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DC micro-grids

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Summary

DC micro-grids

The conventional electrical system in place today sees our electrical devices powered by AC mains. But as renewable technologies such as solar photovoltaic and wind power become more prevalent at a household level, DC micro-grids could be a cheaper and more efficient alternative. New lighting devices (LED) can reduce the electricity consumption substantially. Two alternatives are envisioned in this paper: A stand-alone alternative in which there is no grid connection, that would require local storage (battery), and a grid-connection alternative.

After reviewing and investigating relevant literature for this topic and writing theoretical part of thesis there were the fallowing tasks. One typical four member family household was described and hourly load curves for one year period, with typical summer and winter days, were made for this case. Next task that was completed was generating yearly energy production from solar panels, which the observed household contains, in INSEL software. With having those previously mentioned data, combined with necessary information about prices of all necessary components and prices from Croatian power system, it was possible to make feasibility and cost analysis where the two previously mentioned alternatives were investigated. With changing some parameters in that economical analysis several scenarios were observed. At the end conclusions were made about which one of those two options is more profitable and under what conditions. Also, suggestions were made for further work on this topic.

This assignment is realized as a part of the collaborative project “Sustainable Energy and Environment in Western Balkans” that aims to develop and establish five new internationally recognized MSc study programs for the field of “Sustainable Energy and Environment”, one at each of the five collaborating universities in three different WB countries. The project is funded through the Norwegian Programme in Higher Education, Research and Development in the Western Balkans, Programme 3: Energy Sector (HERD Energy) for the period 2011-2014.

Keywords: direct current, micro-grid, load, load curve, photovoltaic, costs, benefits

Summary in Croatian

DC mikro-mreže

Većina trošila današnjeg konvencionalnog elektroenergetskog sustava pogonjena je istosmjernom strujom. No, kako obnovljivi izvori energije kao što su fotonaponski sustavi i energija iz vjetra postaju sve češći u kućanstvima, DC mikro-mreže mogle bi postati jeftinija i učinkovitija alternativa. Novi izvori svjetlosti (LED) također mogu značajno smanjiti potrošnju električne energije. Dvije alternative predviđene su u ovom radu: samostalna, u kojoj mikro-mreža nije spojena na glavnu elektroenergetsku mrežu te je potrebno lokalno spremište energije (baterija) i alternativa kada je sustav spojen na mrežu.

Nakon pregleda i istraživanja relevantne literature za ovu temu te pisanja teoretskog dijela rada, zadaci su bili sljedeći. Opisano je jedno tipično četveročlano domaćinstvo i za taj slučaj su izrađene satne krivulje opterećenja za period od godine dana, s tipičnim zimskim i ljetnim danima. Sljedeći je zadatak bio generirati godišnju proizvodnju električne energije iz solarnih panela, instaliranih u promatranom domaćinstvu, u programu INSEL. S prethodno navedenim podacima te potrebnim informacijama o cijenama svih nužnih komponenti i cijenama u hrvatskom elektroenergetskom sustavu, bilo je moguće provesti analize izvedivosti i ekonomske analize u kojima su prethodno navedene dvije alternative bile promatrane. Mijenjanjem pojedinih parametara u tim ekonomskim analizama nekoliko scenarija je uzeto u obzir. Na kraju su donešeni zaključci o tome koja je od tih opcija isplativija te pod kojim uvjetima. Također su dani prijedlozi za daljnji rad na tu temu.

Rad je ostvaren kao dio zajedničkog projekta "Sustainable Energy and Environment in Western Balkans" koji ima cilj razviti i uspostaviti pet novih međunarodno priznatih diplomskih studija u području okoliša i održivog razvoja, jedan na svakom od pet suradničkih sveučilišta u tri države zapadnog Balkana. Projekt je financiran kroz program vlade Kraljevine Norveške za visoko školstvo, istraživanje i razvoj u zemljama zapadnog Balkana, Program 3: Energetski sektor (HERD Energy) u razdoblju 2011.-2014.

Ključne riječi: istosmjerna, mikro-mreža, trošila, krivulja opterećenja, fotonaponski, troškovi, korist

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Abbreviations

AC	*Alternating Current*
AM	*Ante Meridiem (Before Noon)*
BLDC	*Brushless Direct Current*
CO_2	*Carbon Dioxide*
DC	*Direct Current*
HEP - ODS	*Hrvatska Elektroprivreda – Operator distribucijskog sustava*
INSEL	*Integrated Simulation Environment Language*
IRR	*Internal Rate of Return*
ISS	*International Space Station*
LED	*Light Emitting Diode*
NASA	*National Aeronautics and Space Administration*
NPV	*Net Present Value*
PFC	*Power Factor Corrector*
PM	*Post Meridiem (After Noon)*
PV	*PhotoVoltaic*
TV	*Television*
VAT	*Value Added Tax*

1. Introduction

Today civilization has to complete one of the greatest current challenges, to ensure reliable and continuous energy supply. In modern society, which now prevails, electric energy has a certain priority. Interrupting supply of electric energy for sensitive customers, for just a few seconds, can cause them some serious damage. In case it lasts longer than that there is a great chance for economical disaster to be created. To every developed country, availability of high quality electrical energy is essential in short as well as in the long run. One of the main reasons for that is the fact that our daily life is depending totally on electric energy. Current problems related to electric energy supply are numerous. Energy crises and level of environment pollution are becoming more and more serious problem of today society, greenhouse effect is becoming more and more widespread and demand for greater amounts of energy is especially increasing in developing countries like India, China and Brazil. Another contemporary issue is constantly growing people's outcry against implementation of new sources of nuclear energy as the well as lack of conventional fossil fuels which are gradually getting depleted. [1]

Due to all those previously mentioned problems renewable sources are becoming more popular solution thanks to their environment-friendly characteristics. Producing clean energy is mostly done using distributed generations like wind turbines, photovoltaic cells, fuel cells or gas engine cogenerations. Those technologies, which are expected to play a key role in reducing environmental pollution and mitigating energy crises, could also cause some problems with power system. In case there are a lot of distributed generations that are connected to the power distribution system, problems with protection and voltage rises are very likely to occur. A solution that could help securing reliability and maximizing operations efficiency is using smart micro-grids and by that enabling electricity production decentralization. [1], [2], [3], [4]

From all those previously mentioned renewable energy sources, solar photovoltaic generation systems are spreading the most quickly thanks to their non limited generation, very easy installation, relatively high efficiency and low cost. Since this is a direct current (DC) source, multiple conversion stages would be needed there before connecting with alternating current (AC) system. For that reason and because today households are partly contained of DC loads (electronic loads – "gadgets" and light emitting diodes (LED) lights) DC micro-grids would be an ideal solution. [5]

2. Overview of DC technology

2.1. History

More than one hundred years ago there was a great technological battle between Thomas Edison against George Westinghouse and Nikola Tesla famous by the name “War of currents”.

The whole story started in 1887 when Tesla filed papers for seven patents related to power transmission and polyphase motors and George Westinghouse heard of it. He immediately realized that this is the man who could have a solution for perfecting long-distance power transmission. After making a deal for buying his patents, Tesla was able to improve his laboratory with the money that he gained. Thanks to the great breakthrough that Tesla’s patents provided, Westinghouse’s alternating current became a great rival to Edison’s direct current. The future of United States industrial development depended on which one of those technologies would be chosen at the end.

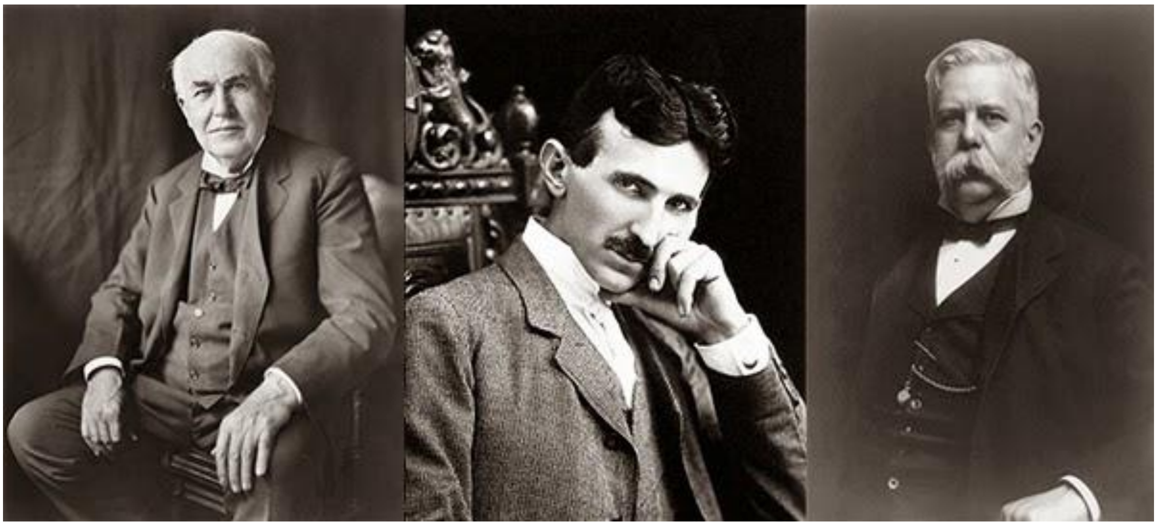

Figure 1: Thomas Edison, Nikola Tesla and George Westinghouse

It did not take much time for Thomas Edison to start his propaganda against Westinghouse’s alternating current. Although he knew that his direct current cannot easily switch voltages, he didn’t want to give up on it. His mission was to persuade public that alternating current represented a great threat to society. When he saw in 1903 that alternating current is probably going to take direct currents place as the standard for distribution of electricity around the United States, Thomas Edison decided to take desperate measures. He wanted to show the public how dangerous the alternating current is by electrocuting the circus elephant, Topsy, with 6600 V charge. His point did not make much sense because direct current is equally dangerous at that high voltage.

Figure 2: Topsy, the electrocuted elephant

As we all know, Edison lost that war because at that moment using alternating current power gave opportunity to shift voltages from one level to another. Because of that it was possible to carry power at high voltages on long distances with minimized losses.

The question whether direct current should be used instead of alternated current power is reappearing today and everybody is wondering if maybe Thomas Edison was right after all. [6], [7]

2.2. Characteristics of DC micro-grids

More than a century after Edison and Tesla's "War of currents", the usage of alternating current is again under a lot of questioning. Since power consumption of all kinds of digital devices and other DC loads is growing more and more, direct current has an opportunity to fight back.

There are some great benefits that could be achieved if DC micro-grids would be implemented. The first one that crosses the mind is the elimination of AC/DC conversion stages in case of electronic devices such as computers, laptops, flat-screen TVs, variable frequency drives, etc. These kind of appliances represent for about 15% of electric loads in households and because of that using direct current would enable lowering the power losses which goes to devices from 15%-40% to 10%-15%. Another example of DC loads are LED lights which are rapidly becoming a part of almost every household. They could drastically lower global consumption which is today considered to account for around 20% only on lighting. Other benefits of DC micro-grids are simplified installation and reduced fuel costs.

As it has been said in the introduction, the need for better efficiency as well as high reliability and more intelligent power distribution is showing in today's market. Implementing DC micro-grids would help, at least partly, to solve these problems. It would also be cheaper and more efficient alternative thanks to solar photovoltaic and wind power that are anyways becoming more prevalent on a household level these days. Solar photovoltaic that are used later in this thesis's observed household are classified in two types. First one of them is a stand alone PV system and the other one is grid connected PV system. Stand alone systems are usually used in cases of isolated or remote regions where power grid is not existent. Since solar cells output power can be changed by some environmental factors, like temperature or irradiation, a battery has to be used to ensure balance between the solar cells input and the output power to the load.

Another great advantage of DC micro-grids is the fact that even if at one load side a short circuit occurs, it will not affect other loads. There is also a very low risk of dangerous electric shocks from low voltage DC. That fact is making plug-and-play grids a possibility. Also, it is much easier to change DC than AC micro-grid to island mode with no problems by disconnecting it from the power system. [2], [3], [4], [8]

2.3. DC micro-grids in the future

In the future it is expected for customers to have the ability to generate, store as well as storage and manage part of the consumed energy with the development of micro-grids. There are predictions for energy system in the future to have installed intelligent devices in all, generation units, substations, transmission lines, controllable loads and distribution networks. A new system is going to be a kind of combination from information and communication system network and traditional power system. Those two mentioned networks will be built-in to together make an advanced architecture in which there will be a two way flow of power and information. It will allow customers to access to information such as current electricity tariffs on the market, peak power demand at the moment and how to minimize their power bills. Customers will in that case have possibility to communicate and sell their surplus stored energy at good price. That distributed generation customer's opportunity to participate in different electricity markets, as well as controlling its individual energy consumption, is the whole idea of modern DC micro-grids. [9]

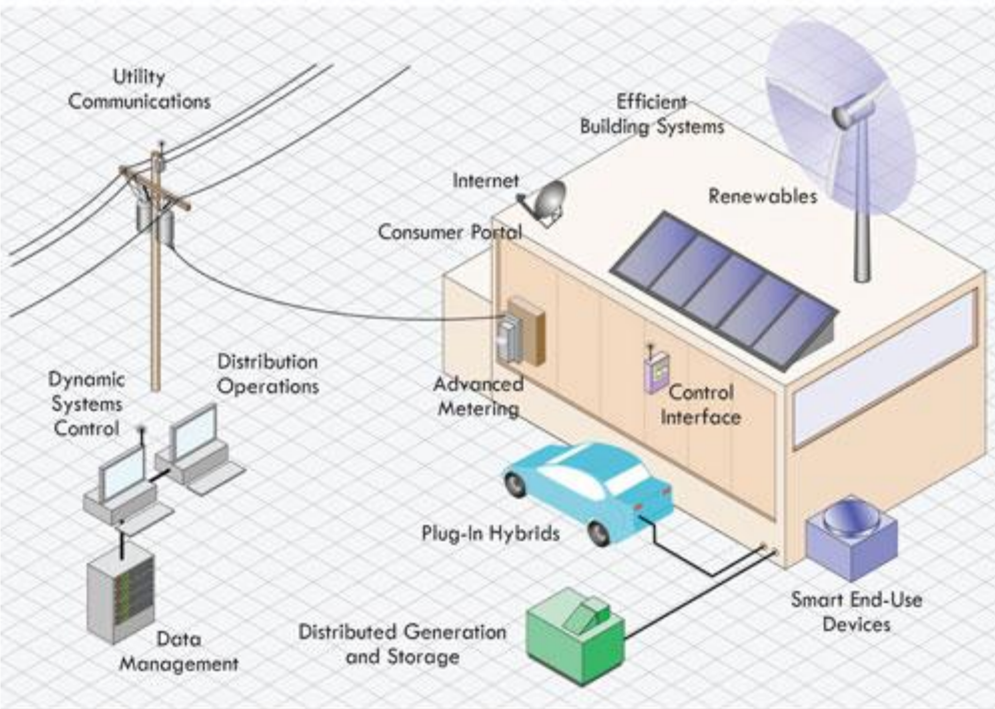

Figure 3: Smart DC micro-grid **[**10**]**

2.4. Existing DC power systems

There are already some existing power systems that use direct current distribution. A few of these systems will be explained in more details below.

2.4.1. Data centers

Today, there are both DC and AC data center power systems. Primary task of these kinds of systems is to transfer and store large amounts of digital information like credit card transactions, cellular communications and of course, internet. The most important feature that has to be sustained in data centers is reliability. Since expected energy consumption of data centers is around 20% of its total costs, low price of energy should also be ensured. The fact that conversion stages are eliminated in DC distribution makes it a more efficient and economical option.

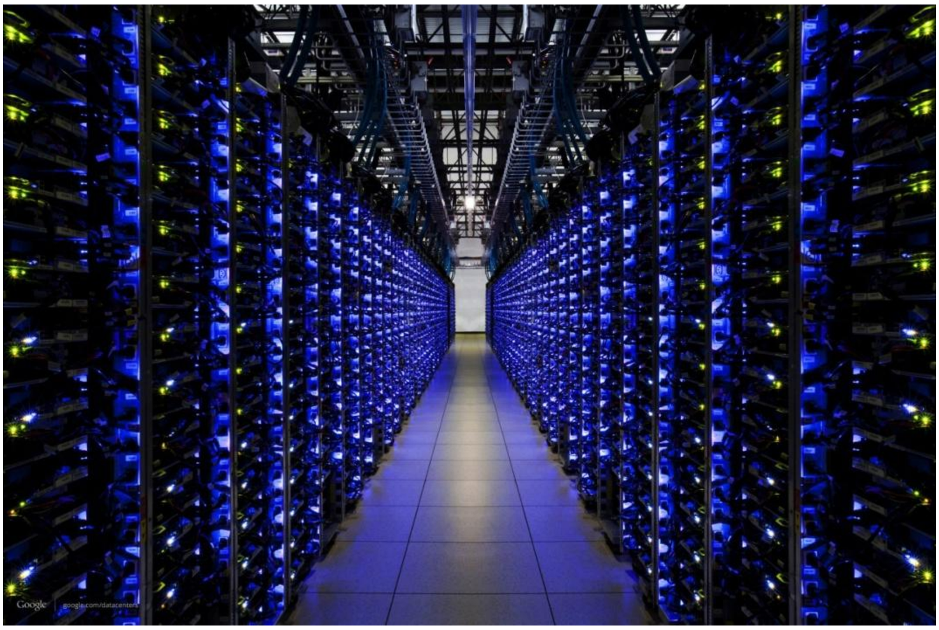

Figure 4: Google data center [11]

2.4.2. Telecommunication

Similar to data centers are telecommunication power systems. Here are also transferred data but much bigger amounts of it than in case of data centers. Therefore, high efficiency and reliability are also needed in this case, preferably at a low cost. For those reasons, DC distribution is used here as well.

2.4.3. Spacecraft

Thanks to enormous amount of solar panels that are needed, as well as batteries, DC/DC converters, battery chargers and DC loads, DC distribution is necessary in case of spacecrafts. As an example could be taken International Space Station (ISS) from NASA, that needs more than 100kW. Two almost independent DC systems with diverse voltage levels make ISS. Russian system has two voltage levels, 120V and 28V, and has installed solar power modules of total 29 kW while American one has even more, 76 kW installed capacities and voltage of 120V. To make power transfer possible between those two systems they are connected with bi-directional DC/DC converters.

Figure 5: NASA International Space Station [12]

2.4.4. Traction

Traction power systems, like trams, underground railways and trolleybuses also use DC distribution, mostly because they typically use DC motors. As far as the traction systems with induction motors are concerned, using DC supply gives advantage for simplifying and reducing conversion stages. That results with increased system efficiency and controlling abilities. Thanks to those benefits, DC distribution is supplying not only vehicles in traction power systems, but other secondary loads on them. Voltage ranges with which systems can be supplied are from 600V and 750V to approximately 1 kV. [8]

3. Household

A household which is going to be observed in this paper is located in a small town, Čazma, in continental part of Republic of Croatia. Precisely, its geographical coordinates are 45º45'14''N, 16º37'24''E. The size of the observed household is 98 m^2 and it has roof surface of 65 m^2 with gradient of 30º in south direction and 45 m^2 with gradient of 30º in north direction.

The observed household consists of a four member family, two adults and their two children from whom one is of younger age and still in primary school and the other one is a teenager who goes to high school. Both of parents work from Monday to Friday and their working hours are from 8am to 4pm. The younger child goes to school from 12am to 5pm and the older one from 2pm to 7pm. This information will be needed for the purpose of defining their consumer habits related to consumption of electrical energy during some specific days in the year 2013 (summer and winter typical week and weekend day) and at the end during that whole one year period.

Later in this chapter all loads used in this household and their individual consumption will be defined, as well as joint consumption of all loads combined, during above mentioned periods. For this, statistics made in the United Kingdom in a "Household Electricity Survey", A study of domestic electrical product usage will be used. [13] At the end load curves for those periods which will be used later in this paper will be made.

3.1. Home appliances

All appliances used in the observed household are operated by direct current electricity, but the important thing to mention is that there is not electric heating in there. Owing to widely spread gas pipeline in the area where the house is located, all house space heating is provided by means of gas the same as boilers and stove.

Advantages of a DC residence, next to elimination of the transformer/rectifier stages and completely eliminating standby losses, are improved efficiency, reduction of CO_2 emissions and, thanks to the absence of reactive power, reduced losses. Also, efficiency can be increased and number of components needed for each appliance reduced by removing conversion stages. And as far as the reactive power is concerned, its absence means that lower current is needed to transfer the same amount of power.

Important thing to mention is that some DC appliances need a DC/DC converter to be able to properly adjust the DC voltage which is needed for specific load, harmonics and eliminate power factor issues. In the future, the plan for motor driver devices is to replace actual motors in domestic appliances thanks to the advances in power electronics technology.

Voltage of the observed household is going to be split in two different alternatives, 48V and 24V, because there are big loads with input voltage of 48V, but also some of the appliances have lower input voltage, like 12 or 24V. Because of that, in some cases DC/DC inverters will be needed. That high voltage (48V) is going to be used because it is expected in a near future for DC appliances to be manufactured in that way, for the purpose of using lower currents which would significantly decrease feeder losses and enhance overall appliance efficiency. [14]

3.1.1. Electronic loads

In the observed household there are two types of electronic loads that consume the most power from that group of appliances and they will be analyzed in this chapter. These are laptop computers and TV's, and by modifying only the input power conversion stages a power reduction can be achieved.

In case of laptop computers, the bus voltage of the distribution system deviates between 19,5V when is connected with wall adaptor and 14,8V when it is run by battery power. In real terms the bus voltage range will be slightly lower, from 10,8V to 16,8V, which depends on number of battery cells and configuration. Because of that there is a need for DC/DC converter which will be connected to the distribution bus so it could supply different voltages for diverse loads inside the computer. While the current "AC laptops" demand a battery charger which first has to rectify the main voltage and then maintain the state of charge of the battery, there is a difference with DC ones. Because the laptop has the capability to run with DC power if we remove the transformer/rectifier stages, using a synchronous buck converter will allow modeling the step down DC/DC converters that are needed.

The other electronic loads that will be analyzed here are LCD TV's which have significantly lower power consumption in comparison with other TV's and that is the reason why are they chosen to be used in the observed household. If we want to operate them with DC power, the transformer/rectifier stage will be eliminated. The things that need to be done are to remove the boost PFC and also modify the flyback standby stage to manage an input voltage of 24V from the bus. [14]

3.1.2. Resistive loads

Home appliances that are considered as resistive loads, commonly known as heaters, include ovens, dryers, stoves and lighting and can very well be modeled as resistance. In this case, gas is used to operate the stove, so from the resistive loads we have oven and dryer. Their input voltage will be 48V.

Lighting that will be used in the observed household entirely consists of light emitting diodes which provide longer operating hours and smaller power consumption than other kinds of lighting. Also, they operate better with DC power containing small ripple. Important thing to mention is also that all of the LEDs used in this household have 24V input voltage. [14]

3.1.3. Appliances with motors

Some of the appliances with motors that are used in households are mixers, dishwashers, cloth washers and dryers, vacuum cleaners and many others, and all of them are loads that incorporate the use of a single phase AC motor. In this observed household those appliances will be using brushless DC (BLDC) motor which will upgrade their efficiency and power density. This three-phase permanent magnet synchronous generator fed with DC input motor is ideal for these appliances also for its high torque, reduced electromagnetic emissions, extended lifetime thanks to absence of brushes and also simpler control.

First of the appliances with BLDC motor that are used in the household is cloth washer. It is fed by DC power but will also need a DC/DC converter in order to increase the battery voltage up to the required input voltage. For this purpose full bridge DC converter will be used, which is able to manage power ratings from 500W and up, as a coupling device between the appliance itself and the battery bank. Input voltage of this appliance is 48V. The same changes will be applied also for the cloth dryer. Rectifying stage will be replaced by the full bridge DC/DC converter stage, since it is also designed for high power appliances, and the input voltage will also be 48V.

Air conditioner units (AC units) that are operated with DC input voltage are already in wider use and commercially available all around the world. They also use the BLDC motors and in this case will have input voltage of 48V.

As far as fridges are concerned, they are the DC appliances which are most popular and commercially available. These appliances can be found with various input voltages and different specifications. In our case unit with input voltage of 24V will be used. [14]

3.1.4. Microwave oven

The household load, which cannot be classified into none of previous group, is microwave oven. This load has two power suppliers and two independent circuits, the low and high voltage section, on which the redesign will be focused. If we want to operate microwave oven with DC power there are some changes that have to be made in order to remover transformer/rectifier stages. High-voltage transformer will be replaced with two flyback DC/DC converters suitable for appliances with higher voltages, and fans and motors will be replaced by BLDC alternatives. Input voltage of the microwave oven that will be used in this household is 48V. [14]

3.1.5. Efficiency of DC appliances

DC appliances are much more efficient than their counterpart AC versions. They owe it to the fact that there is no inverter, so there are no losses in transformation AC to DC power or conversely. Though, there will be need for DC/DC convertors, but DC to DC conversion is more efficient than AC to DC conversion. Also, the fact that LED lighting will be used means that significantly less power will be consumed than in the case of traditional lighting systems. As far as electronic load are concerned, there will also be savings in power consumption thanks to elimination of conversion stages. With all those facts before mentioned, we can surly conclude that using DC appliances will significantly reduce power consumption of the observed household.

3.2. Load curves

With all necessary information about life and consumer habits of people living in an observed household the following load curves for some specific days in a period of one year were made.

First of those four generated curves is for one typical winter week day (Figure 1). Total consumption of that day is estimated at 8,1 kWh. As we can see, there is a very low consumption between 1am and 6am when everyone is asleep and between 1 pm and 4 pm when both children are in school and parents are at work, which represents the base load, the consumption of continuous appliances and the appliances in standby mode. From 6 am, when parents wake up for the work, the power consumption is going up as other appliances start to be in use. The consumption rapidly rises at 4 pm when parent are back home so they start using kitchen appliances as well as electronic loads. Peek consumption, according to the diagram below this paragraph, is between 8 pm and 9 pm and the reason for that is the fact that family uses dishwasher at that time which is an appliance with high consumption, because then they are done with cooking for the next day as well as having their dinner. As the day passes, the consumption gradually decreases.

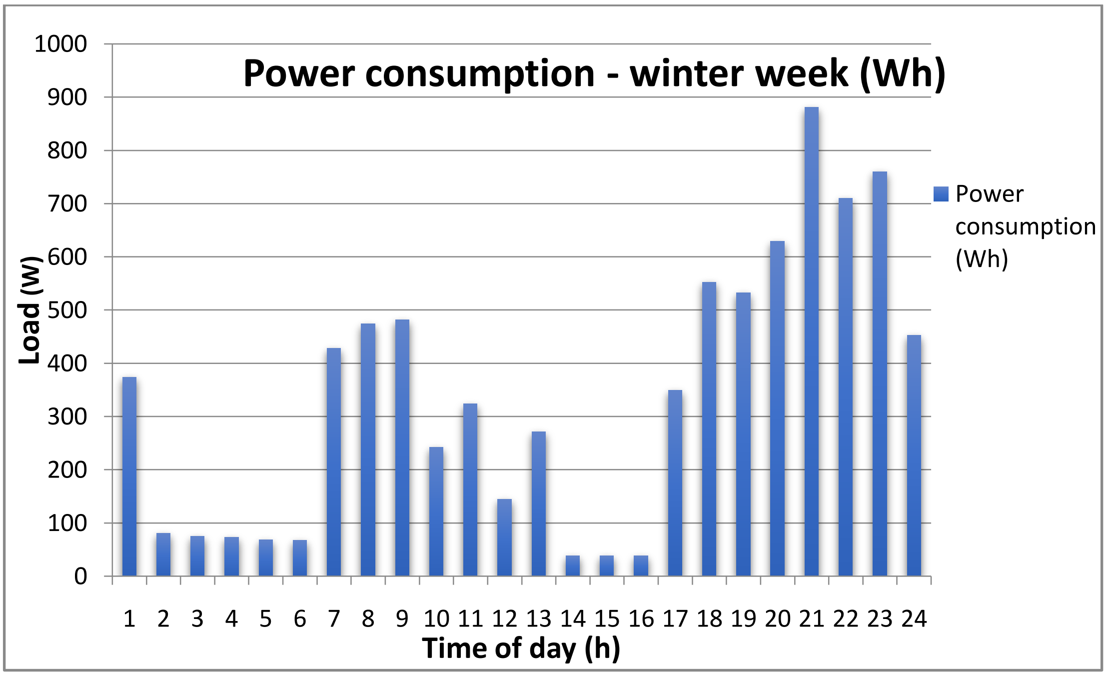

Diagram 1: Power consumption of a typical winter week day

In the next picture we can see a diagram that describes a daily consumption for one typical winter weekend day. (Figure 2) The main difference between this and the previous diagram is in the afternoon period because now all family members are at home, so it is obvious that in this case the consumption is higher than during the work days. Also, it is noticeable that the consumption is higher from 1 am to 2 am, but lower from 6 am to 8 am because family is up longer at weekends and sleeps longer in the mornings. In the total sum, daily power consumption for one typical winter weekend day is 10,8 kWh. It is so because of the fact that all family members are at home most of the day and it is more than expected for consumption in this case to be higher than in the previous one.

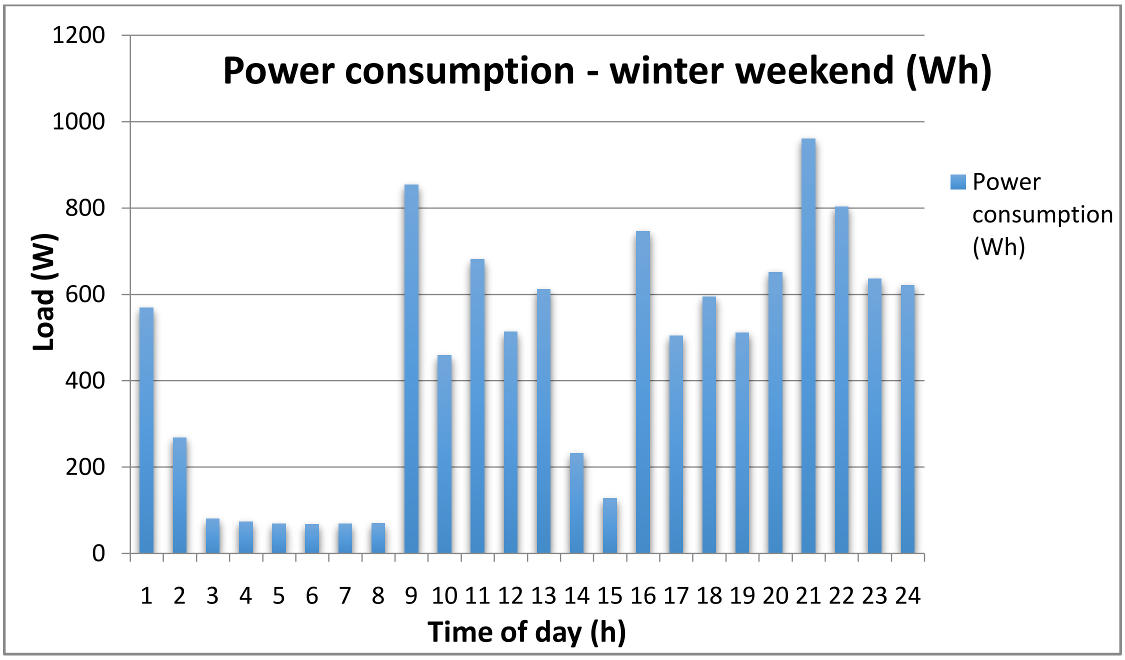

Diagram 2: Power consumption of a typical winter weekend day

In summer days there is a quite big difference noticeable in total consumption in general. The main reason for that are the air conditioning units which work only in that period and have high consumption. Consequently, as it can be seen in Figure 3., the total sum of power consumed in one typical summer week day is significantly higher than in one typical winter week day. If we want to talk in precise numbers, daily power consumption for one summer working day is 10,1 kWh. The same pattern in consumption is apparent as in the winter case because the family members still have the same consumer habits and obligations during the day. To confirm that fact we can compare two diagrams (Figure 1. and Figure 2.), and the result is clear. The minimum consumption, related to base loads, is at the same time in both diagrams as well as the peeks which also occur in the same period in a day. The only difference is in using the air conditioning units, which are necessary in hot summer days, and they increase the total consumption for 2 kWh per day. There is also some difference in using lighting systems because in summer days the day is significantly longer and starts earlier in the morning than during the winter.

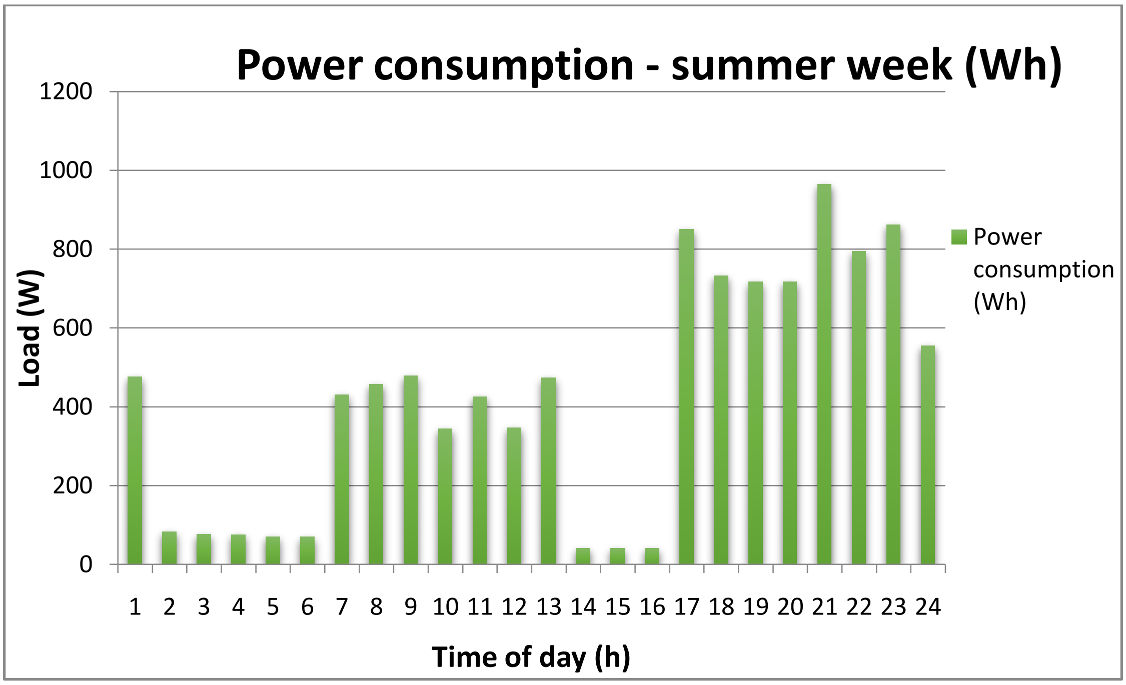

Diagram 3: Power consumption of a typical summer week day

The last diagram (Figure 4.) refers to one typical summer weekend day. In it we can also see the same pattern in power consumption during the day like in the winter weekend days. In this case, unlike the working days, there are few more differences besides using air conditioning units and less lighting. Because of the nice weather and high temperatures in summer days family spends more time outdoors than in the winter weekend days, and during the hottest hours (from 12 pm to 4 pm) inside the house, which also reflects to the total consumption which is for this case 12,6 kWh. [15]

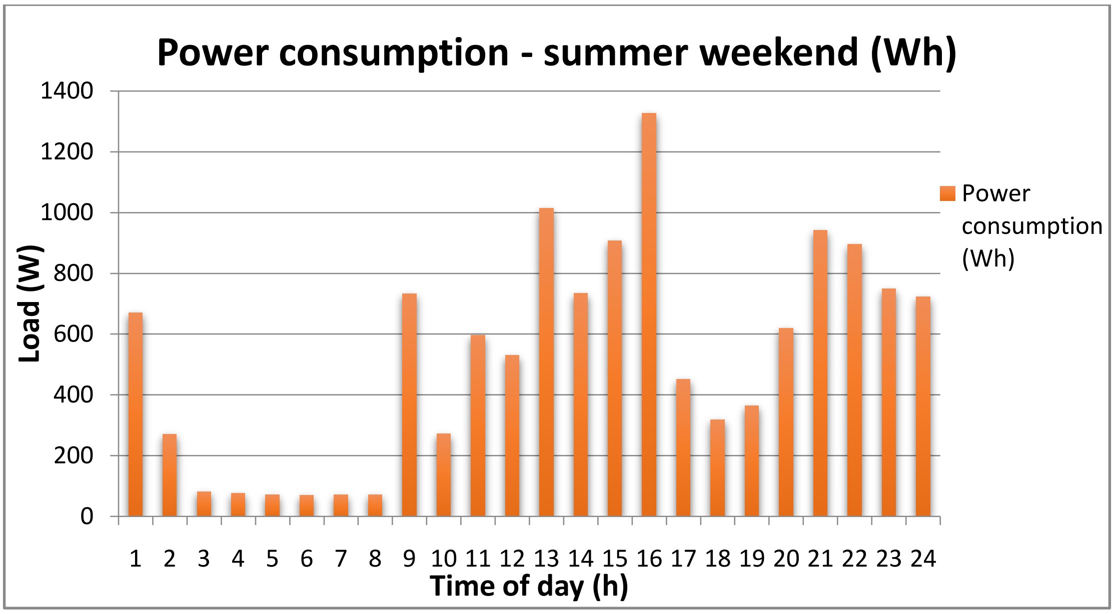

Diagram 4: Power consumption of a typical summer weekend day

The final stage in making load curves is to generate hourly consumption for one year period. That was made by using four typical daily curves, which were previously described, and data that defines average monthly temperatures in the area where the observed household is placed (Table 1.).

Table 1: Average monthly temperatures in Zagreb [16]

Month	JAN	FEB	MAR	APR	MAY	JUN
Temp. (^oC)	0,2	2,2	6,8	12	16,4	19,9
Month	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Temp. (^oC)	22	21,3	17,7	11,8	6,6	2,4

Hourly data for yearly consumption that was generated is contained in attached excel file while the following diagram shows monthly power consumption of the observed household. It is visible that there is the biggest consumption in summer months, primarily thanks to air conditioning units, as it was explained earlier, while in the winter months consumption is slightly smaller. In total sum, power consumed in one year period is 3,283 MWh. [17]

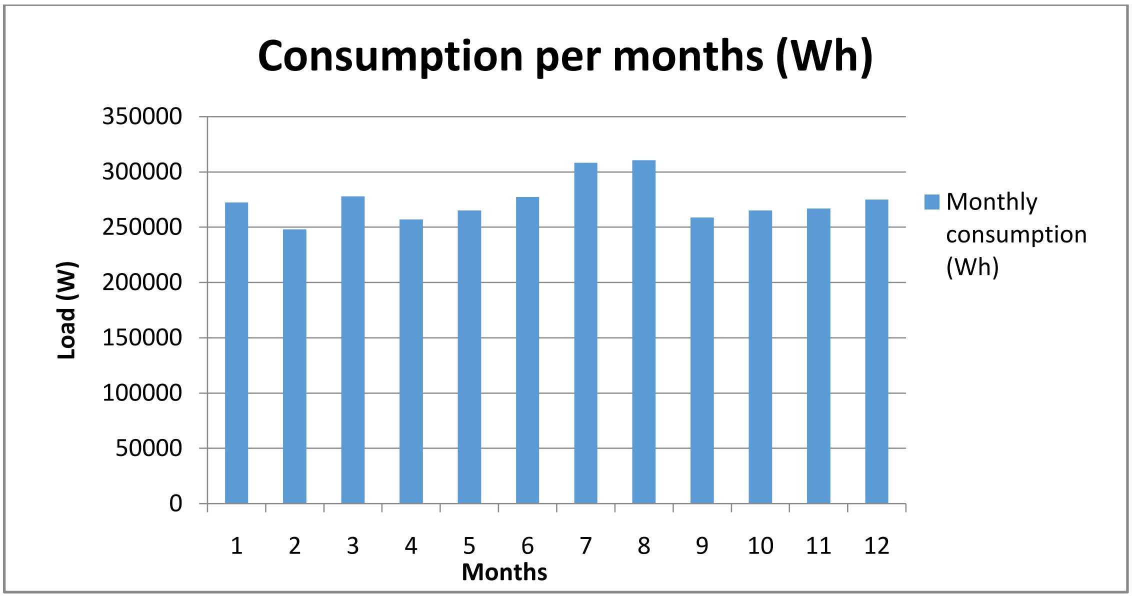

Diagram 5: Power consumption per months

4. DC micro-grid on household level

4.1. DC micro-grid household installation

In an observed household with used voltages of 24V and 48V, prices of all components needed for installing DC micro-grid are numbered in the following table. Prices of all needed supplies and elements are taken from store in Croatia that sells these kind of things, Bauhaus, while the price of hour of work of an electrician has been taken from Croatian chamber of electricians, the same as price of project documentation for this installation. [18]

Table 2: Prices of components needed for DC household installation

	UNIT	PRICE PER UNIT	NUMBER OF UNITS	SUM
Project documentation	**pc**	**3.500,00**	**1**	**3.500,00 kn**
Elements for household installation	**total**		**1**	**2.757,40 kn**
tube Ψ 16	m	3,00	120	360,00 kn
junction box square 100 x 100	pc	4,90	17	83,30 kn
junction box round 47 x 68	pc	3,90	8	31,20 kn
wire 1,5 mm	m	1,50	250	375,00 kn
socket	pc	44,00	23	1,012,00 kn
plug switch	pc	42,00	13	546,00 kn
distribution cabinet	pc	349,90	1	349,90 kn
Work on household installation	**total**		**1**	**5.760,00 kn**
hour of work of an electrician	h	72,00	80	**5.760,00 kn**
Other supplies	**lump sum**	**1.500,00**	**1**	**1.500,00 kn**
SUM				**13.517,40 kn**
				1.776,27 €

As we can see from the previous table, total price for this kind of DC micro-grid household installation in Croatia is around 1.776,00 €.

4.2. Stand alone alternative

The whole idea of a stand alone alternative is to be able to be cut off of the grid, but still be provided with all the electricity needed every moment of each day. That should be carried out with solar panels backed up with big enough battery which would ensure uninterrupted power supply at all times.

Production of electricity with solar panels was calculated in INSEL software (Integrated Simulation Environment Language) and data obtained through those calculations is visible in additional excel file. Many different calculations were made, with different kinds, different numbers and different ways of placing of solar panels, to be able to find the optimal solution for the observed household. Main problem that occurred while doing those calculations was a big difference between insolation during winter and summer period. Thanks to this fact, significantly higher number of solar panels is needed during winter to produce the amount of electricity which is necessary than it is in summer months. For that reason, the observed household will have to have installed a very large number of solar panels to be sure to have enough electricity produced in both summer and winter months.

The thing that also had to be considered was available rooftop surface of 65 m^2 with gradient of 30° in south direction and 45 m^2 with gradient of 30° in north direction. With all those limitations the optimal solution for solar panel distribution was made. 30 solar panels were placed on the roof surface in south direction with 15 panels in series and 2 panels in parallel, and 16 panels were placed on the roof surface in south direction with 8 panels in series and 2 panels in parallel. Since one panel has installed power of 255W, it has the total power of the system of 11,73 kW. Production of electricity during one year period from those solar panels is visible in following diagrams.

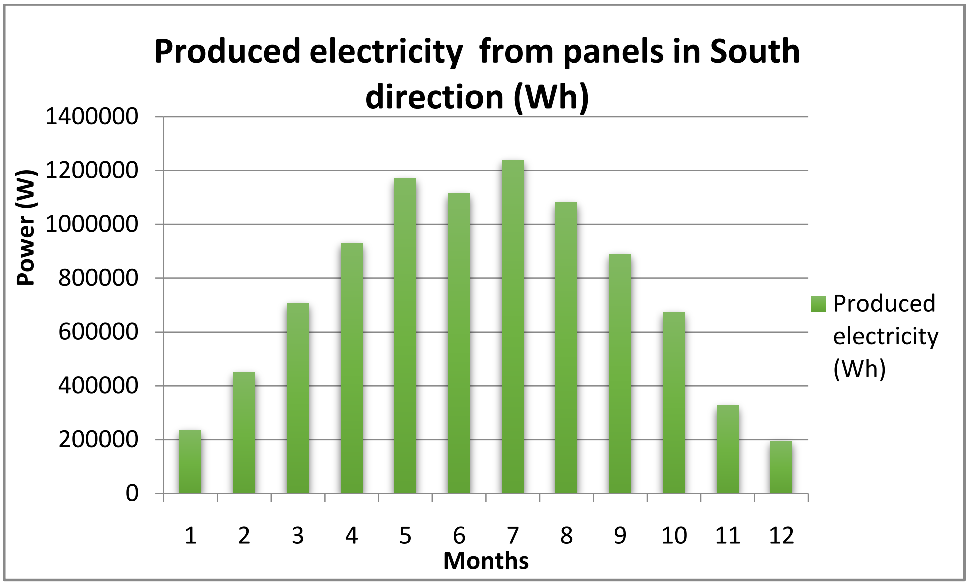

Diagram 6: Produced electricity from panels in South direction

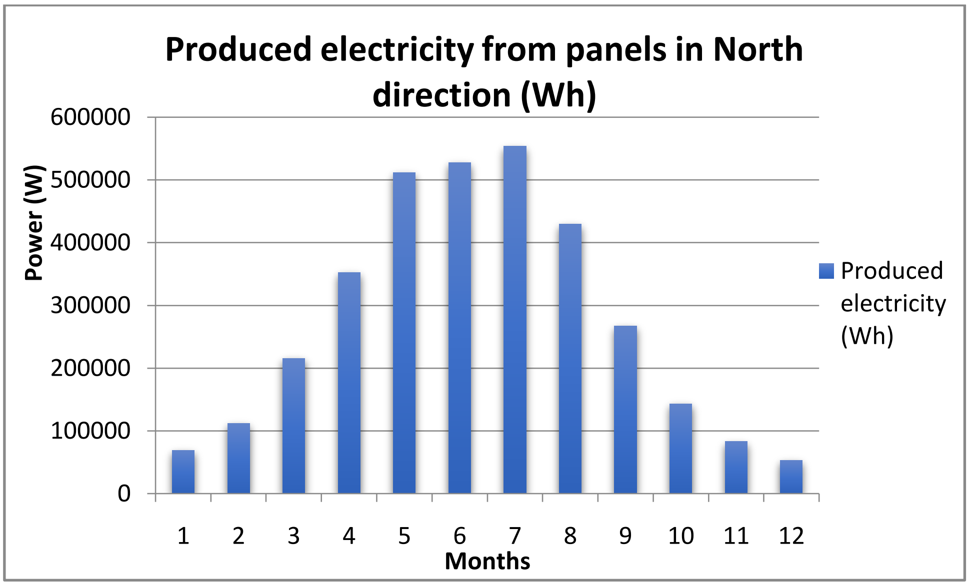

Diagram 7: Produced electricity from panels in North direction

On the previous two diagrams (Diagram 6., 7.) electricity production from solar panels on North and on South side of the rooftop surface can be seen and on the following one (Diagram 8.) is total produced electricity from both mentioned sides on which solar panels are placed.

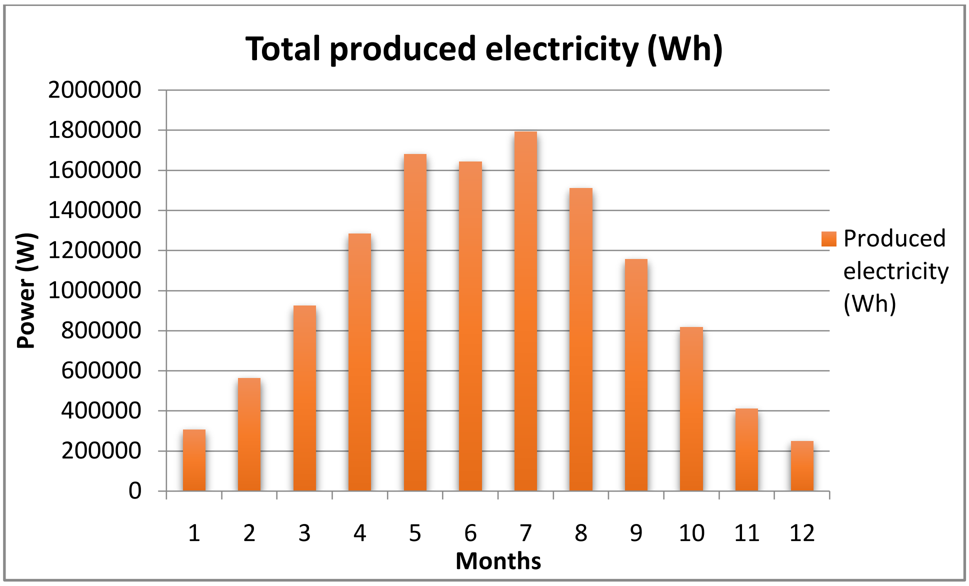

Diagram 8: Total produced electricity from all solar panels

From the previous diagram we can see the significant difference between solar panels production of electricity in summer and in winter months. Because electricity supply has to be ensured at all times, choosing optimal number of solar panels had to be done according to winter months when there is low insolation. For that reason, there is a few times higher electricity production in summer months than is actually needed. On the next diagram (Diagram 9.) is electricity production during one typical winter weekend day (5^{th} of January 2013) when there is a low insolation.

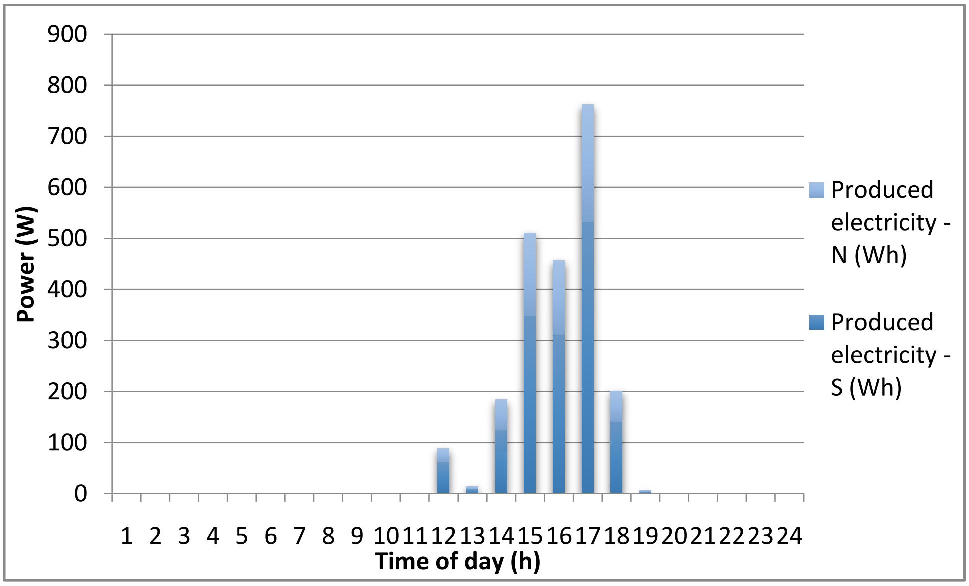

Diagram 9: Produced electricity on one winter weekend day

Important thing is to see the difference between consumption and production of electricity. For one winter weekend day, when there is a low insolation, it is shown on the following diagram (Diagram 10.). It is more than obvious that there is not enough electricity to cover demand on that day. To solve this problem, quite large battery will have to be used. If we want to specify this, the production of electricity on 5th of January is 2,224 kWh, while the consumption on that same day is 10,774 kWh, almost five times higher.

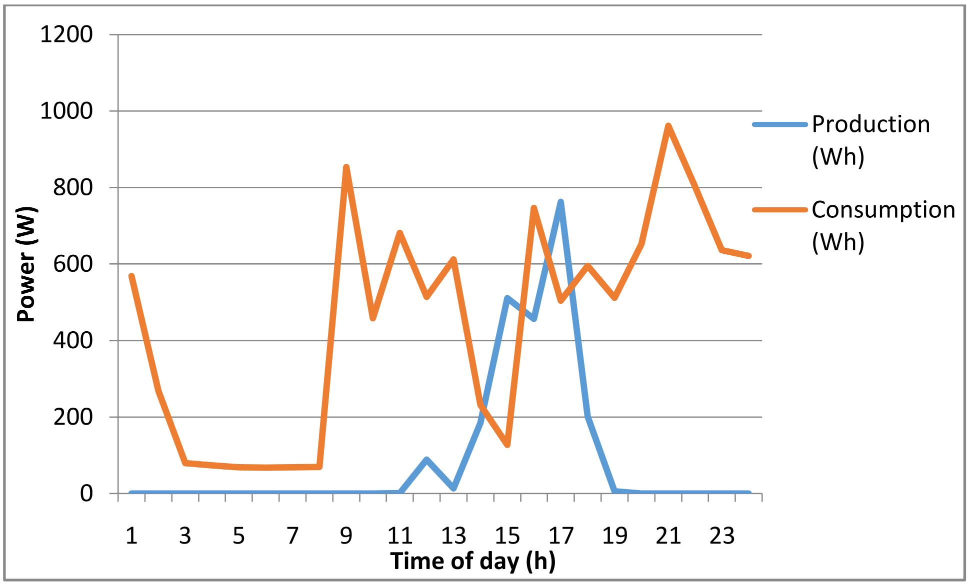

Diagram 10: Comparison of production and consumption on one winter weekend day

For the typical summer, in this example weekend, day (20th of July 2013) the situation is completely different. As it can be seen (Diagram 11., 12.) production of electricity is way higher than consumption because the whole system is overcontured so that the demand could be satisfied in winter months.

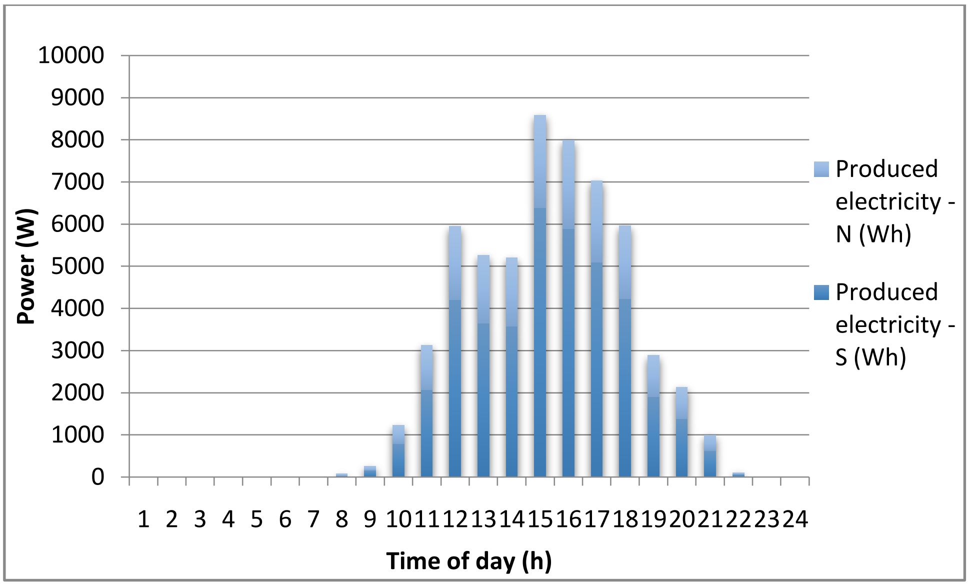

Diagram 11: Produced electricity on one summer weekend day

As it can be seen in the previous and following diagram (Diagram 11., 12.), there is a significantly higher production of electricity than consumption. In concrete numbers, total consumption of 20th of July 2013 is 12,557 kWh while the production is 56,786 kWh, more than four times higher.

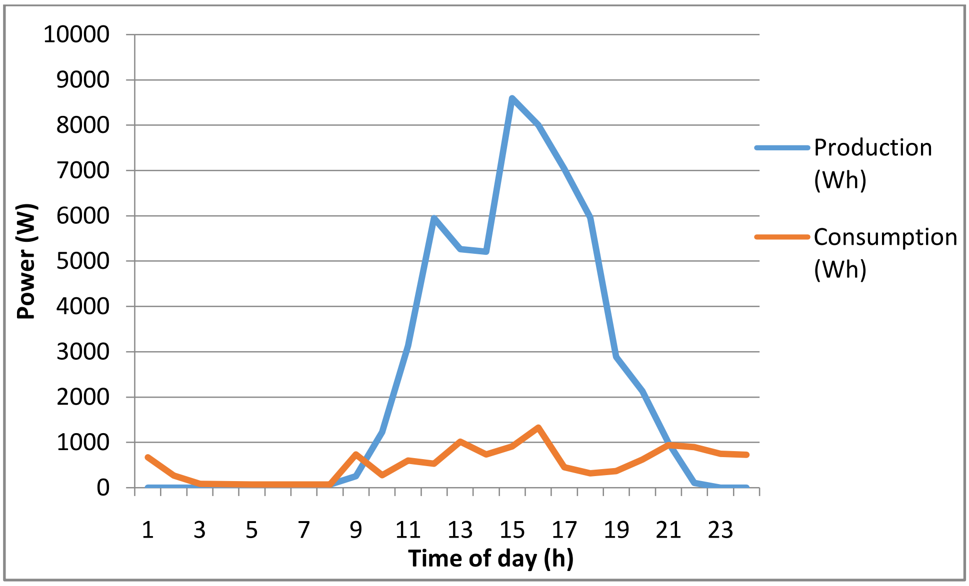

Diagram 12: Comparison of production and consumption on one summer weekend day

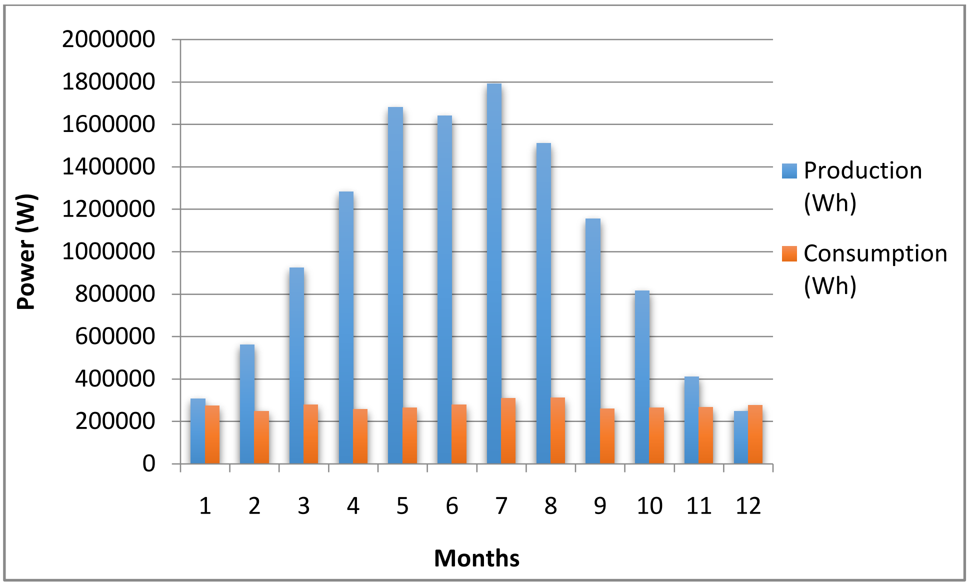

Diagram 13: Comparison of monthly electricity production and consumption

4.2.1. Selection of needed components

4.2.1.1. Battery

In the previous diagram (Diagram 13.) it is clearly visible how the consumption in global is way lower than the production of electricity. As it has been said previously, it is so because of overdimensionig of the whole system. That had to be done to secure electricity supply in winter months. It can be nicely seen in diagram 13. that in that way there is enough electricity to cover supply in every month in a year, except in December. In December the total consumption of electricity is 275,133 kWh, while the production is 247,062 kWh. That makes the electricity deficiency of 28,072 kWh in that month. To cover that lack of electricity a quite large battery has to be used. If we take that into consideration and the fact that the lead-acid battery should never be discharged below 20% of full capacity, and on a regular daily basis should not be allowed to go below 50% of full capacity, we can now try to decide what kind of battery is needed in this case. [19]

Since there is a deficit of 28,072 kWh in December, and we do not want our lead-acid battery to be discharged below 50%, it is necessary to ensure that battery is able to store 28,072 x 2 = 56,144 kWh of electricity. Also, it should be taken into consideration that the voltage that we need for our battery to be is 48V. That means that the required battery should provide with (56144 / 48 = 1170 Ah) at least 1170 ampere hours.

In case it would be decided to use nickel-iron battery things would be different. While lead-acid batteries have 7 year life cycle, nickel-iron battery systems are vastly out-lasting them. They have expected life of 25 years or even more and are quickly becoming the environmentally sensitive choice for off-grid and renewable energy storage applications. With nickel-Iron batteries up to 80% of the total capacity can be discharged without any damages to the cell or its future capacity. That means that we won't need battery with that many ampere hours as it was previously mentioned. Since it is possible to discharge up to 80% of battery without any bad consequences it means that we need from our battery to be able to store at least 28,072 x 1,25 = 35,09 kWh of electricity. With voltage of 48V it means that we need battery of at least 35090 / 48 = 731 Ah. To be sure that electricity supply will be ensured at all times, considering the fact that there might be some winters with even lower insolation, it is necessary to choose slightly bigger battery. So, in this case, the one that would be chosen has 800 ampere hours and its price is, thanks to the large amount of ampere hours and new very efficient technology, very big, 29 440,00 $ = 21 470,70 €. [20]

However, due to a still very high price of nickel-iron batteries, the chosen will be lead-acid one. The type of lead-acid battery used in this case has 1330 Amper hours and voltage of 4V with price of 1.300,00 $ = 948,10 € per unit. That means that 12 battery units will be needed to ensure 48V that are needed in this case which gives the total price for batteries of 11.377,14 €. [21], [22]

4.2.1.2. Solar charge controller

First component that is needed to be able to connect solar panels with the battery is charge controller. In this case a nickel-iron battery which can be overcharged (up to 1,8 V per cell) without any damage is used, but it still needs some control. So, the charge controllers task is to prevent overcharging and protection against overvoltage that could reduce battery performance and life duration. [23] Chosen to be used here is PanPower Charge Controller. Its maximum input wattage per charge controller is 10kW, so in this case (system of 11,73 kW installed power) two of those units will be needed. Price of one controller is 492,00 $ = 358,82 € and that gives the total price for necessary controllers of 717,64 €. Detailed description of this component is in one of the following chapters. [24]

4.2.1.3. Solar DC/DC converter

The other component which significance is huge in this case and the price quite big, so it should definitely be highlighted, is DC/DC converter. Conversion method in this case is more power efficient than linear voltage regulation, which dissipates unwanted power as heat. Its purpose in this case is to lower voltage from existing 48V to 24V that is also needed in an observed household. The one that is chosen to be used here is model YK-DD48S2430, product of Yucoo Network Equipment Co. It's an electronic DC/DC converter that converts 48V DC to 24V DC. Because its maximum output power is 1kW, twelve units will have to be used. Price of one unit is 154,50 € and total price for all needed inverters of this kind is 1 854,04 €. More about chosen converters will be written in the next chapters. [25]

4.3. Grid connection alternative

The other alternative that is envisioned in this thesis is grid connection alternative. The idea of this option is, in the observed household, to use DC electricity which is produced in solar panels placed on rooftop of this same house. All the produced electricity which won't be used in the household will be sold to the utility grid and all the electricity deficit will be satisfied by buying from the grid. To be able to do this, except from solar panels, some other components will be needed. For example, AC/DC inverter will be required for the purpose of converting produced direct current to alternating current which will be sold to the utility grid. Also, AC/DC rectifier will be needed to enable converting bought alternating current to direct current that is used in the observed household. Besides them, to measure bought and sold electricity, it will be necessary to have bi-directional power meter. Also, the same DC/DC converter like in the previous alternative will be needed to convert voltages from 48V to 24V, as well as charge controller, to keep the voltage in balance.

All the calculations related to solar panels production were made, like in the previous case, in software INSEL. Those data were then transferred to excel and further work with them was afterwards done there. All the obtained results from excel file will be analyzed later in this chapter.

Solar panels which were used in this alternative are the same like in the previous. The only difference is the number of used units and where they were placed. Because in this case a significantly fewer panels were needed, all of them were placed on roof surface of 65 m^2 with gradient of 30° in south direction. To be specific, 30 solar panels were placed on rooftop with 15 panels in series and 2 panels in parallel. Since there are 30 panels installed in this system, and nominal power of one of them is 255 W, it gives the total installed power of the entire system of 7,65 kW. Production of electricity during one year period from those solar panels, as well as all the other obtained information, is visible in following diagrams.

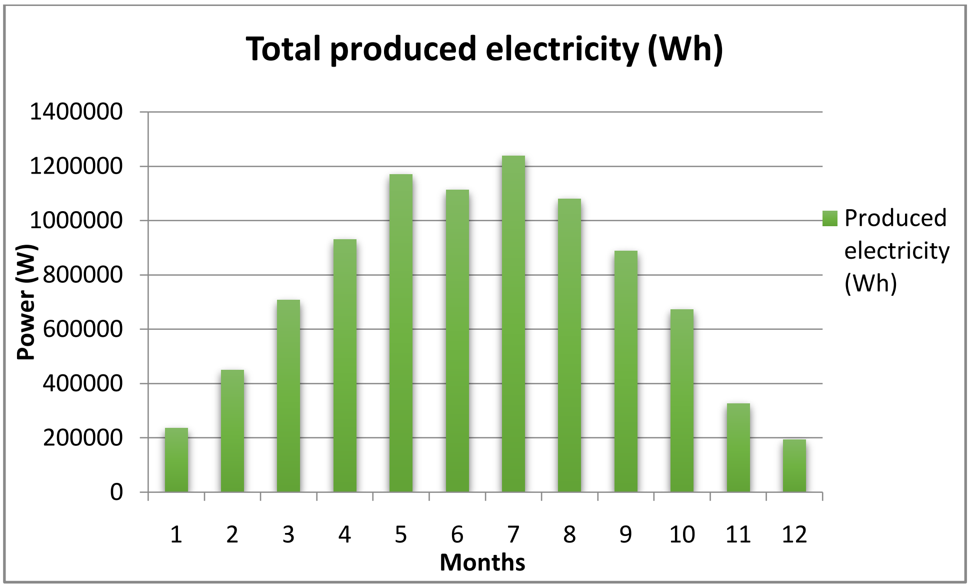

Diagram 14: Total produced electricity from all solar panels

In diagram 14. we can see total produced electricity from all 30 installed solar panels during the year 2013 which is cumulatively 9,009 Mwh while the one year consumption is 3,283 MWh. It seems like too many solar panels have been installed there, but that is not the case because of the difference in insolation during summer and winter months, as it was described in the previous chapter. That is also nicely presented in the following four diagrams.

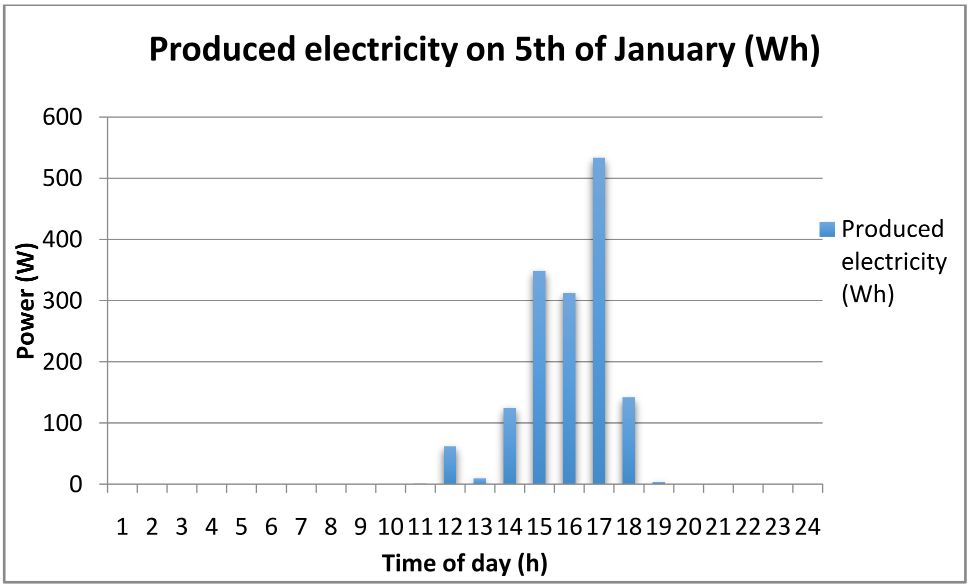

Diagram 15: Produced electricity on one winter weekend day

Diagram 15. shows the production of electricity on 5th of January, one typical winter weekend day, while on diagram 14. it has been compared with the consumption on that same day. As it can be seen, the production during winter is significantly lower than consumption because of low insolation. For that reason it will be necessary to buy quite a lot electricity from the grid while there will be very little surplus to be sold to the grid.

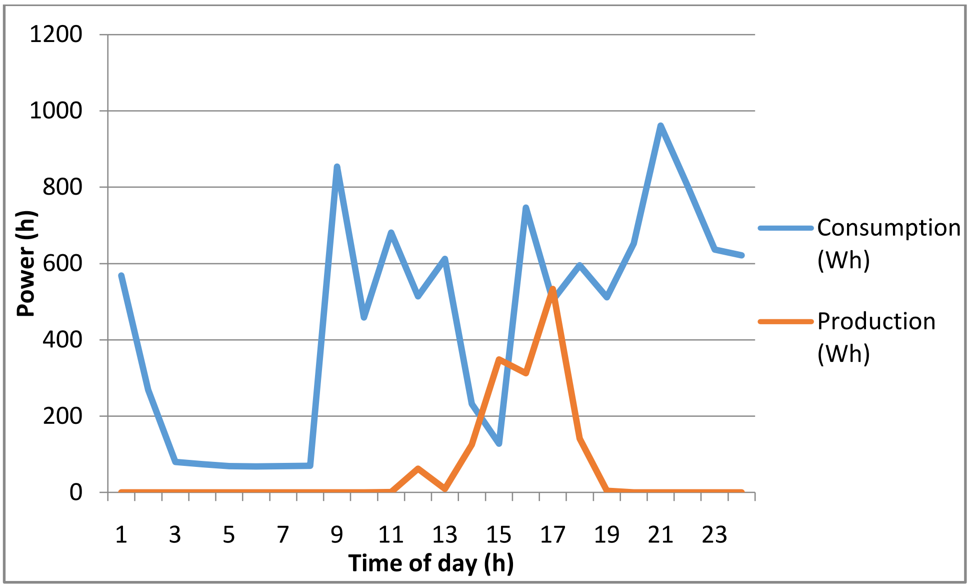

Diagram 16: Comparison of production and consumption on one winter weekend day

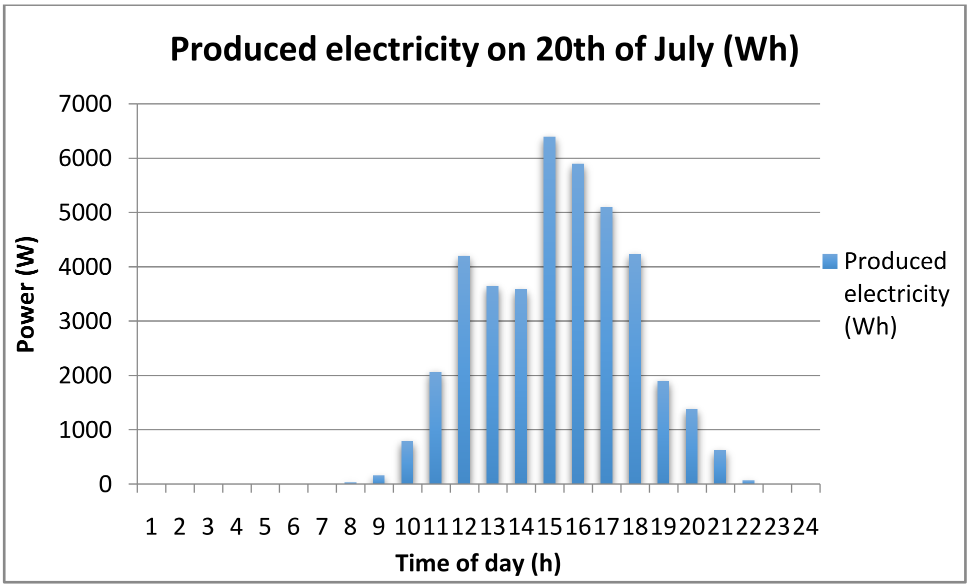

Diagram 17: Produced electricity on one summer weekend day

Like the previous two, in diagrams 17. and 18. also show production and comparison between production and consumption of electricity, but in this case on 20th of July, a typical summer weekend day. On these diagrams a great difference from the previously shown ones can be seen. Due to much higher insolation during summer months electricity production is also bigger. In this example there is a lot of surplus electricity that will be sold, while there is not a big deficit which will be covered with buying electricity from the grid, completely opposite from the previous case, winter day. To be specific, electricity consumption on the observed summer day is 12,56 kW while production is much higher, 40,07 kWh.

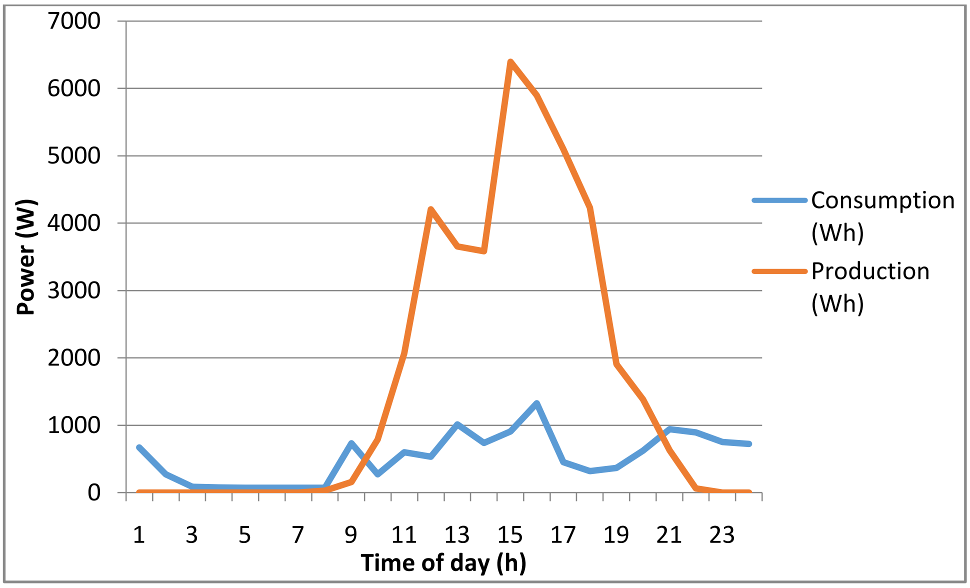

Diagram 18: Comparison of production and consumption on one summer weekend day

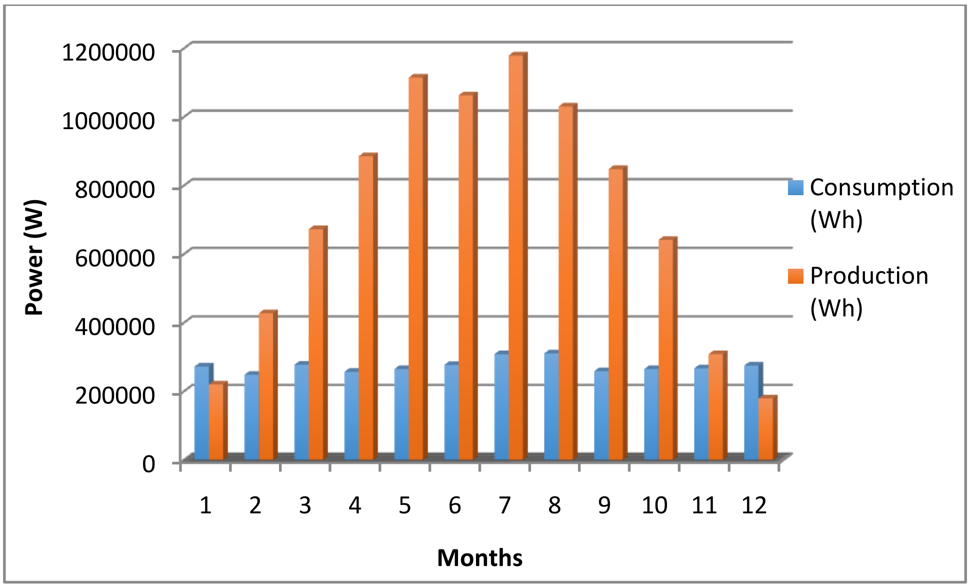

Diagram 19: Comparison of monthly electricity production and consumption

In diagram 19. production of electricity compared with consumption during one year period on monthly bases can nicely be seen. As it is obvious from the observed diagram, in summer months there is electricity surplus which is calculated to be 7297,73 kWh, but with taking into consideration losses in AC/DC inverter the number that occurs is 6932,46 kWh and it will be sold for 0,25 €/kWh. That gives us total yearly profit from sold electricity of 1733,12 €.

Unlike summer months, in winter ones there is a significant electricity deficit which will have to be settled by buying electricity from the grid. That calculation is slightly more complicated from the last one because there are two tariffs on which electricity is bought from the grid, which is explained in more details in the next chapter. Because there is one price for electricity during night period and other during the day, these two consumptions had to be summed separately. In total sum, electricity deficit in one year period is 2093,56 kWh but losses of DC/DC inverter and AC/DC rectifier have to be taken into consideration. With this information we are getting the total amount of electricity that has to be bought from the grid. It is 2540,54 kWh of which 1497,93 kWh has to be bought on low tariff and 1042,62 kWh on high. Knowing that the price of lower tariff is 0,07 €/kWh and of higher 0,14 €/kWh, we are getting information that in one year 104,85 € on lower tariff and 145,97 € on higher had to be paid, which gives us the total sum of 250,82 € that had to be paid for the lack of electricity in that observed year plus 2,86 €/month. In total this is 285,14 €.

4.3.1. Prices in the Croatian system

There are some prices in the Croatian system that should be taken into consideration. One of them is the price of connecting this small solar system to the grid, then, how much current has been sold to the grid and how much bought from it, and on which tariff.

At the moment, price of connecting photovoltaic system to the electric power system which has to be paid to HEP (Hrvatska elektroprivreda) is 11 000,00 kn = 1445,47 €. [26] Also, household has to be connected to the grid, and the price of the connection is 1350,00 kn/kWh = 177,40 €/kWh of installed power. In this observed household with total loads of 5,615 kW, installed power will be 6kW, so this means that the price that will have to be paid is 1064,4 €. [27], [22]

Next to be considered are the prices of electricity. In Croatia, distribution system operator company HEP Operator distribucijskog sustava (HEP ODS) has an obligation to provide with electricity and there are few tariff models. In this case “white model” for customers with installed power of less than 30kW will be used. In the white model there are two prices of electricity, cheaper during the night and more expensive during the day. During the winter time lower price is from 21 – 07h, and higher from 07 – 21h, while in summer time lower price is from 22 – 08h and higher from 08 – 22h. Lower price with VAT (Value added tax) is 0,53 kn/kWh = 0,07 €/kWh, and the higher one is 1,06 kn/kWh = 0,14 €/kWh. What needs to be taken into consideration is also the price of metering service and supply fee which is fixed and paid 21,75 kn/month = 2,86 €/month. [28], [22]

The last thing that has to be observed is the tariff on which excess electricity will be sold to the utility grid. Since in this case there is installed 7,65 kW of power in solar panels, this system can be categorized in group of integrated solar power plants with installed capacity up to 10 kW from which one kWh is paid 1,91 kn/kWh = 0,25 €/kWh. [29], [22]

4.3.2. Selection of needed components

4.3.2.1. AC/DC inverter

The most important component of this alternative is AC/DC inverter. Its task is to convert direct current that solar panels produce to alternating current which will be sold to the grid. The chosen inverter is Schneider XW6048-120/240-60 because it has continuous power 5,752 W. Input voltage range is from 44 to 64V, and output 240V. Price of this unit is 2475,00 $ = 1805,03 €. [30]

4.3.2.2. Selection of AC/DC rectifier

In situations when there is not enough electricity to meet the demand, the rest will have to be bought from the grid. Because there is alternating current on the grid, a rectifier which will convert AC to DC will be needed. Emerson rectifier, model R48-3200 is chosen in this case. Its operating input voltage range is from 176V to 275V AC and output from 42V to 58V DC, while having maximum output power of 3,2kW. The price of this component is 650 $ = 474,05 €. In the fallowing chapter will be described more like other used components. [31]

4.3.2.3. Selection of solar DC/DC charge controller

A charge controller will be needed to keep the voltage under control so that produced electricity can be directly used in the household. Like in the previous alternative PanPower Charge Controller with 10kW input power is here also chosen to be used, which is more than enough for 7,65kW solar system. Price of this controller is 492,00 $ = 358,82 €. [32]

4.3.2.4. Selection of solar DC/DC converter

Out of other necessary components for this observed system it is important to highlight solar DC/DC converter which task is to transform from voltage 48V to 24V. The same one as it’s described in chapters 4.2.1.3. and 4.4.5. will be used. That means that the price of one of those components is 211,85 $ = 154,50 €. Here it will be necessary to provide more of these units, to make sure to be able to provide electricity at all times. To be specific, two of them will be needed since the peak load of this system is, at the most, around 1,3kW and one of them has maximum installed output power of 1kW. That gives the total price of 309,01€.

4.3.2.5. Selection of power meter

In this observed household a meter will be needed which will measure how much electricity will be sold to the grid and how much is going to be bought from grid on which tariff. In this case bi-directional meter, product of Veris Company, model E51C2 is chosen to be used. This meter is designed perfectly for renewable systems because it has the ability to measure power imported from the grid as well as power exported from, in this case, solar panels. The price of this selected meter is 770,00 $ = 561,56 €. Like all the other most important components, it will be described in more details in one of the next chapters. [33]

4.4. Components used

In this chapter all the components that are used in previously mentioned two alternatives will be described. The same solar panels are used in both cases, but the difference is, as it has previously been stated, in the battery that stand alone alternative has and the inverter which is needed in grid connection alternative.

4.4.1. Solar panels

Solar panels that are being used in the observed household are the product of company ET Solar and have polycrystalline silicone solar cells. These kinds of panels are chosen, despite their slightly lower efficiency (typically 13-16%) compared to monocrystalline ones, because their price is significantly lower than in other alternatives. Also, their quite big deficiency is lower space efficiency. It is necessary to cover a larger surface to output the same electrical power as it would be needed in case solar panels made of monocrystalline silicone were used. But, it is important to mention that this does not mean that every monocrystalline solar panel performs better than polycrystalline one. Hopefully, in this case there is a plenty of available rooftop surface so this does not represent any kind of problem. Advantage of this technology that should be mentioned is the fact that the process which is used to make polycrystalline silicon is simpler and costs less, as well as the amount of waste silicon is smaller compared to the monocrystalline alternative.

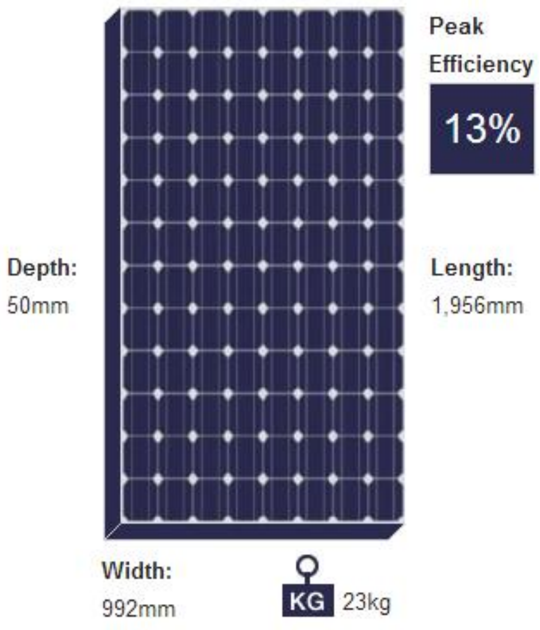

Figure 6: Solar panel ET-P672255 characteristics [34]

Specifically, chosen solar panels are model ET-P672255 which has nominal power of 255W and nominal efficiency 13,14%. Their nominal operating cell temperature is 45,3ºC, while their width is 0,992m and height 1,956m which makes their area 1.94m^2. Weight of each solar panel is 23kg. Also, very important information about panels is their maximum power point voltage, which is 35,2V, and maximum power point current of 7,23A. Existing data are also open-circuit voltage of 43,88V and short-circuit current of 7,85A. Price of one solar panel of this kind is 245$ = 178,68 €. [35]

4.4.2. Battery

As it has been described previously (chapter 4.2.1.1.), the selection process led to picking the lead-acid battery, with 4V voltage of each of 12 units that will be used and 1330 Amper hours, product of Exide Energystore company designed especially for stand alone systems. Dimensions of the battery are: depth 37 cm, width 26 cm and height 66,4 cm and weight of a filled battery is 100 kg. In the end, information that is the most important in this thesis is its price, which is 1.300,00 $ = 948,10 € per unit which gives the total price of 11.377,14 €.

Figure 7: GNB Energystore lead-acid 4V, 1330Ah battery

Main features of this kind of battery are its ability to be transported and assembled easily, its long life quite low maintenance as well as excellent prices. It is ideal for usage in wind, solar, micro-hydro, diesel and also in hybrid systems. [21]

4.4.3. AC/DC inverter

The key component for grid connected alternative is, like it was described in one of the previous chapters, AC/CD inverter. The significance is in its task to enable selling electricity surplus to grid. Without it this wouldn't be possible because solar panels produce direct current while there is alternating current in the grid. As it was mentioned, the chosen inverter is the product of Schneider Company, model XW6048-120/240-60.

Input power that is recommended for this inverter is 5,752 kW while the output one is 4,5 kW and nominal output AC voltage is 240V. Its efficiency is 95% and consumption during operation is <8W. Dimension of the observed inverter are 58 x 41 x 23 cm while its weight is 55,2 kg. Operating temperatures are from -20ºC to 70ºC. [30]

Figure 8: Schneider XW6048-120/240-60 inverter

4.4.4. Solar charge controller

As it was said in chapter 4.2.1.2. in the first system two charge controllers will be used because the system is quite big, installed power is 11.73 kW, and in second one only one (7,65 kW system). Solar charge controllers can be paralleled for large systems. With paralleled charge controllers the large solar photovoltaic array has to be divided into sub-arrays with each sub-array connecting to its own solar charge controller. Outputs of those controllers are then connected to a common battery. [36]

Figure 9: PanPower Charge Controller

PanPower SWC48-200A model which is used here has maximum input power 10kW and nominal input voltage that can be in range from 48 to 68V DC. Its dimensions are 41 x 20 x 16 cm and weight 17kg. Also, it has temperature sensor for charging a battery in compensation and has overloading and overcharge protection. One more of its characteristics is short circuit protection, thunder protection, reversed discharge protection, low voltage protection and conversed polarity connection protection. [32]

4.4.5. Solar DC/DC converter

As stated in chapter 4.2.1.3., solar DC/DC converter that will be used here in the observed household is model YK-DD48S2430, product of Yucoo Network Equipment Co. Its input voltage is 48V, while output is 24V, and maximum output power 1kW. The temperature on which it works without any damages is from -5 to 45ºC.

Dimensions of this converter are 483 x 88 x 285 mm, weight 7,5kg and efficiency around 85%. As it was previously said, the price of one unit is 154,50 €.

This DC/DC converter is designed to satisfy all kinds of requirements of communication equipments and electric power departments. It adopts the high frequency switching technology and has many qualities like high accuracy voltage stabilizing, low output noise, strong capacity of resisting disturbance, small volume, light weight, beautiful external shape, etc. [25]

Figure 10: Yucoo Network Equipment Co. YK-DD48S2430 DC/DC converter

4.4.6. Solar AC/DC rectifier

Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Solar AC/DC rectifier that is chosen to be used in this alternative is, as written in chapter 4.3.2.2., product of Emerson company, model R48-3200. Also, as it was previously mentioned, its operating input voltage range is from 176V to 275V AC and output from 42V to 58V DC. It also has input frequency from 45 to 65 Hz, maximum output power of 3,2kW and peak efficiency 92%. Price of this component is 474,05 €. [31], [37]

Figure 11: Emerson rectifier R48-3200

4.4.7. Power meter

The meter monitors power imported from the grid, as well as power exported from the solar panels. In this way, it is possible to keep track of all energy data, ensuring accuracy in billing and crediting. The chosen meter is from Veris Company, model E51C2 and it has high range of input voltages, from 90 to 600V AC and input current in range 50-32000 A. Operating temperature of this element is from -30°C to 70°C and one more important characteristic that it has is high reliability with 0.5% accuracy. [33]

Figure 12: Veris bi-directional meter, model E51C2

5. Economical aspect

After making sure that all components needed in both alternatives that are envisioned in this thesis, are numbered, it is necessary to make economical analysis to see which one of them Is more cost-effective and under what conditions.

5.1. Economical criteria

Criteria on which it will be concluded if alternatives are profitable, and which will be calculated in next paragraphs, are IRR (Internal rate of return), NPV (Net present value) and profitability index.

5.1.1. Internal rate of return

The internal rate of return is commonly used for the purpose of measuring and comparing profitability of possible investments. To be specific, the IRR of some investment is actually its discount rate at which are equaled net present values of the benefits and net present values of costs of the investment. The higher the projects internal rate of return is, the higher its desirability is. If we assume that all projects that are compared require the same investment in the start, the first one of them that would be taken to consideration would be the one with the higher IRR. Also, if we compared IRR with discount rate mentioned in the following chapter, internal rate of return bigger than discount rate would mean that potential project is profitable. [38]

5.1.2. Net present value

Next to consider is net present value. It can be defined as the sum of all the cash flows of the same entity's present values. The other way that NPV can be described is the amount of difference between the cumulative sums of cash outflows and inflows that are discounted. Also, the NPV's task is to compare the today's money present values with the future's money present value, while taking into account inflation and returns. It is calculated with the formula

$$NPV(i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

where t is the time of the cash flow, i the discount rate, R_t the net cash flow and N the total number of periods. In decision making, NPV>0 means that the project is most probably going to be profitable, and the higher NPV is, there is a greater chance for that, so the project may be accepted. On the other hand, if NPV<0, it suggests that the project definitely is not profitable and should be rejected, while NPV=0 means that observed project would bring no profit or losses to the firm. In that case, decision about accepting or rejecting project should be made according to some other criteria.

Previously mentioned discount rate should also be described because it is a key variable of NPV calculating process. With discount rate future cash flows are being discounted to the present value. In this thesis discount rate of 7% is used according to Croatian national bank. [39], [40]

Also important factor to mention, used in economical analysis in this thesis, is inflation rate. Here inflation rate of 3% was used, the value that was accurate in Croatia in 2013, the time when two alternatives started to be observed. [41]

5.1.3. Profitability index

The last criteria for evaluating if the proposed project is profitable or not is profitability index. The reason why it is such a useful tool for prioritizing projects is its ability to allow quantifying the amount of value produced per unit of investment. It is calculated by the formula:

$$Profitability\ index = 1 + \frac{PV\ of\ future\ \ cash\ flows}{Initial\ \ investment}.$$

Rules which define if project will be selected or rejected are next. If profitability index is >1, then project should be accepted and if it is <1, in that case should be rejected. [42]

5.2. Financing

As far as the financing is concerned, in this thesis economical analysis for both alternatives envisioned with several ways of financing will be made. Calculations will be made for the case when all the needed money is previously owned and for the cases with different percentage of investment financed by the loan that is taken from Croatian bank for reconstruction and development.

Whenever loans will be taken from Croatian bank for reconstruction and development, duration of repayment will be 14 years, the same period as in which the feed-in tariffs exist for electricity sold to grid, with interest rate of 4%. [43]

5.2.1. Income tax

Income tax, also known as profit tax, is government imposed tax on financial income. It is being generated by all entities under their jurisdiction. All the individuals and businesses, by the law, are obligated to file an income tax return yearly to be able to determine if they are qualified for a tax return or owe any taxes. Government uses it to serve the public and to fund its activities. In Croatian system profit tax is 20% and this data was used in the following calculations. [44], [45]

5.3. Costs

5.3.1. Stand alone alternative

As mentioned in the previous chapters, in table 12 all major components necessary for stand alone alternative, number of units needed and their prices are numbered.

Table 3: Cost for stand alone alternative

Component	Number of needed units	Price per unit (€)	Total price (€)
Solar panels	46	178,68	8.219,28
Battery	12	948,10	11.377,14
DC/DC converter	2	154,50	309,00
Charge controller	2	358,82	717,64
Construction and installation of solar panels	1	-	1.000,00
Price of DC installation in a household	1	-	1.776,00
Maintenance cost (per month)	-	-	70,00
TOTAL INITIAL COST			**2.339,06**

5.3.2. Grid connection alternative

The same like in chapter 5.3.1., in the following table components needed for grid connection alternative, the same as their prices and number of necessary units are numbered.

Table 4: Costs for grid connection alternative

Component	Number of needed units	Price per unit (€)	Total price (€)
Solar panels	30	178,68	5.360,40
AC/DC inverter	1	1.805,03	1.805,03
DC/DC converter	2	154,50	309,00
AC/DC rectifier	1	474,05	474,05
Charge controller	1	358,82	358,82
Power meter	1	561,56	561,56
Construction and installation of solar panels	1	-	1.000,00
Connecting solar system to grid	-	-	1.445,47
Price of DC installation in a household	1	-	1.776,00
Connecting house to the grid	-	-	1064,40
Maintenance cost (per month)	-	-	70,00
TOTAL INITIAL COST			**14.154,73**

Also, in this case there are costs from buying electricity from the grid when the system cannot produce enough for its own needs. Prices and tariffs on which electricity is bought are mentioned earlier. Specific numbers will be shown later in cash flow.

5.4. Revenues

Revenues in the stand alone alternative come from savings for using DC appliances and consuming self produced electricity, while in the other case, grid connection one, there are also revenues that are coming from selling electricity to the grid.

Savings because DC loads are used in the observed household are estimated on around 170,00 €/year. Calculation were made in the attached excel document and are based on previously made yearly load curves and study on DC appliances used in households. This applies to both alternatives and the amount of money saved is the same in both cases because the same household is being observed. [14]

In both cases self produced electricity is used to cover household's needs, but the amounts are different. In the stand alone alternative all the electricity that is used comes from solar panels installed on the rooftop, while in the grid connection alternative that amount is smaller because part of needs for electricity is being satisfied by buying it from the grid. Because of that, there is greater revenue on a yearly level, from saving on using its own electricity, in the stand alone alternative, than in the grid connection alternative. Calculations were made by using Croatian white model of electricity pricing that has two tariffs mentioned in previous chapters. Later, in cash flow, it will be shown more precisely.

Revenue that only the grid connection alternative has, is the one from selling electricity surplus to the grid. There are different cases that were observed in this thesis, with and without feed-in tariffs for selling electricity to the grid.

Table 5: Revenues from both alternatives that were envisioned

	Energy (kWh/year)	Price (€/kWh)	Total (€/year)
Sold energy from solar panels (Grid connection alternative)			
Incentive period	6.932,46	0,253	1.753,77
Non-incentive period	6.932,46	0,070	485,27
Savings from using self produced energy (Grid connection alternative)			
High price period			
Incentive period	1.275,12	(0,253 – 0,14)	144,09
Non-incentive period	1.275,12	(0,070 – 0,14)	-89,26
Low price period			
Incentive period	-	(0,253 – 0,07)	-
Non-incentive period	-	(0,070 – 0,07)	-
Savings from using self produced energy (Stand alone alternative)			
High price period	2.126,30	0,14	297,68
Non-incentive period	1.156,55	0,07	80,96
Total	3.282,85	-	378,64
Savings from using DC loads	1.474,90	$\frac{378,64}{3282,85}$	170,11

5.5. Observed cases

Parameters that will be changed, for the purpose of making conclusions about profitability of envisioned alternatives, are funding sources and prices of major components, solar panels and battery. There are three cases that will be analyzed with different funding sources. The one when it is assumed that all necessary funds are previously owned, when 50% of necessary funds are owned and 50% are settled by loan from Croatian bank for reconstruction and development, and when 70% of funds is owned and 30% is settled with loan from the same bank as in previously mentioned case.

The other parameters that will be changed are prices of solar panels and battery. In 2020 it is expected for lead-acid battery prices to drop, in the most optimistic version, to one third of its today price. As far as the solar panels are concerned, in the following diagram it is clearly visible that in 2020 their estimated price is around 0.5 $/kWh, which is around one half of today's price. [46], [47]

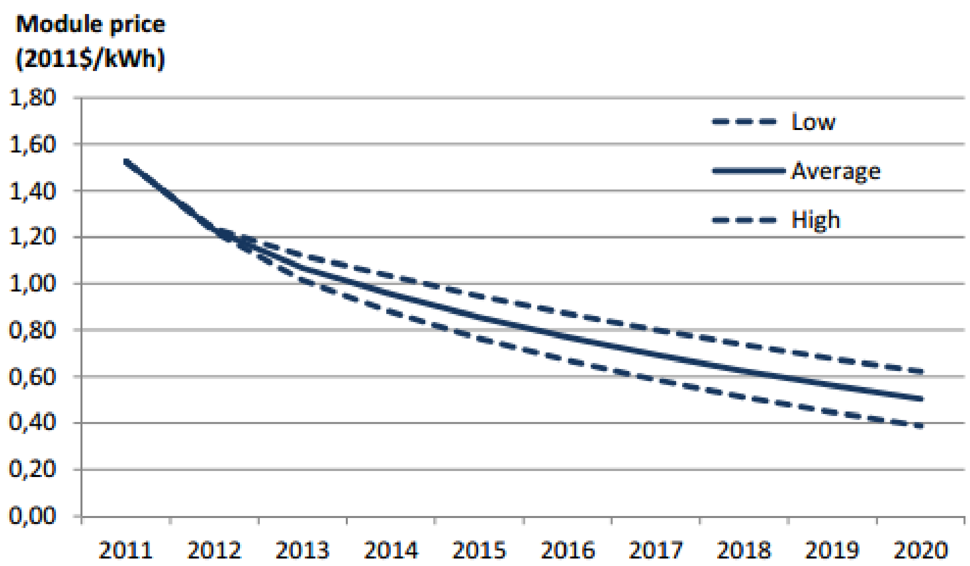

Diagram 20: Module price predictions until 2020

5.5.1. Case with included feed-in tariffs

While making economical analysis, in this case were taken to consideration feed-in tariffs that are currently applied in Croatian system, and were described previously more detailed. Those feed-in tariffs duration is 14 years and after that smaller prices for sold energy are applied.

Year	Initial cost	Loan	Savings for using DC loads	Consumed self produced energy	Maintenance cost	Amortization	Pretax profit	After tax profit	Net revenue	Cumulative net revenue
2012	- 11,704.93 €	- €	- €		- €	- €	- 11,704.93 €	- €	- 11,704.93 €	- 11,704.93 €
2013	0	- €	170.11 €	378.64 €	- 70.00 €	585.25 €	- 106.49 €	- 85.19 €	500.05 €	- 11,204.88 €
2014	0	- €	175.22 €	390.00 €	- 72.10 €	585.25 €	- 92.13 €	- 73.70 €	511.54 €	- 10,693.33 €
2015	0	- €	180.47 €	401.70 €	- 74.26 €	585.25 €	- 77.34 €	- 61.87 €	523.38 €	- 10,169.96 €
2016	0	- €	185.89 €	413.75 €	- 76.49 €	585.25 €	- 62.10 €	- 49.68 €	535.57 €	- 9,634.39 €
2017	0	- €	191.46 €	426.16 €	- 78.79 €	585.25 €	- 46.40 €	- 37.12 €	548.12 €	- 9,086.27 €
2018	0	- €	197.21 €	438.95 €	- 81.15 €	585.25 €	- 30.24 €	- 24.19 €	561.06 €	- 8,525.21 €
2019	0	- €	203.12 €	452.12 €	- 83.58 €	585.25 €	- 13.59 €	- 10.87 €	574.38 €	- 7,950.84 €
2020	0	- €	209.22 €	465.68 €	- 86.09 €	585.25 €	3.56 €	2.85 €	588.10 €	- 7,362.74 €
2021	0	- €	215.50 €	479.65 €	- 88.67 €	585.25 €	21.23 €	16.98 €	602.23 €	- 6,760.51 €
2022	0	- €	221.96 €	494.04 €	- 91.33 €	585.25 €	39.42 €	31.54 €	616.78 €	- 6,143.73 €
2023	0	- €	228.62 €	508.86 €	- 94.07 €	585.25 €	58.16 €	46.53 €	631.77 €	- 5,511.96 €
2024	0	- €	235.48 €	524.13 €	- 96.90 €	585.25 €	77.46 €	61.97 €	647.22 €	- 4,864.74 €
2025	0	- €	242.54 €	539.85 €	- 99.80 €	585.25 €	97.34 €	77.87 €	663.12 €	- 4,201.62 €
2026	0	- €	249.82 €	556.05 €	- 102.80 €	585.25 €	117.82 €	94.26 €	679.50 €	- 3,522.12 €
2027	0	- €	257.31 €	572.73 €	- 105.88 €		724.16 €	579.33 €	579.33 €	- 2,942.79 €
2028	0	- €	265.03 €	589.91 €	- 109.06 €		745.88 €	596.71 €	596.71 €	- 2,346.08 €
2029	0	- €	272.98 €	607.61 €	-		768.26 €	614.61 €	614.61 €	-

					112.33 €					1,731.48 €
2030	0	- €	281.17 €	625.84 €	- 115.70 €		791.31 €	633.05 €	633.05 €	- 1,098.43 €
2031	0	- €	289.61 €	644.61 €	- 119.17 €		815.05 €	652.04 €	652.04 €	- 446.39 €
2032	0	- €	298.30 €	663.95 €	- 122.75 €		839.50 €	671.60 €	671.60 €	225.21 €
2033	0	- €	307.24 €	683.87 €	- 126.43 €		864.68 €	691.75 €	691.75 €	916.95 €
2034	0	- €	316.46 €	704.38 €	- 130.22 €		890.62 €	712.50 €	712.50 €	1,629.45 €
2035	0	- €	325.96 €	725.51 €	- 134.13 €		917.34 €	733.87 €	733.87 €	2,363.33 €
2036	0	- €	335.73 €	747.28 €	- 138.15 €		944.86 €	755.89 €	755.89 €	3,119.22 €
2037	0	- €	345.81 €	769.70 €	- 142.30 €		973.21 €	778.57 €	778.57 €	3,897.79 €
								IRR	**2%**	
								NPV	**- 4,486.02 €**	
								Profitability index	**0.617**	

Table 6: Cash flow for stand alone alternative with 100% owned funds and predicted prices of components in 2020

Year	Capital costs	Annuity	Revenue from sold energy	Savings for using DC loads	Consumed self produced energy	Maintenance cost	Costs of bought energy	Amortization	Pretax profit	After-tax profit	Net revenues	Cumulative net revenues
2012	-14,155.01 €	7,077.51 €	- €			- €	-	- €	-14,155.01 €	- €	-14,155.01 €	-14,155.01 €
2013	0	-1,013.70 €	1,753.77 €	170.11 €	144.06 €	-70.00 €	-285.14 €	353.88 €	2,636.97 €	2,109.57 €	1,449.75 €	-12,705.26 €
2014	0	-1,013.70 €	1,806.39 €	175.22 €	148.39 €	-72.10 €	-293.69 €	353.88 €	2,705.46 €	2,164.37 €	1,504.54 €	-11,200.71 €
2015	0	-1,013.70 €	1,860.58 €	180.47 €	152.84 €	-74.26 €	-302.51 €	353.88 €	2,776.01 €	2,220.81 €	1,560.98 €	-9,639.73 €
2016	0	-1,013.70 €	1,916.40 €	185.89 €	157.42 €	-76.49 €	-311.58 €	353.88 €	2,848.67 €	2,278.94 €	1,619.11 €	-8,020.62 €
2017	0	-1,013.70 €	1,973.89 €	191.46 €	162.14 €	-78.79 €	-320.93 €	353.88 €	2,923.52 €	2,338.81 €	1,678.99 €	-6,341.63 €
2018	0	-1,013.70 €	2,033.11 €	197.21 €	167.01 €	-81.15 €	-330.56 €	353.88 €	3,000.60 €	2,400.48 €	1,740.66 €	-4,600.97 €
2019	0	-1,013.70 €	2,094.10 €	203.12 €	172.02 €	-83.58 €	-340.47 €	353.88 €	3,080.01 €	2,464.00 €	1,804.18 €	-2,796.79 €
2020	0	-1,013.70 €	2,156.92 €	209.22 €	177.18 €	-86.09 €	-350.69 €	353.88 €	3,161.79 €	2,529.43 €	1,869.61 €	-927.18 €
2021	0	-1,013.70 €	2,221.63 €	215.50 €	182.49 €	-88.67 €	-361.21 €	353.88 €	3,246.03 €	2,596.82 €	1,937.00 €	1,009.82 €
2022	0	-1,013.70 €	2,288.28 €	221.96 €	187.97 €	-91.33 €	-372.04 €	353.88 €	3,332.79 €	2,666.23 €	2,006.41 €	3,016.23 €
2023	0	-1,013.70 €	2,356.93 €	228.62 €	193.61 €	-94.07 €	-383.20 €	353.88 €	3,422.16 €	2,737.73 €	2,077.90 €	5,094.14 €
2024	0	-1,013.70 €	2,427.63 €	235.48 €	199.42 €	-96.90 €	-394.70 €	353.88 €	3,514.21 €	2,811.37 €	2,151.54 €	7,245.68 €
2025	0	-1,013.70 €	2,500.46 €	242.54 €	205.40 €	-99.80 €	-406.54 €	353.88 €	3,609.02 €	2,887.21 €	2,227.39 €	9,473.07 €
2026	0	-1,013.70 €	2,575.48 €	249.82 €	211.56 €	-1,907.80 €	-418.74 €	353.88 €	1,901.67 €	1,521.34 €	861.51 €	10,334.59 €
2027	0	- €	501.25 €	257.31 €	-91.68 €	-105.88 €	-431.30 €		992.30 €	793.84 €	793.84 €	11,128.43 €

2028	0	- €	516.29 €	265.03 €	- 94.43 €	- 109.06 €	- 444.24 €		1,022.07 €	817.66 €	817.66 €	11,946.09 €
2029	0	- €	531.78 €	272.98 €	- 97.26 €	- 112.33 €	- 457.57 €		1,052.74 €	842.19 €	842.19 €	12,788.28 €
2030	0	- €	547.73 €	281.17 €	- 100.18 €	- 115.70 €	- 471.29 €		1,084.32 €	867.45 €	867.45 €	13,655.73 €
2031	0	- €	564.16 €	289.61 €	- 103.18 €	- 119.17 €	- 485.43 €		1,116.85 €	893.48 €	893.48 €	14,549.21 €
2032	0	- €	581.08 €	298.30 €	- 106.28 €	- 122.75 €	- 499.99 €		1,150.35 €	920.28 €	920.28 €	15,469.49 €
2033	0	- €	598.52 €	307.24 €	- 109.47 €	- 126.43 €	- 514.99 €		1,184.86 €	947.89 €	947.89 €	16,417.38 €
2034	0	- €	616.47 €	316.46 €	- 112.75 €	- 130.22 €	- 530.44 €		1,220.41 €	976.33 €	976.33 €	17,393.71 €
2035	0	- €	634.97 €	325.96 €	- 116.13 €	- 134.13 €	- 546.36 €		1,257.02 €	1,005.62 €	1,005.62 €	18,399.33 €
2036	0	- €	654.02 €	335.73 €	- 119.62 €	- 138.15 €	- 562.75 €		1,294.73 €	1,035.79 €	1,035.79 €	19,435.12 €
2037	0	- €	673.64 €	345.81 €	- 123.20 €	- 142.30 €	- 579.63 €		1,333.57 €	1,066.86 €	1,066.86 €	20,501.98 €
									IRR	**10%**		
									NPV	**3,272.54 €**		
									Profitability index	**1.462**		

Table 7: Cash flow for grid connection alternative with 50% owned funds and today prices of component

In previous tables cash flows are shown for some of the cases of the observed alternatives with all revenues and costs that were observed in each one of alternatives, while in the next table economical criteria calculated for several options for each alternative are visible.

Table 8: Economical criteria for case with feed-in tariffs

Financing	**Component prices**	**NPV (€)**		**IRR**		**Profitability index**	
		Stand alone	Grid connection	Stand alone	Grid connection	Stand alone	Grid connection
100% owned	Today prices	-14.459,54	16.764,05	-2%	22%	0,382	2,184
	• ½ today PV modul price • ⅓ today battery price	-4.486,02	17.297,35	2%	26%	0,617	2,507
30% loan 70% owned	Today prices	-23.251,03	8.669,14	-	15%	-0,420	1,875
	• ½ today PV modul price • ⅓ today battery price	-8.883,74	10.735,19	-	19%	-0,084	2,336
50% loan 50% owned	Today prices	-29.112,03	3.272,54	-	10%	-1,488	1,462
	• ½ today PV modul price • ⅓ today battery price	-11.815,56	6.360,41	-	14%	-1,019	2,109

As it can clearly be seen in the previous table, in case when there are feed-in tariffs, grid connection alternative is much more profitable than stand alone alternative, no matter what parameters are being changed in economical analysis. Of course, there are differences between all numbered cases. For example, it's obvious that the bigger the loan is, project is less cost-effective. The same is with components price, the lower the price is, project is going to be more cost-effective.

Conclusion is clear, grid connection alternative is most probably going to be profitable project and changing parameters only means how long is payback period going to be. If prices are loan lower the payback period is going to be shorter. Compared to other envisioned alternative, this one is much more profitable. In fact, the other alternative is, according to economical analysis, going to turn out to be not profitable even if all necessary funds are already owned and prices are lower, like they are expected to be in 2020.

5.5.2. Case without feed-in tariffs

In this case feed-in tariffs will not be taken into consideration. That is because it is expected in Croatian system to stop existing, at least in this form, in the following years.

Table 9: Economical criteria for case without feed-in tariffs

Financing	Component prices	NPV (€)		IRR		Profitability index	
		Stand alone	Grid connection	Stand alone	Grid connection	Stand alone	Grid connection
100% owned	Today prices	-14.459,54	5.648,38	-2%	12%	0,382	1,399
	• ½ today PV modul price • ⅓ today battery price	-4.486,02	6.181,68	2%	14%	0,617	1,539
30% loan 70% owned	Today prices	-23.251,03	-2.446,53	-	5%	-0,420	0,753
	• ½ today PV modul price • ⅓ today battery price	-8.883,74	-380,48	-	7%	-0,084	0,953
50% loan 50% owned	Today prices	-29.112,03	-7.843,13	-	1%	-1,488	-0,108
	• ½ today PV modul price • ⅓ today battery price	-11.815,56	-4.755,26	-	3%	-1,019	0,171

As it can be seen from table 9, in the case with non existing feed-in tariffs, profitability of grid connection alternative is drastically reduced. It is so because feed-in tariff purchase price is almost four times bigger than the regular one. When energy is sold on that lower price the whole lifetime of the system, economical criteria are becoming significantly less favorable. Like it is visible in the previous table, according to calculated economical criteria, grid connection alternative without feed-in tariffs is going to be profitable only in case when all necessary funds are previously owned by project owner. Only in that case NPV is positive and IRR is bigger than discount rate.

Although, in this case that is very likely to happen in near future, economical criteria for grid connection alternative are much closer to other alternative ones. Profitability of two envisioned alternatives is much more similar than in case with existing feed-in tariffs.

In the next table cash flow for grid connection alternative with no feed-in tariffs is shown, 100% owned funds and current prices of needed components. It is clear that the difference is only in the first 14 years, during which now the revenue is significantly lower.

Year	Capital costs	Annuity	Revenue from sold energy	Savings of using DC loads	Consumed self produced energy	Maintenance cost	Costs of bought energy	Amortization	Pretax profit	After-tax profit	Net revenues	Cumulative net revenues
2012	- 11,474.81 €	- €	- €			- €	-	- €	- 11,474.81 €	- €	- 11,474.81 €	- 11,474.81 €
2013	0	- €	486.65 €	170.11 €	- 89.01 €	- 70.00 €	- 285.14 €	573.74 €	1,356.64 €	1,085.31 €	1,659.05 €	- 9,815.76 €
2014	0	- €	501.25 €	175.22 €	- 91.68 €	- 72.10 €	- 293.69 €	573.74 €	1,380.13 €	1,104.10 €	1,677.84 €	- 8,137.92 €
2015	0	- €	516.29 €	180.47 €	- 94.43 €	- 74.26 €	- 302.51 €	573.74 €	1,404.32 €	1,123.45 €	1,697.19 €	- 6,440.72 €
2016	0	- €	531.78 €	185.89 €	- 97.26 €	- 76.49 €	- 311.58 €	573.74 €	1,429.23 €	1,143.39 €	1,717.13 €	- 4,723.59 €
2017	0	- €	547.73 €	191.46 €	- 100.18 €	- 78.79 €	- 320.93 €	573.74 €	1,454.90 €	1,163.92 €	1,737.66 €	- 2,985.93 €
2018	0	- €	564.16 €	197.21 €	- 103.18 €	- 81.15 €	- 330.56 €	573.74 €	1,481.33 €	1,185.07 €	1,758.81 €	- 1,227.13 €
2019	0	- €	581.08 €	203.12 €	- 106.28 €	- 83.58 €	- 340.47 €	573.74 €	1,508.56 €	1,206.85 €	1,780.59 €	553.46 €
2020	0	- €	598.52 €	209.22 €	- 109.47 €	- 86.09 €	- 350.69 €	573.74 €	1,536.61 €	1,229.29 €	1,803.03 €	2,356.49 €
2021	0	- €	616.47 €	215.50 €	- 112.75 €	- 88.67 €	- 361.21 €	573.74 €	1,565.49 €	1,252.39 €	1,826.13 €	4,182.62 €
2022	0	- €	634.97 €	221.96 €	- 116.13 €	- 91.33 €	- 372.04 €	573.74 €	1,595.25 €	1,276.20 €	1,849.94 €	6,032.56 €
2023	0	- €	654.02 €	228.62 €	- 119.62 €	- 94.07 €	- 383.20 €	573.74 €	1,625.89 €	1,300.71 €	1,874.45 €	7,907.01 €
2024	0	- €	673.64 €	235.48 €	- 123.20 €	- 96.90 €	- 394.70 €	573.74 €	1,657.45 €	1,325.96 €	1,899.70 €	9,806.72 €
2025	0	- €	693.85 €	242.54 €	- 126.90 €	- 99.80 €	- 406.54 €	573.74 €	1,689.97 €	1,351.97 €	1,925.71 €	11,732.43 €
2026	0	- €	714.66 €	249.82 €	- 130.71 €	- 1,907.80 €	- 418.74 €	573.74 €	- 81.55 €	- 65.24 €	508.50 €	12,240.93 €
2027	0	- €	736.10 €	257.31 €	- 134.63 €	- 105.88 €	- 431.30 €		1,184.20 €	947.36 €	947.36 €	13,188.30 €
2028	0	- €	758.18 €	265.03 €	-	-	-		1,219.73 €	975.78 €	975.78 €	14,164.08 €

					138.67 €	109.06 €	444.24 €					
2029	0	- €	780.93 €	272.98 €	- 142.83 €	- 112.33 €	- 457.57 €		1,256.32 €	1,005.06 €	1,005.06 €	15,169.14 €
2030	0	- €	804.36 €	281.17 €	- 147.11 €	- 115.70 €	- 471.29 €		1,294.01 €	1,035.21 €	1,035.21 €	16,204.35 €
2031	0	- €	828.49 €	289.61 €	- 151.53 €	- 119.17 €	- 485.43 €		1,332.83 €	1,066.27 €	1,066.27 €	17,270.61 €
2032	0	- €	853.34 €	298.30 €	- 156.07 €	- 122.75 €	- 499.99 €		1,372.82 €	1,098.25 €	1,098.25 €	18,368.87 €
2033	0	- €	878.94 €	307.24 €	- 160.75 €	- 126.43 €	- 514.99 €		1,414.00 €	1,131.20 €	1,131.20 €	19,500.07 €
2034	0	- €	905.31 €	316.46 €	- 165.58 €	- 130.22 €	- 530.44 €		1,456.42 €	1,165.14 €	1,165.14 €	20,665.21 €
2035	0	- €	932.47 €	325.96 €	- 170.54 €	- 134.13 €	- 546.36 €		1,500.11 €	1,200.09 €	1,200.09 €	21,865.30 €
2036	0	- €	960.44 €	335.73 €	- 175.66 €	- 138.15 €	- 562.75 €		1,545.12 €	1,236.09 €	1,236.09 €	23,101.39 €
2037	0	- €	989.26 €	345.81 €	- 180.93 €	- 142.30 €	- 579.63 €		1,591.47 €	1,273.18 €	1,273.18 €	24,374.57 €
									IRR	**14%**		
									NPV	**6,181.68 €**		
									Profitability index	**1.539**		

Table 10: Cash flow for grid connection alternative without feed-in tariffs, with 100% owned funds and today prices of components

5.5.3. Case with energy exchange with grid

Third case that was observed in this thesis is the one with exchanging energy with grid, but without money exchange. The whole idea of this option is to give to the grid the same amount of energy that will be taken, in one year period. Energy is being given to the grid in periods when system has surplus of energy which it cannot spend, and taken from the grid when there is a energy deficiency. For this option to work, at the end of one year period, amount of energy taken from the grid and given to it has to be the same.

To be able to produce the exact amount of energy that is needed to cover demand, only 14 solar panels need to be installed on the rooftop. That significantly lowers initial costs of grid connection alternative of this kind. In the following table NPV, IRR and profitability index for this case and standard stand-alone option are compared.

Table 11: Economical criteria for case with exchange of energy

Financing	**Component prices**	**NPV (€)**		**IRR**		**Profitability index**	
		Stand alone	Grid connection	Stand alone	Grid connection	Stand alone	Grid connection
100% owned	Today prices	-14.459,54	2.725,41	-2%	10%	0,382	1,241
	• ½ today PV modul price • ⅓ today battery price	-4.486,02	2.974,29	2%	11%	0,617	1,296
30% loan 70% owned	Today prices	-23.251,03	-3.734,57	-	3%	-0,420	0,528
	• ½ today PV modul price • ⅓ today battery price	-8.883,74	-2.770,42	-	3%	-0,084	0,606
50% loan 50% owned	Today prices	-29.112,03	-8.041,22	-	-2%	-1,488	-0,424
	• ½ today PV modul price • ⅓ today battery price	-11.815,56	-6.600,22	-	-1%	-1,019	-0,314

This third observed case, like it is shown in the previous table, is way less profitable than previous two cases. It is so because there is no energy surplus which would be sold to the grid with or without feed-in tariffs. There is only energy, and not money, exchange. This way of satisfying systems needs for energy is not very profitable, regardless of two times less solar panels that had to be installed. Only profitable option, according to economical criteria that were given by economical analysis, is when 100% of needed funds are previously owned. However, this option is still more profitable than all observed stand-alone ones.

6. Conclusion

Nowadays, in times of increasing energy demand while conventional fossil fuels are constantly depleting and climate changes caused by CO_2 emissions are rapidly growing, renewable energy sources are becoming a very practical and popular solution. Considering a fact that renewable sources like solar photovoltaics, which are lately gaining on their popularity especially on household level, are inherently DC sources, DC micro-grids are turning out to be a very appropriate new idea. The fact that it is expected for DC loads to take for about 50% of all household loads in 2020, only favors it.

In this thesis two alternatives were envisioned. First one of them was a stand alone alternative which needed a local storage, a battery, to be able to ensure energy supply in the observed household from installed solar photovoltaics at all times. The other one was a grid connection alternative in which lack of energy problems was solved by buying energy from the grid. Equally, when there was an energy surplus, all energy that wasn't spent in the observed household was sold to the power system grid. While making cost and benefit analysis, several scenarios were observed. The first case was with current feed-in tariffs in Croatian power system, the second without any feed-in tariffs and the third without any money, only power exchange between household and power system grid. Also, all these three cases were observed with current prices of needed components and with prices that are predicted to be accurate in 2020. Economical criteria which were observed are NPV, IRR and profitability index.

With results that were obtained through economical analysis the fallowing conclusions were made. Today feed-in tariffs are still pretty high, and thanks to that fact grid connection alternative is quite profitable at the moment. Even if those feed-in tariffs decrease yearly or even stop existing at all, this alternative will still keep its cost-effectiveness. Compared to stand alone alternative, this one is in any situation that was observed way more profitable. Because of still high prices of needed components and necessity to over capacitate, stand alone alternative cannot in any way compete with grid connection one, but profitability of this alternative is going to get higher with years as the prices of components will fall. In the future, when smart grids are going to be spread widely and DC household appliances used more, it is expected for these kinds of DC stand-alone systems to become much more prevalent. Also, it is anticipated for DC households to be interconnected to DC micro-grid for the purpose of increasing their efficiency.

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