data sources that we would possibly have connected to Grafana. In the first line, we can also choose specific databases and add certain conditions to it. This feature might be useful in a case where the database consists of a wide variety of folders and subsections, and we need to choose a particular section. In our case, we have chosen the "power-meter" database. In the second line, we can select specific data and add certain functions, e.g. Aggregation functions (count, mean, sum, median, etc.), Selectors (min, max, first, last, percentile, etc.), derivative functions, mathematical equations, and more. We have chosen our "power" values and the "mean" function, which results in displaying the mean value of the power consumption data from our database over time.

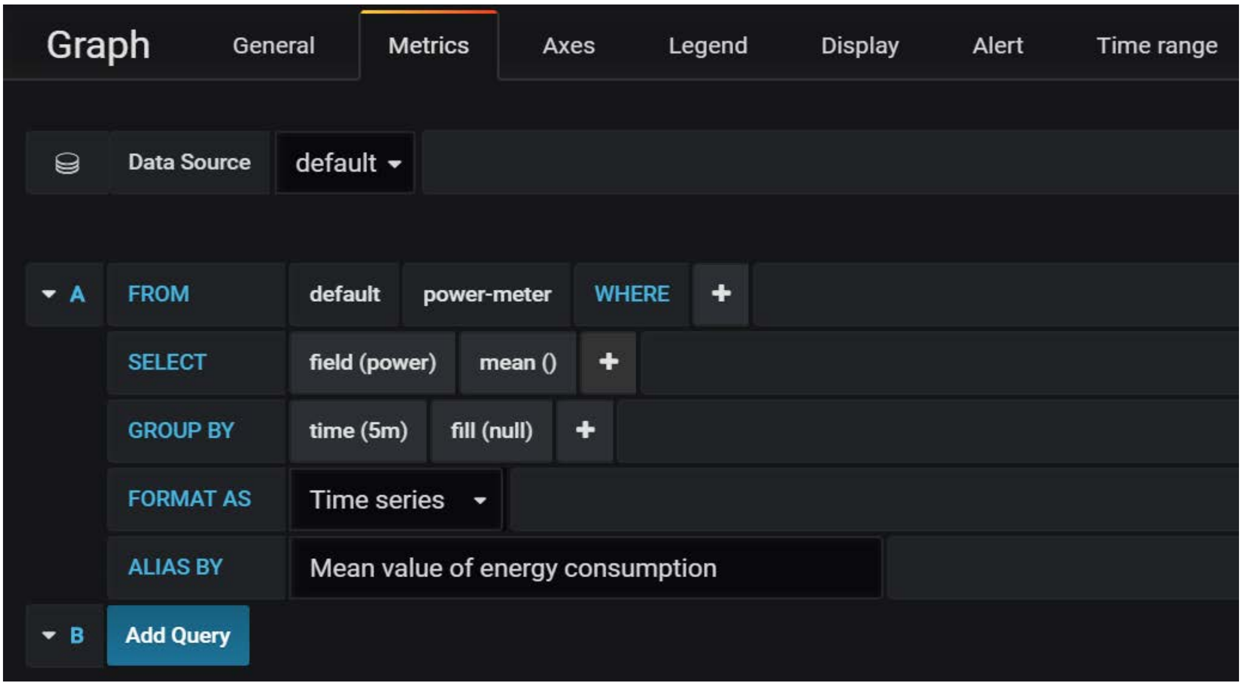

Figure 8 – Metrics tab of the editing section (Bazal Stanislav)

In the third line, we may group the data by time, which changes the data distribution on the graph. If we choose "*time (1m)*" then the values will be written into the graph every minute, which would make the graph more accurate but much sharper, which in my opinion is less appealing. In figure 9, I provide a comparison of two graphs, where the first one has its values written every minute and the second one every five minutes. The difference is instantly visible. The last feature in the third line in figure 8 represents the function of filling the missing values. If there are any missing values, the function can fill it with zeros, previous values, or do nothing and leave it empty. The fourth line allows us to choose whether we want our data to have a form of time series or table, and the last line only serves a naming purpose for the legend.

Figure 9 – Comparison of graphs with different grouping by time (Bazal Stanislav)

7.1.3 Editing section – Axes tab

In the *Axes* tab, we can configure the horizontal and vertical axes. In figure 10, we may notice that the tab allows us to show vertical axes on both left and right side, and also there is an option to align them. Each of the Y-axes has multiple options where we can adjust the unit, scale (linear or logarithmic), the minimum Y-value, the maximum Y-value, how many decimals are displayed for Y-value, and the Y-axis label. It is truly impressive that Grafana provides over 150 options of units.

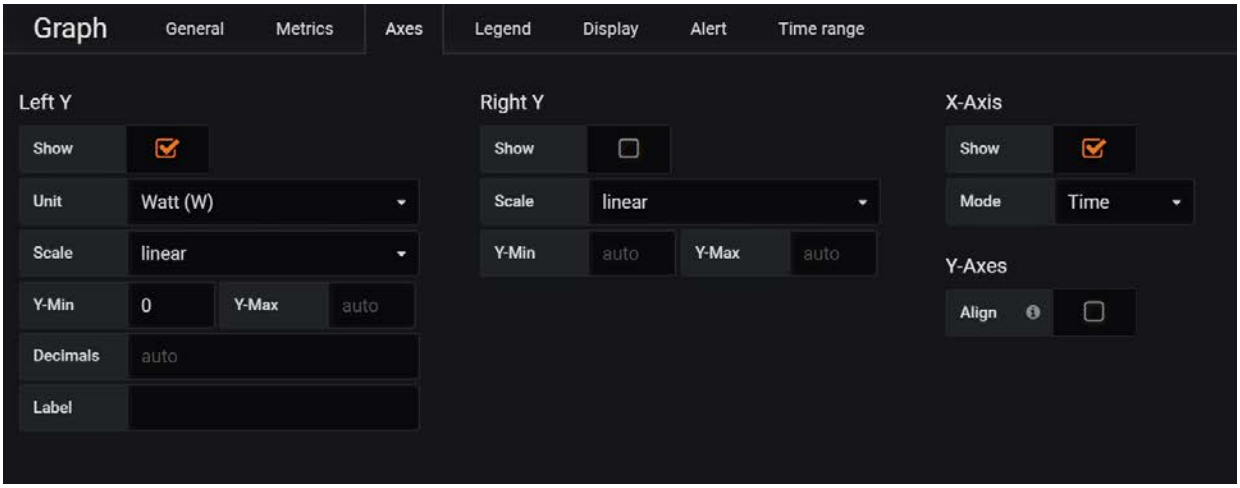

Figure 10 – Axes tab of the editing section (Bazal Stanislav)

7.1.4 Editing section – Legend tab

The *Legend* tab provides us the option to display the legend of the graph, put it to the right side of the chart, display specific types of values (min, max, average, total, and current) in the legend, specify the number of decimals of values, and lastly hide series with null or zero values (see fig. 11).

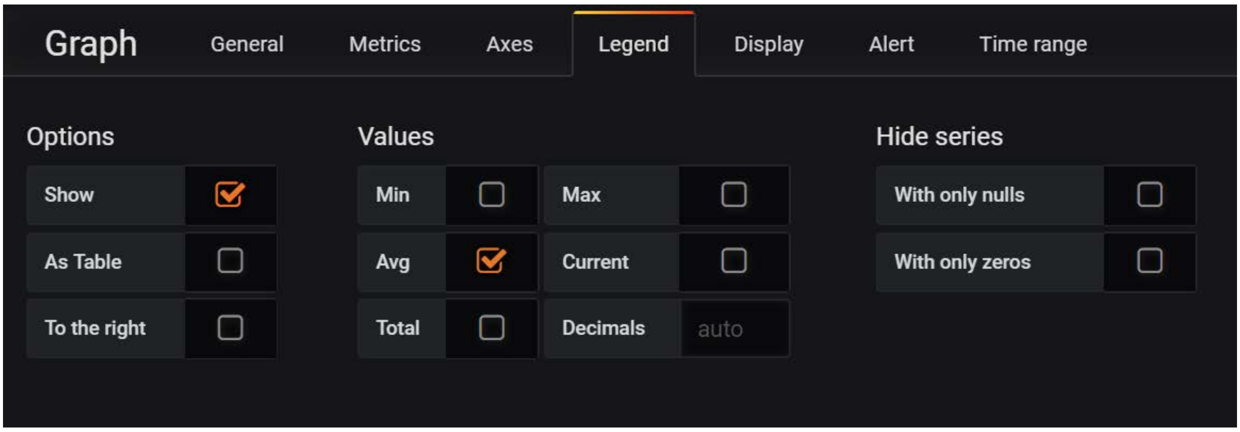

Figure 11 – Legend tab of the editing section (Bazal Stanislav)

7.1.5 Editing section – Display tab

Draw options in the *Display* tab allow us to display values as a bar chart, line graph, and display points for values. Furthermore, we are able to adjust the amount of colour fill of the graph, which means changing the opacity. What is more, we can adjust the line width, the radius of the points, and draw adjacent points as a staircase. Finally, there is the possibility to display multiple series as a group, control how series are sorted, and how many series are displayed when we hover over a point in time (see fig. 12). The *series overrides* section allows a series to be rendered differently from the others, e.g. one series can have thicker line width or it can be moved to the right side of Y-axis. Thresholds section allows us to add lines or sections to the graph to make it easier to see when the graph crosses a certain threshold.

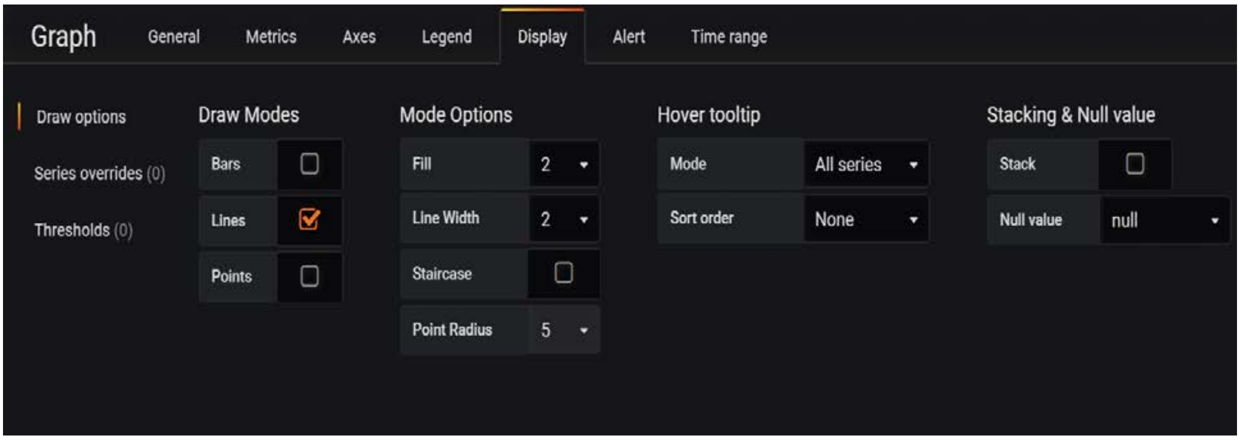

Figure 12 – Display tab of the editing section (Bazal Stanislav)

7.1.6 Editing section – Alert and Time range tabs

The *Alert* tab provides the possibility to set alerts based on the thresholds that we were able to make in the previous tab. Despite the fact that the alerting function could provide significant benefits to the whole dashboard, I have decided not to use it since there was no need to use it for this project. I personally believe it could be useful in more complex systems, where the panels would display multiple inputs and it would be necessary to monitor the values if they do not exceed particular thresholds (e.g. temperature rise). The time range tab allows us to override the dashboard time range and to add a time shift in the graph (see fig. 13).

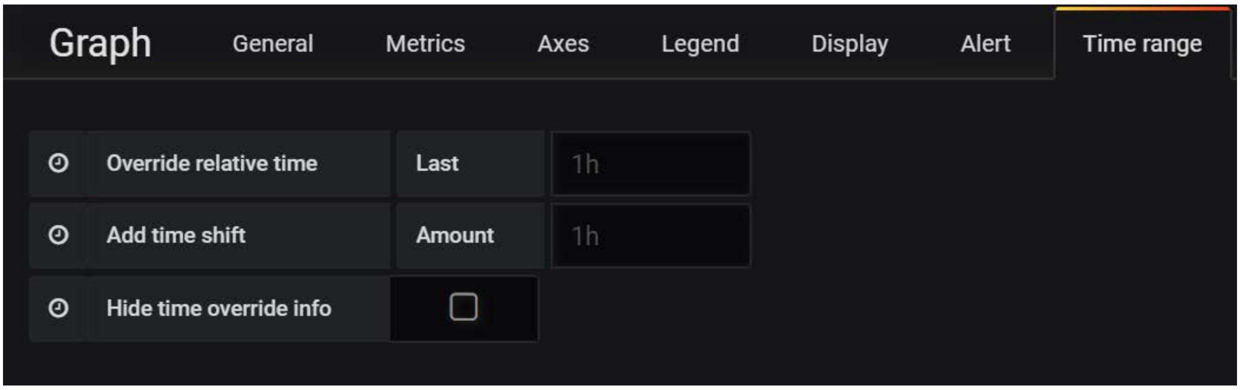

Figure 13 – Time range tab of the editing section (Bazal Stanislav)

7.2 Gauge of present power consumption

The gauge itself can be seen in figure 14. It is necessary to mention that all values of the gauges correspond to the specific date we have set. Therefore, the current value in this gauge represents the last value of the selected date, which should be the value at midnight of April 11th, 2019. When the device is set to measure real-time values, the gauge would display the last input, therefore the current value of power consumption.

Figure 14 – Gauge of present power consumption (Bazal Stanislav)

The present power consumption gauge has been created by using the singlestat panel and slightly adjusting its options in the editing section. As the name of the panel says, it is supposed to show the current value of power consumption. To achieve this, I have changed the stat value to *current* in the panel's options (see fig. 15), adjusted the font size, and chosen the appropriate unit. For achieving the look of a gauge, I had to tick the show button in the gauge section and set minimum and maximum values. With only the options I have mentioned so far, the gauge would be rather plain and colourless. For this reason, I have chosen to add thresholds that are distinguished by colours. Green colour represents all values from 0 to 10 000, the yellow colour represents values between 10 000 to 15 000, and the red colour represents values from 15 000 to 40 000. Although the thresholds do not possess any alerting functions, they still symbolise a certain warning based on how much power we might consume at a given time. I have also decided to change the colour of the given value based on the thresholds, thus if we consume too much power at a given time, the value would turn yellow or even red. This has been done by ticking the *value* button in the *colouring* section.

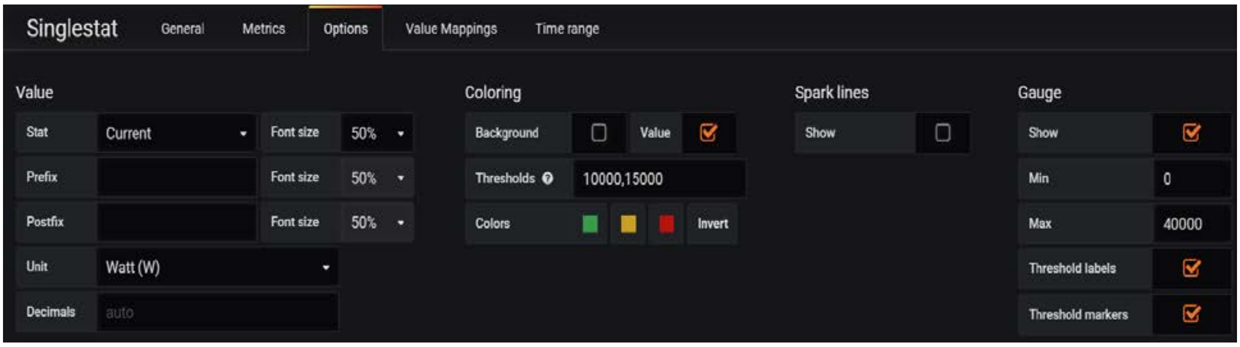

Figure 15 - Options tab of singlestat panel (Bazal Stanislav)

7.3 Gauge of average daily energy consumption

The average daily energy consumption gauge has been created similarly to the previous gauge. The difference between those two is the fact that this gauge displays the average value for the last 24 hours. This has been done in the editing section by changing the stat value to *average* in the options tab, and writing a value of 24h into the time range tab to override relative time (see fig. 16).

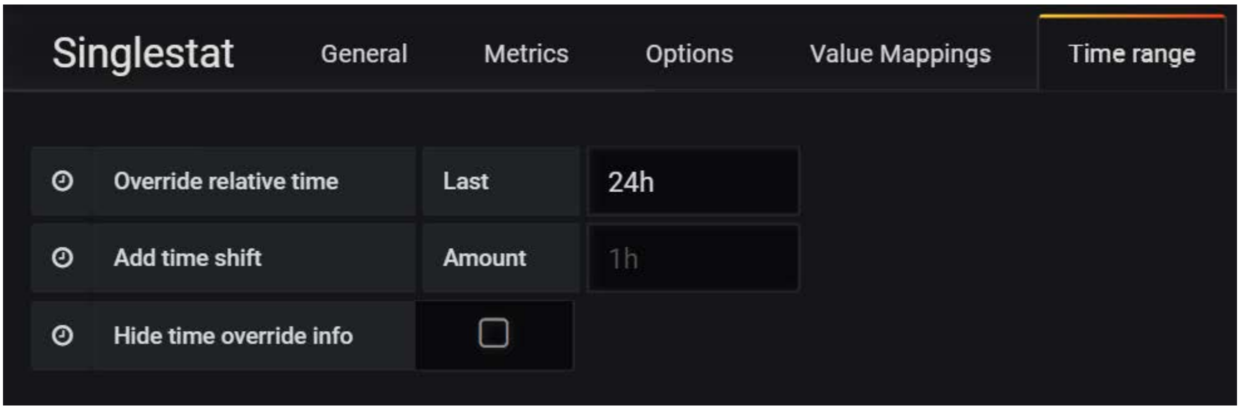

Figure 16 – Time range tab of singlestat panel (Bazal Stanislav)

Although this sounds like an interesting feature, I discovered that a slightly confusing situation might occur by using this panel. When the device is set to measure real-time values, this panel works as intended and it provides average energy consumption for the last 24 hours. It is necessary to mention that in this thesis we do not have the device set for measuring real-time values, but we set a specific date. Therefore, the values changed according to the particular date we set, and they do not represent average daily energy consumption for the last 24 hours but only average value for the data in the specific time that was set. An enlarged picture of the gauge can be seen in figure 17.

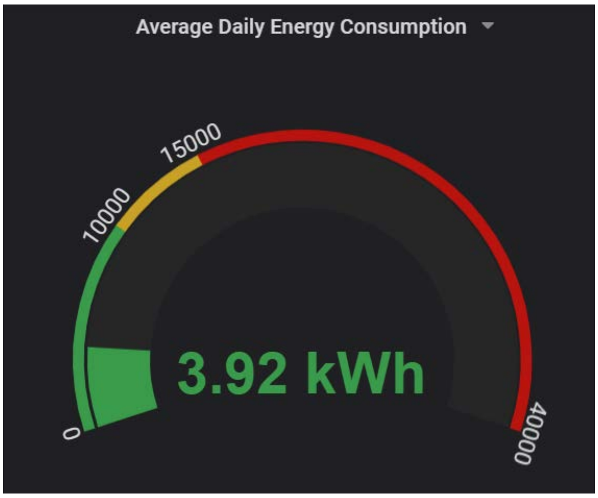

Figure 17 – Gauge of average daily energy consumption (Bazal Stanislav)

There is also a second approach on how to achieve the same result, but this approach includes one mathematical operation. Instead of changing the stat value to *average*, we change it to *total*, and in the metrics tab, we must select a *sum* aggregation and a mathematical expression. To fully understand that, let me provide specific numbers. With these options, we get a sum of 5 646 780 Watt-hours (see fig. 18). This corresponds to the sum of all values of Watt-hours per the whole selected date, which in our case is 24 hours. To achieve the average value, we need to divide the sum value by the total number of inputs throughout the whole day. Since one input is uploaded into Grafana every minute, this gives us 60 inputs per hour times 24 hours. Therefore, we have to divide this large number by 1440 to achieve the average value of the whole day. The mathematical equation for the second approach is "*math (/1440)*" and it can be seen in figure 18, where we can also see the comparison of the values before and after the division, and if we compare the resulting value with the one in figure 17, we can see that they match. Thus, both approaches are viable, but I personally prefer the first one since it is simpler and a person does not have to bother with mathematics.

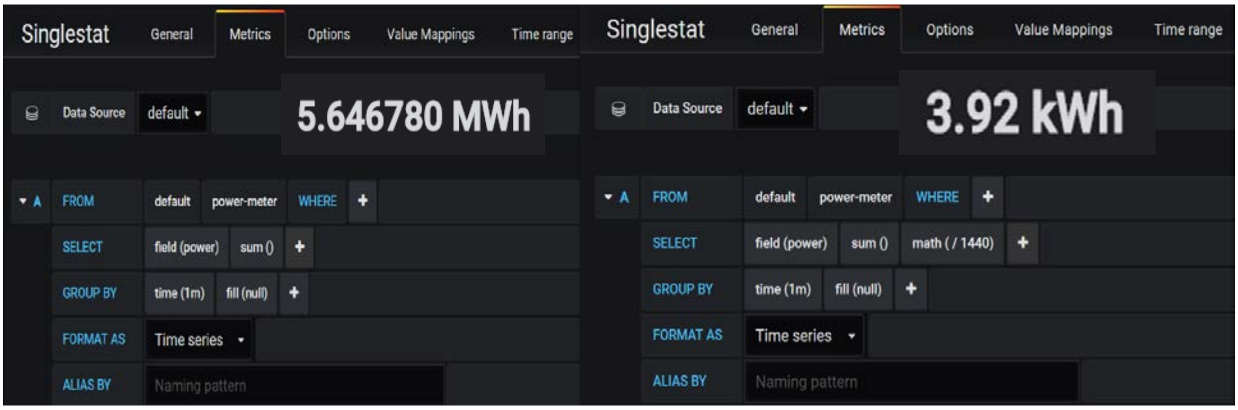

Figure 18 – Comparison of values before and after division (Bazal Stanislav)

7.4 Gauge of estimated daily/monthly electricity cost

Last two gauges that I am going to talk about provide estimated electricity costs either for the last 24 hours or for a whole month. It is necessary to say that the values are rough estimates and they are not perfectly accurate. Their purpose is to provide an insight into how much you would possibly pay for the day before or for the following month. The estimated costs are based on values measured a day before and based on the approximate energy cost per kilowatt-hour in the Czech Republic, which has been roughly 4.58 CZK in 2019 ("Průměrná cena elektřiny za kWh v roce 2019 zdražila na 4,6 korun"). The energy prices differ among the energy distributors and also based on the regions of our country.

Firstly, I should describe the gauge of estimated daily electricity cost and the mathematics behind it. It is necessary to mention that we are again working in a time range of the last 24 hours, which has been set in the *time range* tab. As we can see in figure 19, there is again a mathematical expression in which we divide the sum of all values of the last 24 hours by the number 1440 to achieve the average value. Since we now have an average value in watt-hours, we have to divide the number by 1000 to receive the number in kilowatt-hours, multiply it by 24, which represents the number of hours, and also multiply it by 4.58, which is the approximate energy cost per kilowatt-hour in the Czech Republic. This provides us an approximate energy cost of the previous day. The mathematical equation used to achieve the result of 431 CZK, which can be seen in figure 19, is "*math (/1440/1000*24*4.58)*". It is quite obvious that the resulting cost is rather enormous and most people would not be able to pay such price at the end of the month. This is due to the fact that my simulated data represent energy consumption which is, unfortunately, higher than average and it obviously reflects on the energy costs. In figure 19, we can see both gauges next to each other and we can compare their options. We can see that the results can be achieved by both approaches that we have mentioned in the previous chapter. The mathematical expression for the second gauge only differs in a way that we multiply the number by 30, which represents the number of days in a month, and we do not have to divide it by 1440 since we are already working with the mean value. The mathematical operation of the second gauge is "*math (/1000*24*30*4.58)*".

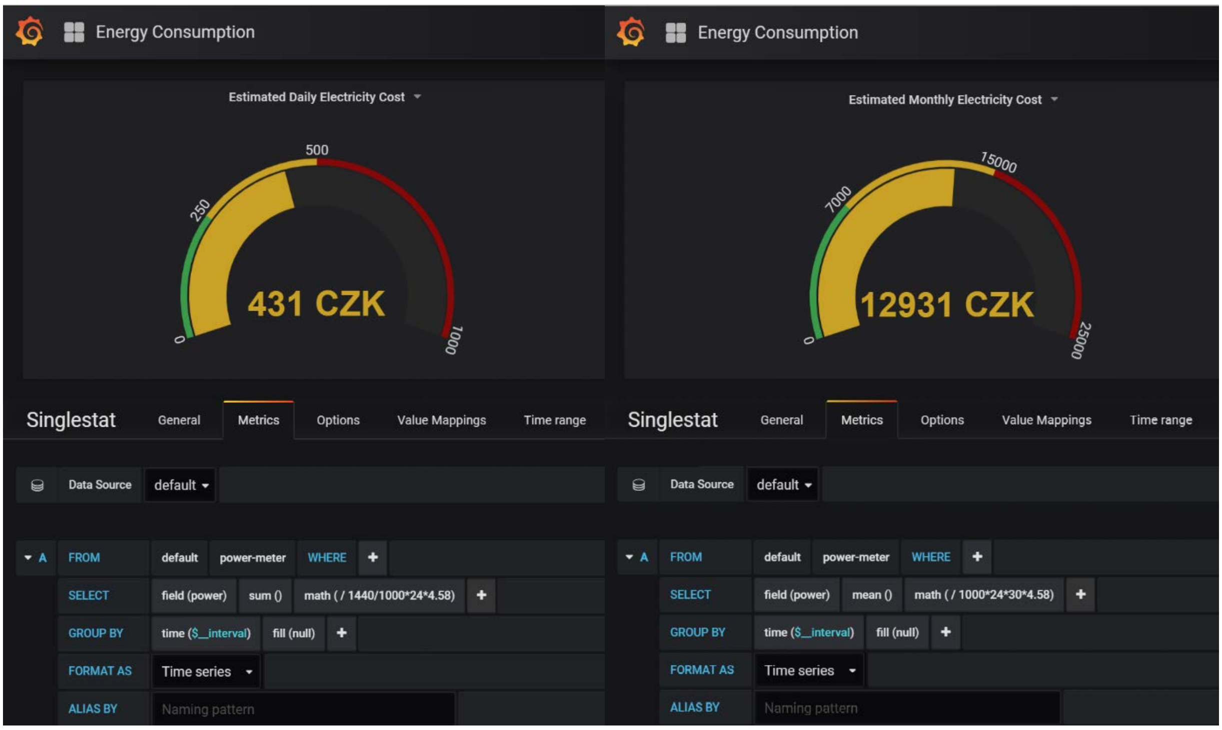

Figure 19 – Metrics options for the gauges of daily and monthly electricity cost (Bazal Stanislav)

As I have mentioned before, these values are rough estimates and they are not perfectly accurate. I believe that the gauge of daily electricity cost can prove highly accurate, but the accuracy of the second gauge, unfortunately, is not that high. Theoretically, there might be a way how to increase the accuracy of the second gauge, but I doubt that this approach would be achievable in practice. Since the second gauge works on the same principle as the first one, but we only multiply it by 30 for the number of days in a month, the resulting value only considers an average value of one day in a month and multiplies it by 30. If there had been an option to choose average values of each day for the last 30 days, we would have theoretically had the option to solve our problem provided we would have done the mathematical operations for each day, and we would have added them up. This would result in much more accurate measurement. Unfortunately, this is only a theoretical approach since Grafana does not provide the feature of splitting the selected time region into smaller parts. Thus, it is impossible to calculate the prices of each day and add them up.

8. Conclusion

In this thesis, we have explained the fundamentals of smart metering technology, what smart meters are and also their possible benefits for both people in households and for energy suppliers. Rising demand for electricity has become one of the major concerns which have brought smart grid technologies to the spotlight. This work shows the overall implementation of smart meters across foreign countries and continents. There are several projects in different countries and they all have the similar purpose – to determine whether the smart metering technology could truly be beneficial for us and whether it would provide reliable and eco-friendlier energy production with the possible outcome to replace the traditional power plants that are not environmentally friendly. Throughout this work, we have described the possible impacts of smart grids, the countries that have been doing their researches on smart metering technologies, and we have shown some financial costs and benefits for the energy utility companies distributing the smart metering technology. Most of the projects are going to be in progress until 2020 and some until 2025. Despite the fact that there already are some studies covering the benefits of smart metering technologies in terms of efficiency of energy production, it is not possible to draw a final conclusion yet, because the majority of the projects are still in progress.

As far as my practical part is concerned, I have been working on a device that has the capability of collecting data of energy consumption of electricity meters. The practical part of this thesis was done under the guidance of my technical consultant who proved to be a great support whenever I encountered any problems. My particular task was to create a user interface in Grafana, which is an open-source software for time series analytics, where I presented the data of energy consumption in a useful graph and gauges. My aim was to make the user interface look simple, useful for its users, and also accurate. For these reasons, I decided to use only two types of panels in Grafana to secure simplicity and not to make it appear complicated and confusing for the user. For securing the usefulness of the user interface, I decided to display the graph of energy consumption over time, the gauge that provides how much power a person consumes in real time, another gauge that tells the user how much energy s/he spent for the last 24 hours, and finally, two other gauges which inform the user how much money s/he would approximately pay for the previous day or at the end of the month. Despite the fact that I have not been able to connect the device to my electricity meter at home for the reasons stated above, I have still collected a great amount of data by simulating the light flashing of the diode, and I have proved the usefulness of the device.

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