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ISTANBUL AYDIN UNIVERSITY

INSTITUTE OF NATURAL AND APPLIED SCIENCES

RENEWABLE ENERGY AS SOLUTION TO ENERGY DEFICIENCY IN BURUNDI: SOLAR ENERGY

THESIS

Samuel MACUMI

Department of Electrical and Electronics Engineering

Thesis Advisor: Prof. Dr. Mehmet Emın TACER

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M.Sc.THESIS

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İSTANBUL AYDIN ÜNİVERSİTESİ
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DECLARATION

I hereby declare that all information in this thesis document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results, which are not original to this thesis.

Samuel MACUMI

To my father and mother;

To my brothers and sisters;

To my roommates;

FOREWORD

I would like to express my gratitude to the people who, in a way or another, contributed to the completion of this work.
First of all, my special thanks go to Prof. Dr. M. EMINE TACER, lecturer at the ISTANBUL AYDIN UNIVERSITY for accepting to supervise this work in spite of his heavy schedule. His pieces of advice and suggestions have contributed a lot to the concretization of this study. His guidance and careful attention in reading and correcting this work helped in getting this study to its present form.
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December, 2018 Eng. Samuel MACUMI

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ABBREVIATIONS

AC	: Alternative Current
Ah	: Ampere-hour
API	: Burundi Agency for the Promotion of Investments
BRARUDI	: Brasserie et Limonaderies du Burundi
CEPGL	: Communauté Economique des Pays des Grand Lacs.
COMESA	: Common Market for Eastern and Southern Africa
DRC	: Democratic Republic of Congo
DC	: Direct Current
EAC	: East African Community
FAO	: Food and Agriculture Organization
GDP	: Gross Domestic Product
GWh	: Giga Watts Hour
IEA	: International Energy Agency
KWh	: Kilo Watts Hour
MDGs	: Millennium Development Goals
MPPT	: Maximum Peak Power Tracking
MW	: Mega Watts
ONATOUR	: Office National de la Tourbe
OTB	: Office du Thé du Burundi
PCC	: Point of Common Coupling
%	: Percentage
PNUB	: Programme des Nations Unies au Burundi
PV	: Photovoltaic
RC	: Residual Capacity
REGIDESO	: Régie de Production et de Distribution d’Eau et d’Eléctricité.
SINELAC	: Société Internationale d’Electricité Des Pays des Grands Lacs.
SNEL	: Société Nationale d’Electricité
SOSUMO	: Société Sucrière de Moso
UC	: Useful Capacity
UN	: United Nations
UNDP	: United Nations Development Program in Burundi
V	: Voltage
W	: Watt
WP	: Watt peak

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ÖZET

Bu çalışma, Burundi'nin elektrifikasyonuna ve Burundi'nin yeterli enerjiyle nasıl donatılıcağına odaklanmıştır.
Burundi, Doğu Afrika Topluluğu (EAC), Doğu ve Güney Afrika Ortak Pazarı (COMESA) ve Büyük Göl Ülkeleri Ekonomik Topluluğu (CEPGL) gibi çeşitli ekonomik toplulukların bir üyesidir. Birçok ekonomik topluluğa bu üye olmasına rağmen, Burundi hala dünyanın en fakir ülkeleri arasında yer almaktadır. Bu yoksulluk durumunun nedenleri arasında en hassas olanı neredeyse tüm ekonomik zinciri yavaşlatan enerji eksikliğidir.
Bu tezde, Burundi'nin sahip olduğu doğal (yenilenebilir) enerji kaynakları kullanılarak ülkenin gelişimini etkiyen elektrik enerjinsinin yeterli durumuna getirilmesi inclenmeye alınmıştır. Öyleki yapılan araştırmad, Buruni'nin coğrafi konumu nedeniyle yenilenebilir enerji kaynakları içinde en uygun enerji kaynağının güneş enerjisi olduğundan güneş enerjisi üzerine yoğunlaşılmıştır. Bu bağlamda, hala elektrik enerjisi kullanılmayan tüm bölgelere elektrik enerjisinin ulaştırlması sağlanması, dolayısıyla hem ekonomik hem de yaşam stanadardının yükselmesi öngörülmüştür.
Bu tezin ardından, Burundi Hükümeti, Burundi ekonomi işletmecileri, çeşitli ortaklar ve yatırımcıların kalkınma zorluklarını üstünden gelebilecekleri ve bunun sonucunda, dünya çapında bir alanda sürdürülebilir bir sosyoekonomik unsurun direği olarak kabul edilen bu enerji alanın iyileştirlmesi yolu açılacaktır.

Anahtar Kelimeler: *Güneş enerjisi, kara ülkesi, enerji, enerji santrali, yenilenebilir enerji, enerji arzı, enerji eksikliği,*

RENEWABLE ENERGY AS SOLUTION TO ENERGY DEFICIENCY IN BURUNDI: SOLAR ENERGY

ABSTRACT

This study focused on the electrification of Burundi and how to equip Burundi with enough energy.

Burundi is a member of various economic communities such as the East African Community (EAC), the Common Market for the East and South Africa (COMESA) and the Economic Community of the Great Lake Countries (CEPGL). Burundi is still one of the poorest countries in the world, although it is a member of many economic communities. The most sensitive cause of this poverty situation is the lack of energy that slows down almost the entire economic chain.

In this thesis, using the natural (renewable) energy sources of Burundi, the development of the electric energy that influences the development of the country has been taken into consideration. As a result of this research, due to the geographical position of Buruni, solar energy is focused on the most suitable energy source among renewable energy sources. In this context, it is envisaged to provide the transportation of electric energy to all regions that are not still used in electricity, and thus to increase both economic and lifestyles.

Following this thesis, the Burundi Government, the Burundi economy operators, various partners and investors will be able to overcome the development challenges and, as a result, will lead to the improvement of this energy field, which is considered as the pillar of a sustainable socioeconomic element in a worldwide area.

Keywords: *Solar energy, landlocked country, energy power, power plant, renewable energy, energy supply, energy deficiency,*

1. INTRODUCTION

1.1. Background

To carry out a research on electrical system of a country, such as Burundi, requires to have a brief understanding of its historical, geographical and socio-economic situation.

1.2. Geographical location

Burundi is located in eastern Africa and extends between 28 ° 58 'and 30 ° 53' east longitude and between 2 ° 15 'and 4 ° 30' south latitude. It is bounded by Rwanda in the North, the Democratic Republic of Congo (DRC) in the West and Tanzania in the South and East. It covers an area of 27834 $Km^2$of which about 2000 $Km^2$are occupied by the Burundian part of Lake Tanganyika.

1.3. Socio-economic context

The Burundian population is of 11.099.298 [1]. Burundi is ranked among the smallest African countries and is a densely populated country with a high population growth rate. Despite its enormous potential in energy resources and natural mineral resources, Burundi is among the poorest countries in the world. [2].The periods of war that Burundi went through until 2003 did not promote the energy developpement. Today, the country is stable. The population has considerably increased.

With the increase in the population, the energy consumption has increased so much that the energy system of Burundi has become weak due to the enormous energy demand. In addition, the energy demands caused by rapid urbanization and the creation of industries and activities requiring electrical energy have led to the insufficiency of the Burundi’s energy system.

However, the majority of the Burundian population lives in the countryside and the access to the electric energy remains very low. The rural population is estimated about 90 percent [2]. Less than 5% of the population has access to the national grid. This implies a huge consumption of fuel wood as a source of primary energy, thus presenting serious negative consequences for the environment. Traditional biomass alone presents 99% of which 70% comes from firewood, 18% comes from agricultural residuals, 6% comes from coal, and 1% comes from bagasse [3,7].

Despite this energy deficiency, Burundi's hydroelectric potential is 1700MW, of which 300MW are economically exploitable, but only 32 MW are developed [7, 13]. Solar potential is estimated at an annual average of sunshine of 2000 KWh /m^2.year; equivalent to the sunniest European regions of the Mediterranean [7, 13].

However, despite all these potential energies, Burundi has such a severe energy crisis that has a major impact on its ability to reduce poverty and achieve the Millennium Development Goals (MDGS).

There is obviously a question for the government of Burundi to find how to ensure sustainable and permanent supply of energy so as to allow a real economic take - off and to achieve the Millennium Development Goals. (MDGs).

1.4. Objective of this Study

The Burundian population is unequally distributed. Most of Burundians live in the countryside and therefore do not have access to the national electricity grid.

The aim of this thesis is to find a better solutıon that could allow the Burundian population and especially that living in the most remote areas of the national electricity grid to have access to electricity.

For this reason, this topic is chosen as thesis subject.

1.5. Methodology

To achieve this goal with a good result, a systematic study in all domains influencing the energy systems of countries include Burundi will be done. For this purposes, the following studies will be put into consideration:

- Briefly review the evolution of energy throughout the world from its discovery to the present day.
- Determine all types of energy that countries use and how it is produced;
- Determination all forms and categories of energy encountered around the world.
- Identify the elements that could cause changes in the energy System of a country;
- Determination of a brief historical, geographical and socio-economic situation of Burundi ;
- By taking into account the evolution of Burundian population, supply and demand; determine how much energy is available and what is missing to satisfy everyone in need of electrical energy in Burundi;
- Determination of the type of reneable energy for Burundi;
- Determination of how to develop and implement the use of solar energy and related technologies in Burundi’s energy sistem;
- The planned policy to satisfy the demand now and in the future for Burundi;
- Formulate recommendations and suggestions to eradicate the lack of energy and ensure sufficient and permanent energy supply.

1.6. Structure of the Thesis

This thesis has been systematically subdivided into four major parts assimilated to the chapters.

- The first chapter includes the general introduction. In this chapter, the why of the choice of the subject is given, the problematic of the study, the hypotheses, the objective, the structure as well as the methodology used to reach the expected results.
- The second chapter concerns the Burundi’s energy system already in place, gives the different sources of energy used in Burundi. It is during this chapter that we find whether the current energy system in Burundi responds to the

needs of customers considering the supply and demand. It is through this chapter that we see which type renewable energy used, its evolution from its discovery to the present time.

- The third chapter deals with the sources of renewable energies most specifically the solar energy which is supposed in this research to be a solution to the lack of energy which is observed in the energy system of Burundi as well as the techniques related to this new technology of solar energy.
- The fourth and last chapter deals with the various suggestions and recommendations that take into account the different results obtained in previous chapters. The study ends with a general conclusion.

2. ENERGY BEING USED IN BURUNDI

2.1. Introductıon

Burundi is one of the poorest countries in the world. Its population; in addition to being among the densest of the African continent, is unequally distributed.

However, this inequality in the distribution of the Burundian population largely influences access and connectivity to the national electricity grid.

In this chapter; taking into account the distribution of the population and its connection to the national power grid, the whole energy system of Burundi will be deeply evaluated in order to concretely identify what types of energy are being used and how this energy is generated. This will then allow to evaluate supply and demand in order to be able to see the energy available and the missing one to ensure the total demand in view of the increase rate of subscribers and of different activities in need of electrical energy.

2.2. Distribution of the burundian population and its energy consumption

The Burundian population lives mainly in the countryside and therefore has no access to the national electricity Grid. It is a population with a growth rate varying between 0% and 4% if we take into account the forecast of the population evolution from 2005 to 2045.

Table 2.1: Prediction of Burundian population horizon 2045[5]

Year	Population	Density/Km^2	Growth Rate
2005	7,423,289	266.70	3.01%
2010	8,766,930	314.97	3.38%
2015	10,199,270	366.43	3.07%
2020	11,939,227	428.94	0.00%
2025	13,810,006	496.16	2.95%
2030	15,798,849	567.61	2.73%
2035	17,970,195	645.62	2.61%
2040	20,377,076	732.09	2.55%
2045	22,998,539	826.28	2.45%

However, to live, this population needs to obtain basic energy; an essential energy especially for cooking and other activities requiring heating. This energy is obtained mainly from the combustion of biomass including firewood and charcoal. Despite this energy variety, firewood and coal come first with a share of around 97.5% of Burundi's overall energy consumption, while the remaining 2.5% is between electricity and oil.[7,10].

According to research conducted in 2008 on the level of connectivity on the national electricity grid, only the 39,204 subscribers were connected to the national electricity grid, including households, governments, and businesses. Still according to the study done in 2008 on the level of connectivity on the national electricity grid; there are 34,700 households out of a total of 1.6 million households in Burundi, and this represents only 2% of households with access to electricity. The majority of households with access to electricity are concentrated in Bujumbura (80% of the households).

That research conducted between 2000 and 2008 showed that growth in connection to the electricity grid is high among households, while it is almost constant for businesses and enterprises. Growth at connectivity is estimated to be about 4.2% .However; the finding is that with agriculture and the use of firewood and coal as a means of obtaining primary energy for cooking and for other activities requiring heating

According to the U.N. FAO, 6.7% or about 172,000 ha of Burundi is forested, according to FAO. Of this 23.3% (40,000) is classified as primary forest, the most bio diverse and carbon-dense form of forest. Burundi had 69,000 ha of planted forest. Change in Forest Cover: Between 1990 and 2010, Burundi lost an average of 5,850 ha or 2.02% per year. In total, between 1990 and 2010, Burundi lost 40.5% of its forest cover or around 117,000 ha [8]. It shows that if nothing is done as soon as possible, the remaining 59.5% of forests will be eliminated by 2040.

Burundi's forests contain 17 million metric tons of carbon in living forest biomass. Biodiversity and Protected Areas: Burundi has some 819 known species of amphibians, birds, mammals and reptiles according to figures from the World Conservation Monitoring Centre. Of these, 0.7% is endemic, meaning they don’t exist in any other country, and 2.7% are threatened. Burundi is home to at least 2500 species of vascular plants [8].

The amount of electricity being consumed in Burundi comes from the production of hydroelectric power stations and thermal plant built in Burundi. There are other news hydro power plants being built like Jiji Murembwe and Mpanda hydroelectric plant while another part of the electricity is imported from neighboring countries power plants such as RUZIZI 1 and RUZIZI 2 in the Democratic Republic of Congo. Another important quantity of electricity will be imported from the RUSUMO FALLS hydroelectric power plant, which is being built between Burundi, Rwanda and Tanzania [9].

Nevertheless, the use of solar energy is still less developed despite its effectiveness throughout the whole of Burundi's sunny territory throughout the year. Individuals, hospitals and secondary establishments are beginning to self-fuel with solar energy, but always in low numbers and often with less advanced technology leading to poor returns. Big hospitals like Kamenge university hospital center have their own solar power plan to ensure energy self-sufficiency whereas the extra energy is rejected to the national electrical grid.

Large companies such as SOSUMO, OTB are producing the electrical energy they need. Other large companies such as BRARUDI, the mobile telephony companies use oil to power the electricity generating units, thus managing electricity during breaks on national electrical grid.

Considering the current energy situation in Burundi; the little energy available in Burundi comes mainly from hydroelectric plants, fuel, solar energy, biomass, peat, firewood, coal, wind energy and bagasse.

2.3. Characteristic of access to national electricity grid in Burundi

In Burundi, the access to the national electricity grid is characterized by:

- Very low access to electricity: Although Burundi is one of the densely populated countries in Africa, the population with access to electricity is smaller and represents only 2.4% of the total population [10].
- Despite Burundi's immense energy potential, demand is so much higher than supply [11]. This makes the population use firewood as the main source of energy for most artisanal or industrial thermal activities (brick making, bread making, etc.). The use of firewood is also the main fuel that the vast majority of the population uses for cooking.

Over a period of 10 years from 2005 to 2015, a meticulous survey of electricity consumption for all levels in Burundi was made in order to draw inspiration from it to establish consumption and electricity needs in the coming years.

The tables below showing how has been the consumption evolution over a period of 10 years from 2005 to 2015.These tables talking about the evolution of electricity consumption by center (in Kwh), the evolution of electricity consumption by region (in Kwh), the evolution of electricity consumption by category of consumers (in GWh),the evolution of the number of electricity subscribers per center and the inventory of hydroelectric plants found in Burundi until 2015.

Table 2.2: Evolution of electricity consumption by center (in Kwh)[11]

Center	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Low and medium voltage	124915104	105247178	142814906	161716920	144184405	189128121	199292159	-	-	225 644 610	183389559
Bujumbura	96230721	85264644	103061675	122461690	126554776	142884348	144699083	11984374048	13339341772	10999380362	128647656
South Region	4818105	3331433	5818274	6529815	6647898	9332391	9178707	1302627836	1127986275	1909241301	7 021 693
Rumonge	2129199	1272153	2842437	2866150	3189267	4398939	4693632	456041935	817712913	1066777199	3 708 835
Nyanza-Lac	210240	293078	429748	617748	608295	691492	814782	282896757	-41690502	126702544	785296
Makamba/Mabanda	975774	719826	1062075	1394425	1559951	2098154	1729309	213008001	225473114	132301833	1 443 393
Bururi/Matana	1502892	1046376	1484014	1651492	1290385	2143806	1940984	213008001	225473114	132301833	1 084 169
East Region	9269494	7021407	14623088	10689496	11702931	15340517	14377852	2267718921	1606070423	2317190361	14 514 194
Gitega	7741804	5189851	93881759	8828080	9442741	11988135	11691434	2070195826	1354759325	1775602011	11 702 143
Cankuzo	80071	1139578	294042	360699	473238	1137540	271088	56061979	109254424	69509761	592 300
Ruyigi	655018	433267	3657979	723648	1156075	1335389	1157903	17413931	147207511	147950877	1 140 956
Rutana	792602	258711	1289308	777069	630877	879453	1257427	158875047	5150837	324127712	1 078 786
North Region	6665 108	5566319	876494	12176693	10237020	10028811	15840547	1725350344	2858180008	2310400154	16 104 379
Ngozi	2933654	2827871	3500738	6163317	3943951	3329896	7011102	721657272	1241735395	616843739	5 703 832
Kayanza	2680683	1415386	3400738	3016711	3579050	3427359	4748251	487786712	692771118	771999487	4 213 339
Muyinga	242965	282344	842111	1539224	1263501	1433791	1794460	224330149	570804512	486259358	2 645 327
Kirundo/Marangara	499261	773619	889408	1063259	1010850	1310132	1680455	231307166	235189556	294765701	2 331 041
Karuzi/Buhiga	308545	267099	231949	394182	439668	527633	606279	87269045	117679427	140531869	1 210 840
West Region	7931676	4063375	10546925	9 859226	10620231	11542054	15195970	2215943003	2744308896	3966785288	18 471 186
Cibitoke	1312128	1013402	2263044	2749341	2065326	1441232	4313731	679715353	818103107	1007030910	5 309 294
Bubanza	685454	727420	820044	872275	935858	1053046	965451	170906522	193293383	224467646	1 307 672
Gatumba/Muzinda/Isare/Gihanga	1075184	1163642	1557113	1317089	1826207	2415926	2377541	310730075	488792670	1023408771	4 644 008
Tora/Ijenda/Mwaro	3106303	670772	3679176	3119762	3503334	3549464	4748882	650642529	835153155	1135624510	4 212 296
Muramvya/Bukeye	1752607	488139	2227548	1800759	2289506	3082386	2790365	403948524	408966581	576253451	2 997 916
Total Général	249830208	210494356	285629812	323433840	309947261	378256242	398584318	19496014152	21675887374	21728642076	224986817

Source: Regideso

Table 2.3: Evolution of Electricity Consumption by Region (in Kwh) [11]

Center	Bujumbura	South Region	East Region	North Region	West Region
2005	96230721	4818105	9269494	6665108	7931676
2006	85264644	3331433	7021407	5566319	4063375
2007	103061675	5818274	14623088	8764944	10546925
2008	122461690	6529815	10689496	12176693	9859226
2009	126554776	6647898	11702931	10237020	10620231
2010	142884348	9332391	15340517	10028811	11542054
2011	144699083	9178707	14377852	15840547	15195970
2012	11984374048	1302627836	2267718921	1725350344	2215943003
2013	13339341772	1127986275	1606070423	2858180008	2744308896
2014	10999380362	1909241301	2317190361	2310400154	3966785288
2015	128 647 656	7021693	14 514 194	16104379	18471186
TOTALS	37144253119	4392533728	6274004490	6979314327	9015267830

Source: Regideso

Table 2.4: Evolution of electricity consumption by category of consumers (in GWh).[11]

Consumer categories	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Government	4.3	5.1	4.9	5.7	4.8	5.5	5.6	6.07	6.2	6.1	-
Common and public lighting	0,5	0,4	0,5	0,9	0,5	0,3	0,2	2,7	0,4	1, 3	-
Trade	12,0	8,9	13,2	21,1	27,7	16,2	28,7	21, 7	37, 6	33, 7	-
Industries and crafts	1,6	1,1	1,3	22,2	20,7	19,9	27,0	25, 2	27, 6	33, 3	-
Households	45,9	40,7	53,3	61,6	57,8	56,2	47,4	37, 8	36, 3	105, 3	-
REGIDESO	1,0	0,8	1,4	5,3	6,6	30,6	9,3	9, 2	4, 4	4, 9	-
International organizations	2,5	2,1	1,4	2,2	3,0	2,4	2,2	1, 7	-3, 3	1, 2	-
State corporations	1,0	1,1	1,1	7,5	8,4	8,2	9,4	7, 16	9, 8	10, 6	-
Administration, personalized management	3,4	1,3	4,0	7,7	7,7	10,0	10,9	10, 9	12, 5	12, 5	-
Religious Confession and social organization	2,9	2,1	2,9	4,2	4,1	4,4	4,3	5,1	2,8	4,3	-
Prepaid sales	4,7	8,0	15,1	21,9	27,2	54,4	-	-	-	-	-
Total	79,8	71,6	99,1	160,3	168,7	189,0	199,4	-	-	-	-

Source: Regideso

2.4. Energetic efficiency in Burundi

In Burundi the consumption of wood is too high. However, domestic fuel wood production is inadequate and only covers about 2/3 of demand [8]. This leads to deforestation due to inefficiency in the management of the forest resources. The carbonization is archaic and the yield is insufficient. Cooking is done with traditional fireplaces with poor yields. The small amount of electrical energy produced in Burundi faces several problems, especially those related to excessive electrical losses on the national electricity grid. Thus, in 2012 recorded losses were 24% [10]. The obsolescence and the lack of maintenance of the production facilities, the old and archaic transmission and distribution equipment are at the origin of these too high electrical losses.

Despite the actions to optimize the consumption of households as the distribution of low consumption lamps; there are no actions likely to favor energy-saving behavior, no action to sensitize the industrialists to promote changes towards energy-saving processes.

Table 2.5: Evolution of the number of electricity subscribers per center [11]

Center	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Bujumbura	21510	24774	23025	24685	37696	41771	15 912	53 016	55 248	59 239
South Region	2754	3247	3482	3898	4 228	4642	5 055	5388	5 478	6 464
Rumonge	1 014	1 190	1 283	1 410	1 543	1 687	1 904	2 028	2 053	2 385
Nyanza-Lac	250	319	331	382	409	480	518	544	560	709
Makamba	622	713	770	914	989	1 119	1 182	1 348	1 370	1 638
Bururi/Matana	868	1 025	1 098	1 192	1 287	1 356	1 451	1 468	1 495	1 732
East Region	3558	4130	4463	5314	5 869	6 638	7 051	7530	7942	9 318
Gitega	2 641	3 052	3 255	3 919	4 341	4 954	5 255	5 634	6 009	7 099
Rutana	280	338	371	403	434	470	496	535	547	615
Ruyigi	400	472	545	637	693	767	815	837	844	996
Cankuzo	237	268	292	355	401	447	485	524	539	608
North Region	4409	5142	5 581	6329	6 943	7 817	8 588	9376	10311	11 876
Karuzi/Buhiga	288	452	457	511	581	639	774	810	818	1 078
Muyinga	774	890	997	1 100	1 155	1 315	1 414	1 503	1 786	2 026
Kirundo/Marangara	534	572	605	690	786	841	933	966	1 021	1 128
Ngozi	1 812	2 080	2 292	2 626	2 898	3 263	3 581	3 894	4 171	4726
Kayanza	1 001	1 148	1 230	1402	1 523	1 759	1 886	2 203	2 517	2918
West Region	2905	3876	3982	13112	5091	5672	6256	6809	7467	7 728
cibitokebuhoro	601	862	930	938	1 035	1 266	1 481	1 872	1 928	2 206
Muzinda/Gihanga	353	601	626	803	898	946	1 101	1 120	1458	1051
Bubanza	415	621	557	649	733	804	845	920	1 039	1166
Mwaro/Ijenda/Tora	130	141	142	606	815	181	910	964	982	1 036
Mutambu/Isare	349	352	362	130	147	415	196	207	225	239
Gatumba	454	544	564	409	409	881	420	431	378	401
Muramvya/Bukeye	604	755	801	9577	1 054	1 179	1 303	1 295	1 470	1 629
Genaral Total	35 136	41 169	40 533	53 338	59 827	66 540	46025	82119	86446	94625

Source: Regideso

2.5. Renewable energy resources in Burundi

The current states of renewable energies in Burundi show that Hydropower is the main form of renewable energy in the Burundi power grid. It accounts for almost 95% of the electricity consumed in Burundi [7,10]. The rural areas are almost without electricity despite the few projects using the photovoltaic.

As indicated by the study conducted in 2013 by the Ministry of Energy and Mines of Burundi with the support of the United Nations Development Program in Burundi (UNDP) on the Diagnostic of the Energy Sector in Burundi in the framework of the initiative of the United Nations Secretary-General on Sustainable Energy for All; Burundi should not have problems related to the lack of electricity because has huge potential hydraulic.

Burundi being an equatorial and mountainous country, the study has shown that it benefits from a very interesting hydraulic regime coupled with possibilities of catchment and favorable falls. Thus, the hydroelectric field of Burundi has been evaluated at 1700 MW of which approximately 300 MW are economically exploitable. Recent evaluations have shown that this potential may even be greater than that calculated in 1983. According to a recent literature review, 156 potential sites are identified and 29 existing or in the process of being equipped. Actually, fewer than 30 sites are operated. Despite all these potentials, the electrical capacities installed in Burundi are very minimal.

Indeed, we can enumerate in below table all hydroelectric plants encountered in Burundi so far in 2018:

2.5.1. Hydroelectric energy

Table 2.6: Inventory of hydroelectric plants [10]

Denomination of the plant	River	Year of commissioning	Installed power in Mw
Rwegura	Gitenge	1 986	3 x 6
Ruvyironza	Ruvyironza	1980/1984	3 x 0,425
Nyemanga	Siguvyaye	1 988	2 x 0,72
Gikombe	Mubarazi	1 982	2 x 0,425
Kayenzi	Kavuruga	1 984	2 x 0,425
Marangara	Ndurumu	1 986	2 x 0,12
Sanzu	Sanzu	1 983	0,072
Kigwena	Nzibwe	1 984	0,05
Butezi	Sanzu	1 990	0,24
Ryarusera	Kagogo	1 984	0,02
Nyabikere	Nyabisi	1 990	0,139
Murore	Rusumo	1 987	0,024
Kiremba	Buyangwe	1 981	0,064
Masango	Kitenge	1 979	0,025
Musongati	Nyamabuye	1 981	0,006
Mutumba	Kirasa	1 983	0,045
Mpinga	Mukanda	1 983	0,016
Teza	Nyabigondo	1 971	0,36
Kiganda	Mucece	1 984	0,044
Gisozi	Kayokwe	1 983	0,015
Burasira	Ruvubu	1 961	0,025
Kayongozi	Kayongozi	2011	0,5

Source: Ministry of Energy and Mines

The RWEGURA hydropower plant:

It is the most important among those already built in BURUNDI. It has been started in 1986 and it is operated by REGIDESO. It provides an installed electric power of 18MW equivalent of a productivity of 55.2 GWh / year.

The MUGERE hydropower plant:

It has been started in 1982s and it is operated by REGIDESO. It provides an installed electrical power of 8 MW which equates to a productivity of 45.04GWh / year.

The RUVYIRONZA hydropower plant:

Built between the years 1980-1984, the RUVYIRONZA hydroelectric plant provides an installed electrical power of 1.275MW. It is operated by REGIDESO and its annual productivity is 5.02GWh / year.

The GIKONGWE hydropower plant:

The GIKONGWE hydropower plant was built in 1984. Its installed electric power is 1.44MW. Its management is operated by REGIDESO and it has an annual productivity of 4.24GWh / year.

The NYEMANGA hydropower plant:

The NYEMANGA hydroelectric power station was launched in 1988 with an installed electric power of 1.44MW and provides an annual productivity of 11.40GWh / year. It is also operated by REGIDESO.

The MARANGARA hydropower plant:

This hydroelectric plant started up in 1986 with an installed electric power of 0.14MW. Its annual productivity reached 1.17 GWh / year and it is operated by REGIDESO.

The KAYENZI hydropower plant:

The KAYENZI hydropower plant has been started in 1984 with an installed electric power of 0.408MW. Its annual productivity is about 1.53 and REGIDESO ensure its operation.

The total electrical power developed is 30.133 MW; a total annual productivity of 123.33GWh / year[10]. Except REGIDESO, which has a monopoly on the operation of hydropower plants in Burundi, there are also micro hydropower plants operated by ABER (Agence Burundaise de l'Electrification Rurale). The ABER deals with the electrification of the isolated centers of the national electrical network. ABER operates 5 hydropower plants with an installed electrical power of 0.473 MW.

Some missions, some large companies such as SOSUMO operate small private hydroelectric plants totaling an installed electric power estimated at 0.65MW.

However, Burundi also uses imported electric power from neighboring countries: Two hydropower plants built on the RUZIZI River are shared between RWANDA, BURUNDI and the Democratic Republic of CONGO.

The RUZIZI II hydroelectric plant:

It was launched in 1989. It is operated by the Congolese company named SNEL. Burundi imports an installed electric power of 13.3MW estimated at an annual productivity of 79.22544GWh / year.

As for RUZIZI I; it was launched in 1958. It is operated by SINELAC (International Electricity Company of the Great Lakes Countries) which is a Tri-national organization. This hydropower plant provides Burundi with an installed electrical power of 3 MW equivalents to an annual productivity of 23,652Gwh / year.

Then, the total installed electric power imported from neighbor countries equals to 16.3MW, the annual productivity of 102.88GWh/year[11].

2.5.2. Thermal energy

In Burundi, thermal plants are less frequent. These use hydrocarbons as fuel. They are so expensive when compared with hydroelectric plants. The whole transport sector has no other sources of energy than fuel. However, thermal energy also plays a predominant role in Burundi's energy sector. Large enterprises and private ones like some hospitals, some health centers, some dispensaries located in rural areas without access to the national electrical network, certain secondary establishments or other individuals with means make use of the thermal energy to compensate for the irregularities of the national power grid or simply to self-sustain themself by generating sets . REGIDESO has only one thermal power plant in BUJUMBURA. This one provides an electric power installed of 30MW. Some of the most important industrials of BURUNDI like the BRARUDI, the companies of mobile telephony all have large generating units which can produce in term of quantity of MW. La BRARUDI could produce an electric power installed of 2.6MW in 2012.

2.5.3. Solar energy

By its geographical position, Burundi is one of the sunny countries throughout the year. Burundi could benefit considerably from solar energy. Burundi has very interesting solar deposits in such a way that the annual sunshine is equivalent to that of the regions of the Mediterranean coast. The average annual sunshine is close to 2000 KWh / m2 year; what would make this source of energy the best solution to the lack of energy observed throughout Burundi. [16].

However, despite this excellent solar distribution, this energy form is not exploited to the maximum. Some individuals, some hospitals and health center, some schools, some rural households exploit this energy form using photovoltaic panels. Although there has been no census to determine the amount of solar energy used in Burundi, the constant point is that this energy form is not yet exploited to the full.

Indeed, in Burundi, there are 115 solar installations composed of 1,679 modules and totaling an installed capacity of 72,384 Wp. Their use is broken down as

follows: 83% for lighting; 4% for pumping; 4% for refrigeration; 7% for telecommunications and 2% for other uses [45]

The KAMENGE University Hospital Center has a solar power station that allows it to keep its energy consumption on a regular basis. Other solar power plants will soon be built as planned by the Burundi government to increase supply.

2.5.4. The Peat

The National Peat Office (ONATOUR) in the country has the mission to exploit and commercialize production and use of peat; primarily in industry and agriculture and conduct further research and studies of the peat potential. Peat has been known in Burundi since the time the country was under Belgian control. Exploitable reserves have been estimated at 57 million tons at 30% humidity in an area of around 15Km^2.

ONATOUR is the only enterprise in the Great Lakes region of Africa that mechanically produces peat sods [12]. Since it was established in 1977, the quantity of peat available in Burundi is estimated at 600 million tons but only 47 to 58 million tons of peat would be exploitable [12]. Some 0.5% of reserves have been processed. The major users of peat are military camps and prisons, which account for 90% of production. The remaining 10% is lost during handling or stockpiling. ONATOUR has sold nearly 225 000 tons of peat since its formation, with the army being the principal client. Following the acquisition of new production installations, production of peat is expected to increase [12].

2.5.5. Bagasse

Bagasse is an efficient source of energy but not enough in Burundi. Only SOSUMO (Société Sucrière de Moso) has an electric power plant powered by biomass from bagasse.This power station of SOSUMO is a form of cogeneration unit fed by the residues of sugar cane known as bagasse.

The company produces itself all the electrical energy it needs throughout the crop and production season as well as all the electrical energy used in the premises of the administrative and the employees. This plant supplies installed electrical power up to 4 MW.

2.5.6. Biogas

As defined by the book entitled "LIVRE BLANC DU BIOGAZ", biogas is an energy deriv ed from the degradation of organic matter.

It is a renewable gas resulting of the degradation of organic matter in the absence of oxygen, mainly composed of methane. It can come from the degradation of organic matter stored in non-hazardous waste storage facilities or be produced by the methanisation of organic matter non-woody in a digester.

However, although easy to produce and despite its relevance, biogas is not widely exploited in Burundi. Throughout Burundi, there are some sixty collective projects (such as schools, campuses, etc.) carried out in the 90s from animal or human waste. The facilities are currently poor and the yield is mediocre [13].

2.5.7. Firewood

In Burundi, wood in its raw form or in the form of coal is the main source of energy for cooking and other craft and commercial activities requiring heating. This source of energy may be exhausted. Thus, according to studies and research carried out on the forest sector in Burundi, the annual demand is higher than the annual production. Consumption is estimated at between 3.3 and 4.5 million tons against estimated production of between 1.3 and 2.9 million tons [13]. According to sources, Burundi's forest reserve was estimated at 200,000 ha in 2010 for a population of more than 8 million, and between 96 and 99% use wood as fuel; which suggests an imminent danger in the next 15 and 20 years if nothing is done as soon as possible.

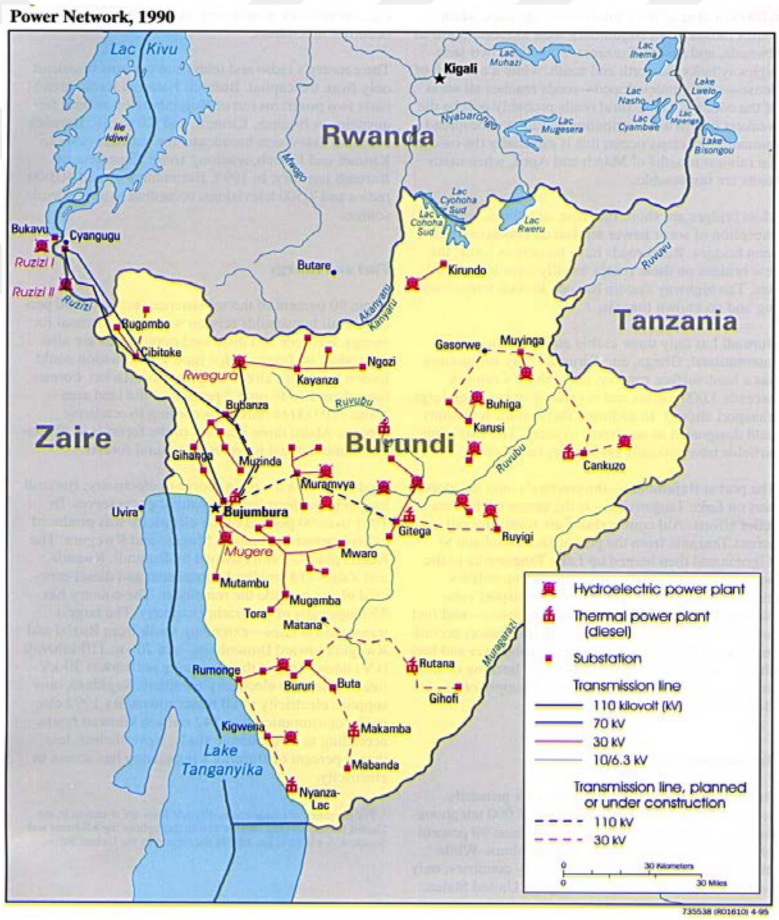

Figure 2.1: Burundi energy map

Burundi's energy consumption is dominated by firewood, coal and agricultural residues, which represent 95.5% while the remain part is electricity. By combining the electrical energy hitherto documented in Burundi from all sources, an electrical power of 84,408 MW is installed. Hydroelectricity occupies 95% of the electricity production in Burundi while the remain amount is divided between photovoltaic, thermal, bagasse [7,10].

Conseqently, according to the explanations above, since it is understood that Burundi is a sunny country throughout the year, it is concluded that the development of electric power technology and to solve the lack of energy in question will be solved by linking solar energy sources with the existing energy sources.

3. RENEWABLE ENERGY RESOURCES: SOLAR ENERGY IN BURUNDI

Burundi is a sunny country. Solar energy is an abundant energy source in Burundi[13].

Table 3.1 Annual global average of radiation by climate region [45]

Climate region	Annual averages (kWh / m² / day)
Plain of the Imbo	4.79
Congo-Nile Ridge	3.9
Northeast depression	4.30
Eastern depression	4.80
Central Trays	4.38

However this source of energy implies some technics and methodes to transforme solar irradiation into electrical energy . For the case of Burundi which is concerned by this thesis , photovoltaic technic will be used to transform solar energy in electrical energy. The implementation of solar energy in Burundi's energy system will follow diffrennt steps related to the Photovoltaic Sizing Technics.

3.1. Brief history of photovoltaic technic

In 1839, ANTOINE BECQUEREL dicovered that the light energy generated by the sun can be transformed into electrical energy by the photovoltaic effect. In 1930, helio electricity appeared with copper oxide cells and silicon. Around 1954, the possibility of providing energy was realized. The first terrestrial uses appear around the 70's. Global production of photovoltaic modules increased from 5 MW in 1982 to more than 18GWc in 2013[17].

3.2. Conversion of solar energy into electrical energy

To be usable, solar energy must be transformed into electrical energy. The conversion of solar energy into electrical energy is possible thanks to the photovoltaic panels. Photovoltaic is the direct conversion of sunlight to electricity. The figure below shows how the conversion of solar energy into electrical energy is done. It also shows the elements taken into account during this conversion.

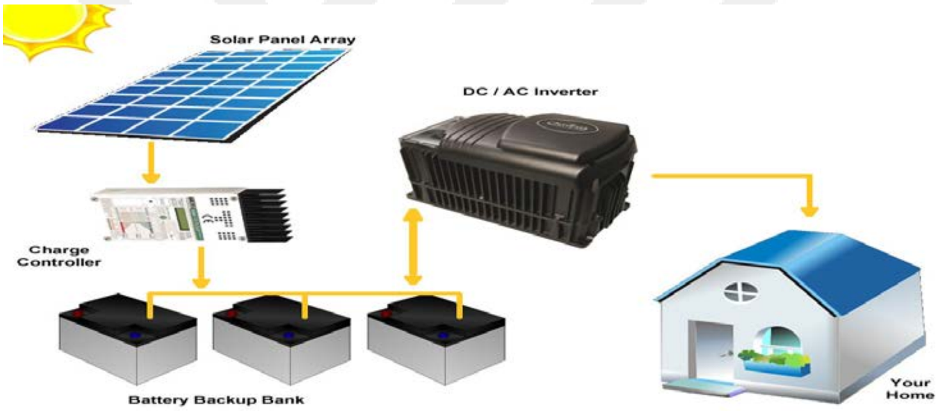

Figure 3.1: Basic diagram for photovoltaic installation

Source :
https://www.google.com.tr/search?q=Typical+electrical+diagram+of+a+photovoltaic+system

The solar panel is exposed towards the sun. This one recuperates the sunlight and transform it into the electrical current. This electric current is afterwards sent to the accumulator batteries passing through the charge controller. The current sent to the batteries is the DC current. From the batteries, the inverter transforms the DC current stored in the batteries into AC current. The inverter also adapts the voltage stocked in batteries to the domestic nominal voltage. Then the electrical energy is available for use.

Photovoltaic system is mainly composed by solar array, charge controller, battery, inverter, DC load, AC load as shown on figure below.

3.3. How solar energy may increase access to electricity in Burundi

As seen in previous chapters, the energy system in Burundi is marked by a very remarkable energy deficit. All electrical power installed in Burundi remains below to 100 MW. Demand is far higher than supply. The minimum power required by 2020 is of the order of 280 MW, whereas the new programs in progress expect to reach only about 180 MW more by this time; energy requirements for the mining sector are estimated between 300 and 800 MW in the next 10 years for the nickel industry alone and its associated minerals; the electrical installations are very old and cause a lot of losses [19].

However, as already it have been mentioned in the previous chapters, the solar field of Burundi is very interesting. The average sunshine received annually is close to 2,000 kWh / m^2.year which are equivalent to the best European regions (southern Mediterranean) [20]. Despite the significant cloudiness due to the equatorial situation of Burundi and periods of rain, the exploitation of solar energy in Burundi is therefore an interesting solution to electrical energy deficiency. The production of electricity by solar energy can be achieved by photovoltaic technology or by thermal solutions. In the case of Burundi, only the photovoltaic option seems appropriate [20].

To see its importance, we can, by the sun, define five particular types of uses that could meet needs in Burundi.

- Rural electrification by photovoltaic kits
- Solar pumping
- Isolated photovoltaic generators
- Hybrid photovoltaic plant for isolated centers
- Photovoltaic power plants connected to the grid

The different visions of the Republic of Burundi, whether Vision 2025, Vision 2045 and others, predict that Burundi will no longer be among the poorest countries but rather among the emerging countries. In this way, the energy sector is one of the key sectors for this change. It is expected that the country will see the industries increase, the cities will expand and their number will increase, the roads will be lit, the population will also increase and its standard of living will improve and even the energy consumption will increase in turn.

Photovoltaic solar energy is suitable for the electrification of isolated centers or mini thermal-photovoltaic hybrid plants. With a view to developing the rural electrification of scattered populations, the power supply solution using photovoltaic kits seems a possible solution. Finally all isolated public or private infrastructures (health center, schools, hotels, telecommunications pylons, public lighting of roads) should be powered by solar energy as part of a vast program of decentralized electrification. These projects could involve private investment and public service delegation.

Thus, in this study is given a plan to follow in order to allow the Burundian population to have access to the electrical energy whatever the place where someone is on the soil of Burundi because the solar radiations reach all the national territory of Burundi from morning to night just at the same level.

3.4. Implementation of solar photovoltaic system in Burundi's energy system

Taking into account Burundi's vision for energy by 2020 and 2045 horizon responding to the Millennium of Development Goals, to be able to serve the largest number of people in electricity, considering the evolution of the number of electricity subscribers per center (Table 2.5), the evolution of electricity consumption by category of consumers (Table2.4) as well as on the basis of the forecast of the increase of the Burundian population by 2045 and beyond (Table2.1), an estimated inventory of the electrical load of all categories of consumers registered in Burundi's electricity grid is made in order to be able to size photovoltaic power plants that could considerably reduce the lack of electricity that Burundi faces when added to the existing one.

Thus, for households, villages and neighborhoods, the forecast of electricity consumption in the next 10 years, 20 years, 30 years, etc. seems to be simple. Taking into account the data in the table of the projection of the evolution of the population, it is enough to make an estimated inventory of the needs in electrical energy for a household supposed to be modern and after to multiply by the estimated number of households which can constitute a village or a modern neighborhood. However, as the population continues to increase, it will be sufficient to increase energy production according to new villages and neighborhoods that will be created as electricity consumption of a village, modern neighborhood will be known.

Table 3.2: Estimated Daily Electrical Load Table for a Single Modern Household and a Modern Village

No.	**Equipment**	**Quantity**	**Power(w)**	**Total Power(w)**	**Hours/Day**	**Watt-hour/day**
1	Lamps LED	12	5	60	6	360
2	Cell-Phones	3	5	15	3	45
3	Radios	1	10	10	8	80
4	Televisions	1	40	40	6	240
5	Refrigerators	1	75	75	20	1500
6	Iron	1	1000	1000	0.25	250
7	DVD Player	1	30	30	2	60
8	Water pumps	1	500	500	1	500
9	computer	1	100	100	3	300
10	Washing machine	1	2000	2000	0.25	500
Total Energy Consumption						3835
No. of Households						100
Total Energy Consumption for households						383500

Based on these values, a typical daily load curve for an estimated single modern household responding to millennium development Goals in remote regions of Burundi with hourly resolution has been described. The estimated maximum power consumption demand with respect to the obtained load profile, for the chosen single modern household is approximately equal to 3835Wh/day. Villages can, however, be established in the most remote areas of the national power grid to allow to everyone access to electricity regardless of the part of the country where we are.

For the other categories of consumers, the forecast of electricity consumption also seems not to be complicated. The tables of the evolution of the electric consumption and the evolution of the number of the subscribers for the 10 years run give an idea on what will look like the consumption of electricity in the years to come. From there, an estimated electricity consumption projection inventory is made on the basis of these data presented in these tables mentioned above. Subsequently, a summary table of electricity consumption forecast is released in order to make the sizing phase easy and possible.

Table 3.3: Recapitulative table of estimated daily electricity consumption for all categories of subscribers of the Burundi energy system horizon 2023, 2032, 2041 (in GWh)

Consumer categories	2005	2014	2023	2032	2041
Government	4.3	6.1	7.9	11.5	18.7
Common and public lighting	0.5	1.3	2.1	3.7	6.9
Trade	12.0	33.7	55.4	98.8	185.6
Industries and Craft	1.6	33.3	65.0	128.4	255.2
Households	45.9	105.3	164.7	283.5	521.1
REGIDESO	1.0	4.9	8.8	16.6	32.2
International Organizations	2.5	1.2	1.0	2.0	1.5
State Corporations	1.0	10.6	20.2	39.4	77.8
Administration, personalized management	3.4	12.5	21.5	39.6	75.8
Religious confessions and social organizations	2.9	4.3	5.7	8.5	14.1
Prepaid sales	4.7	9.8	14.9	25.1	45.5
Total	79.8	223	345.7	617.9	1234.2

To meet at least the needs of different subscribers in electricity and to give access to electricity to as many Burundians as possible, an installed electrical power estimated at **345.7 GWh** could be implemented by 2023 while the estimated power of **617.9 GWh** could be installed for 2032**.** Going beyond, a nearby installed electrical power of **1234.2 GWh** could be implemented by 2045.

3.5. Sizing of photovoltaic system.

So that a work of establishment of a photovoltaic system can be done well and efficiently, it is obligatory to carry out a sizing of the system which means to fix the size, the optimal characteristics of each element of a system which the configuration is known.

Indeed; Considering the technical factors, sizing can eventually lead to any decision-making even changing the system, for example if it is noted that technically optimal elements are very expensive or indispensable.

This sizing method consists in first determining the peak power that provides the electrical energy needed during the least sunny month. It's about determining when you need electricity, and measuring your consumption. This is a step that involves few calculations, but requires relatively much thought because an error at this stage will distort the results until the end.

The method has 7 steps: The result of a step directly influences the result of the following steps. If you get an aberrant result, it does not necessarily mean that you were wrong in your calculations. Do not hesitate to go back, especially in the first step, to redefine your needs (such as reduce your consumption by choosing more economical devices).

3.5.1. A stand-alone photovoltaic system

Components of solar PV system :

Solar PV system includes different components depended on your system type, site location and applications such as solar charge controller, inverter, battery bank, auxiliary energy sources and loads (appliances).

Major Components of PV System:

- PV Module or photovoltaic solar panel that can produce the required quantity electricity.
- MPPT Charge Controller or solar charge limiter that protects the batteries accumulators against overloads and deep discharges
- Battery Bank that store the energy produced by the panel solar photovoltaic.
- Accessories such as:
    - Cables that connect the components
    - Converter: it adapts the DC voltage delivered by the solar battery to the voltage receiver power if it is higher or lower.

- Inverter: It transforms direct current (DC) into alternating current (AC)

- Loads are then the devices that use electricity: lamps, radios, televisions computers, pumps, refrigerators.

Thus, the process of sizing the photovoltaic system is done by the following steps:

3.5.1.1. Determine power consumption demands:

During this stage we try to estimate the consumption of equipment supposed to be known with the aim of obtaining the average total consumption per day and per period (summer, winters, holidays),

The average total energy required each day **E** $(\boldsymbol{Wh/d})$ is the sum of energy consumption of the various equipment constituting the system to be studied, such as television, lighting lamps, electronic devices, etc. It is given by the following law [23].

$$\mathbf{E} = \sum_{i=1}^{n} \boldsymbol{E_i} \qquad \textbf{(3.1)}$$

With: **E** the total consumed energy

$\sum_{i=1}^{n} E_i$ the summation of each item in installation.

The determination of the average time of use is more difficult and must take into account:

- The season,
- The number of occupants
- The mode of use

For equipment which is not used daily and for all high consumption equipment, start from the duration of the task's operating cycle. Thus, the consumption of each equipment can be calculated as follows [23]:

$$\boldsymbol{E_i} = \boldsymbol{P_i} * \boldsymbol{t_i} \qquad \textbf{(3.2)}$$

Where the daily energy consumption of a device $\boldsymbol{E_i}$ ***(Wh/ day)*** = $\boldsymbol{P_i}$ the power of this equipment x $\boldsymbol{t_i}$ the duration of use of each (hour)

3.5.1.2. The energy to be supplied to the inverter and its use

Figure: Example of solar inverter diagram

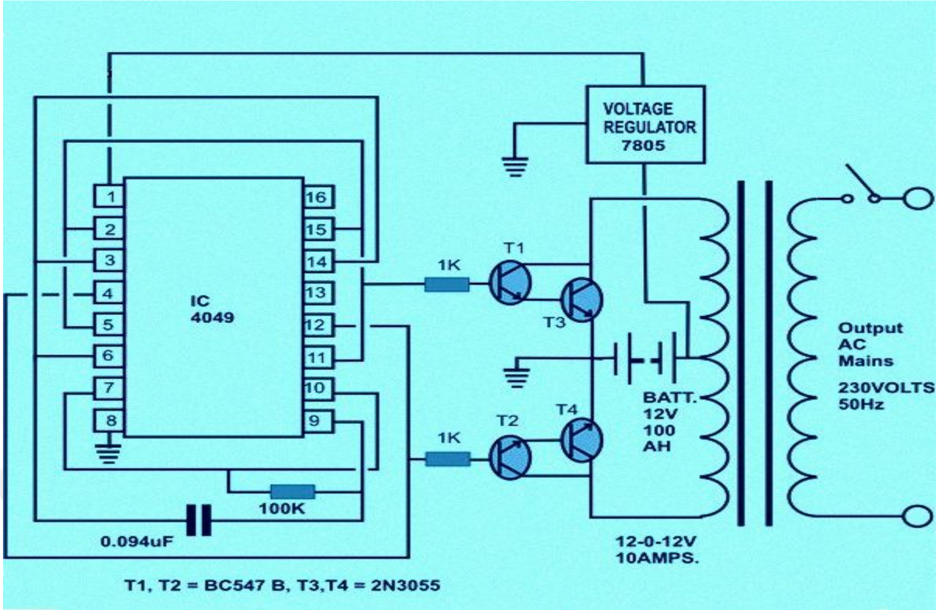

Figure 3.2: Example of solar inverter diagram

Resource: inverter+diagram+pdf&client=opera&hs=Npt&tbm=isch&tbo=u&source

When an inverter is used, it supplies:

Consumption in 220V AC of small powers (television, radio, cell-phone...) that we note X;

Consumption in 220V AC of long duration or high power such as the fridge, that we note Y;

And possibly the lighting; energy rated W.

The actual efficiency, average of a well-designed inverter, of good quality, depends on its charge rate η [23]

$$\eta = \frac{P_{AC}}{P_{DC}} \quad \textbf{(3.3)}$$

With P_{AC}, P_{DC} respectively power output and power input.

If we assume that the inverter is well used: its charge rate must be high (from 0.75 to 1).

The conversion yield is then 0.7 to 0.9 and we retain the average value of 0.8.

Thus, the power to be supplied to the inverter to dispose of the energy E at the output (at 220 V AC) is [24]:

$$P = \frac{E}{0.8} 1.25E \qquad \textbf{(3.4)}$$

the power to be supplied to the inverter(Wh/day) =
the energy demanded from the inverter(Wh/day)/inverter load rate

The energy demanded from the inverter E is worth:

$$E=X+Y+W \qquad \textbf{(3.5)}$$

Where E: The energy demanded from the inverter (*Wh /day*)

X: The consumption of small power equipment in 220V AC.

Y: The consumption of high power equipment in 220V AC.

W: The lighting

And the energy to be supplied to the inverter is:

$$1.25^{*}\ E=1.25^{*}(X+Y+W) \qquad \textbf{(3.6)}$$

3.5.1.3. The energy to be supplied to the battery and its use

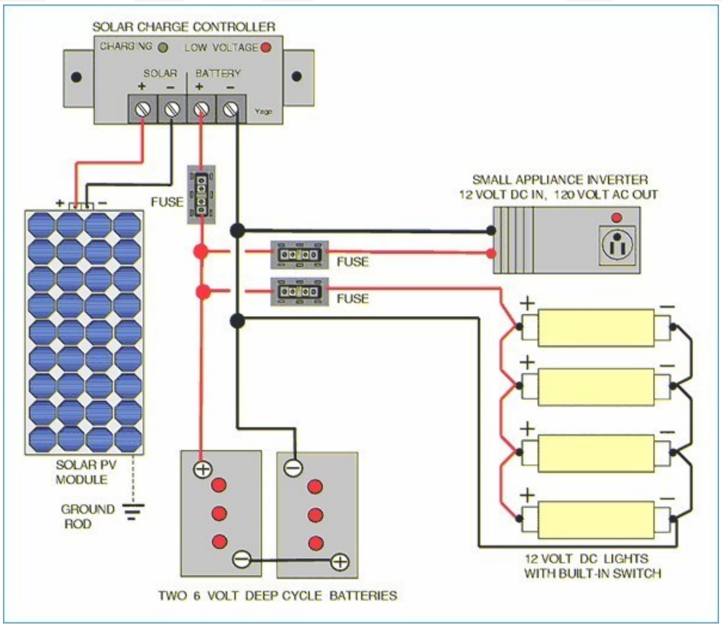

Figure 3.3: Example of solar battery diagram

Resource: https://www.google.com.tr/search?q=solar+battery+diagram +pdf& client =opera&hs

The use of the battery is not at all reliable and causes some losses that are often due to:

- Energy efficiency of the battery;
- Self discharge, which depends on the storage duration (for a given battery)

For a so-called solar battery, means well suited to photovoltaic systems, energy efficiency is 0.80 to 0.85 and self-discharge of 3% per month.

The overall efficiency found in a habitat system is 0.8 in general [25], so:

$$E_B = E_P * 0.8 \qquad \textbf{(3.7)}$$

Whee: E_B the energy supplied by the battery

E_P the energy supplied by the panel

3.5.1.4. The electrical energy supplied by the photovoltaic generator

The sunshine received and the orientation of the panel influences the content of the electrical energy supplied by the panel. The estimate of the solar energy received on the site is not at all complicated, but it is necessary to take into account the characteristics specific to the site of the installation itself [25].

Estimate of solar energy received at a given site

This estimate must take into account both:

- Statistical data on solar energy received on the installation region;
- Specific characteristics of the site and likely to prevent the photovoltaic panel from receiving all the energy possible (due to masks, snow, dust ...).

3.5.1.5. Statistical values of solar energy

It is necessary to know with as much accuracy as possible the solar energy received on average per day on the site during a given period. This period is generally equals to one month [25].

Depending on the country, for a given period; the quantities are determined from one of the following data (for a given period):

- Average number of hours of sunshine per day (or sunstroke duration);
- The average irradiation received on the ground (horizontal plane);
- Overall sunlight on a plane inclined at a certain angle.

However, global sunlight on an inclined plane at a certain angle is by far the most interesting since it allows the angle to be easily tilting panels given, to determine the electrical energy produced by a given peak power panel.

3.5.1.6. Site specific characteristics

Before taking any action to implement a solar energy site, it is too recommended and mandatory to know the characteristics of the site where you want to implement it.

These characteristics can be:

The exceptional atmospheric conditions

The snow, the dust are likely to decrease during certain periods the solar energy received by the modules. A reduction coefficient must then be applied to the data defined in the previous paragraph to take into account the particular atmospheric conditions and system maintenance conditions (frequency of cleaning, etc.)[26]

Masks

The most important cause of reduction is the masks (tree, houses ...) shading all or part of the panel during part of the day each day, or during a certain period of the year (usually the winter) [26].

3.5.1.7. Estimation of the energy supplied by a photovoltaic panel

For a given angle of inclination of the photovoltaic panel, the series of amounts of solar energy received makes it possible to estimate the electrical energy supplied by the panel on average, per day, for each month.

So, to obtain the production of the photovoltaic module during a day, we will multiply the peak power of the panel by the equivalent number of hours of this day:[43]

$$E_{elec} = N_e \times P_{peak} \tag{3.8}$$

E_{elec} : Electric energy produced during the day (Wh / day)

N_e: Number of equivalent hours (h / day)

P_{peak}: Peak power (W)

Unfortunately, this panel actually produces a much lower amount of electrical energy because:

- The panel rarely works at its optimum operating point (unless a slave adaptive electronic device is used). In particular, a panel charging on a battery almost never works at its maximum power point (16 V for a 12 V battery, but variable with illumination).
- The diodes and the connections cause energy losses.
- Disparities between modules cause energy losses.
- The maximum power point also depends on the panel temperature.

In practice it is therefore appropriate to use the following formula:

$$E_{elec} = E_{Solar} * P_{peak} * L_C \quad \textbf{(3.9)}$$

Where: E_{elec} is energy W per hour

: E_{Solar} is energy in KW per hour
: P_{peak} is a power peak in W
: L_C is loss coefficient

***3.5.1.8.* Dimensioning of the photovoltaic panel**

During the year, the sunshine is not always the same. Some days or months are very sunny while others are not. The determination of installed peak power is of particular interest, given the cost of the watt-peak. Generally, the variation of the energy provided by a photovoltaic panel of inclination given does not follow that of the energy needs of a dwelling.

If you set the peak power to best meet the needs of a given month, you usually get a deficit or a surplus for another month.

Over what period efforts should be made to match needs and inputs? An inclination equal to the latitude of the place makes it possible to capture a maximum amount of annual energy, but:

- Some of this energy may be useless; energy is expensive to store.
- The panel may be too expensive.

However, during winter times, means when the sun is low, a strong inclination closer to the vertical (latitude of the place for example +20°) favors the capture of solar energy.

3.5.1.9. Principles of sizing and positioning of the solar panel

The objective of sizing and positioning the solar panel being able to maximize the capture of solar energy, it makes use of two extreme principles that illustrate the reasoning used to confront:

- The energy the panel must provide.
- The energy that the panel can provide from sunshine

3.5.1.10. Sizing on the least sunny month

A simple and safe solution is to choose a peak power such that during the least sunny month, the energy supplied by the panel satisfies the needs, with a slope close to the latitude of the place. This is the solution generally adopted by companies marketing and installing photovoltaic systems [27].

This solution unfortunately leads to a significant waste of energy during the other periods, and especially for the sunniest period.

To reduce these losses, and thus save on the peak power of the panel, it is possible:

- Promote the exposure of the sign during the least sunny season by choosing an inclination greater than 10 to 20 ° (15 ° in general) at the latitude of the site;
- To oversize the battery by actual needs (mainly related to the possible number of sunless days during this less sunny season [28];

It is then possible to size not more on the month the sunny month, but on months a little sunnier to fill the month's deficit in the sunny month thanks to a sufficient capacity of the battery.

3.5.1.11. Sizing on the sunniest month

The peak power is sufficient to meet the needs during the sunniest month and generally quite insufficient to meet winter needs. Such sizing involves the use of a complementary source of energy. In a two-source system, it is necessary to favor the use of solar energy during the sunnier months and therefore, choose a low inclination of the modules (α = latitude -10 °to 20°). This dimensioning finds its limit in the cost of complementary energy [23].

A cost calculation (investment, operation) makes it possible to decide on the optimal solution between:

- Small panel slightly inclined and complementary source very solicited.
- Larger and more inclined panel and less solicited source.

3.5.1.12. Inter-seasonal storage of energy

It is conceivable to better adapt the solar contributions to the needs by using in winter energy stored in battery during the sunny periods. It is conceivable to better adapt the solar contributions to the needs by using in winter energy stored in battery during the sunny periods.

The long-term storage (3 to 6 months) in battery and yet practically excluded because of its cost: the capacity of the necessary battery is too important.

Furthermore:

- The charge of the battery is then delicate (it would be necessary to split the capacity or increase the current of the load).
- The panel cannot recharge the battery alone if the discharge is too deep.
- Self-discharge represents about 10% of the capacity in 3 months, that’s to say that in average, about 10% of this large capacity is installed in pure loss.

3.5.2. Sizing procedure of the solar panel:

Whatever the principle adopted, it is ultimately a question of ensuring the adequacy between the contributions and the needs for a given period (generally a given month), that is to say, comparing that the panel must provide with tables that give the energy provided by a given power panel, according to various inclinations.

3.5.2.1. Choice of operating voltage:

The availability of materials such as modules and receivers influences the choice of the rated voltage of a system. In addition, it depends on the power and energy levels required depending on the type of application.

Table 3.4:.The corresponding system voltages at each peak power interval [26].

Peak power (Wp)	< 500 Wp	500Wp - 2KWp	>2KWp
System voltage (V)	12 VDC	24 VDC	48 VDC

3.5.2.2. Sizing of the battery

This step consists in determining the storage capacity C of the battery in KWh then in Ah .The energy stock meets two needs, and the choice of capacity must also satisfy 4 constraints namely:

3.5.2.3. Role of the energy stock

- Dealing with periods with insufficient sunlight: the stock can meet the needs despite the random amount of solar energy received; in particular, it ensures the continuity of service during periods without sun (of a certain length).
- Make the best use of the solar panel: if it has not been sized in the least sunny month, the battery must fill a possible deficit during certain periods.

3.5.2.4. Battery capacity

The battery capacity is given by:

$$C=C_R+C_U \qquad \textbf{(3.10)}$$

With: $C_{R,}$ C_U respectively residual capacity and useful capacity

The residual capacity C_R is the capacity that is not used, to preserve the battery, while the useful capacity C_U, is the capacity that can be effectively discharged if necessary.

It is equal to [24] :

$$C_{U=}\,C_{1+}C_2 \qquad \textbf{(3.11)}$$

Where : - C_U is useful capacity

C_1 the ability to face the sun

The capacity needed to make the best use of panel sizing

3.5.2.5. Choice of battery capacity

It is a question of choosing C, the capacity in Ah; we can make three choices:

1- $\frac{C_U}{C}$

2- $C1$

3- $C2$

3.5.2.6. The constraints to be respected

For the choice of the capacity C, we are faced with different criteria:

The maximum discharge current (IDC max)

For a period of more than 10 to 30 seconds, the maximum discharge current must be less than $\frac{1}{10}$C [23] :

$$\boxed{IDC\ max < \frac{1}{10}C} \quad \textbf{(3.12)}$$

Where: C is expressed in Ah.

So

$$PDC\ max < \frac{1}{10}CP \quad \textbf{(3.13)}$$

The maximum power in direct current (Wh) <$\frac{1}{10}$ of stored energy

For example, for a 500 Ah battery, the maximum discharge current must be less than 50 A [24].

The maximum amount of energy taken each day (QDC max)

The sizing must take into account the maximum amount of energy taken each day. It must be at most 10 to 20% of the total capacity (depending on the type of battery) [24]:

$$QDC\ max < 0.1 \text{ à } 0.2\ C \quad \textbf{(3.14)}$$

Considering the same example as above, for a 500 Ah battery, the maximum amount of electrical energy taken in one day will be from 50 to 100 Ah.

The depth of discharge ($\frac{C_U}{C}$)

The depth of discharge, that is to say the percentage of the capacity of the battery that is allowed to take, determines its total life.

This constraint differs according to the type of battery used, the purpose of life and its mode of operation.

3.5.2.7. Charge and recharge of the battery:

From an "empty" state ($C_U = 0$), the recharge time must be such that the stock can cope with its two roles (C_1 and C_2) as needed

Where: C_U is useful capacity

C_1 is the capacity needed to cope with the sun

C_2 is the capacity needed to make the best use of panel sizing

Practically, the ideal is to ensure the charge according to the optimal procedure for the battery. However, it must be avoided in all cases that the charging current of the battery is less than $\frac{1}{50}C$.

Therefore, the current delivered by the panel will partially serve to recharge the battery [1]:

$$IPV=IU+ICH \quad \textbf{(3.15)}$$

Where: IPV is the current charged by the panel

: IU is the current used by occupants

: ICH is the charging current

3.5.2.8. The choice of C1 capacity

It is based firstly on an estimate of the maximum number of consecutive days in which the overall radiation is very low, that is to say days without sun or duration of sunshine less than the hour. Long "no sun" periods usually occur in winter or during the rainiest months. Moreover, in each period without sun the demand for electrical energy is directly addressed to the battery. For a period without a sun of K consecutive days

$$CS_K=K\times Bi \quad \textbf{(3.16)}$$

Where: CS_K is total energy demanded from the battery

K is the number of days without sun

Bi is the electrical energy required per day from the battery

3.5.3. Sizing of the inverter:

To set the nominal power of the inverter, it is necessary to estimate:

- The maximum probable load for duration greater **than 10 - 20 minutes**: the charges of short durations are not taken into account.
- The maximum instantaneous load: it is generally equal to 04 times the power of the most powerful engine that the inverter will have to start.

They must be able to provide the probable maximum load for a period of more than 10-20 minutes continuously and the maximum load for a few seconds. These two values are well known to manufacturers [29].

Maximum power must be as low as possible to minimize losses at low or no load, especially if the inverter is to operate continuously.

If the nominal power is calculated as accurately as possible, the inverter circuit breaker will trip from time to time. For an average dwelling, the inverter has a nominal power between ***0.5 and 2.5 KVA,*** depending on the system chosen (average value 1.8 KVA) [29].

3.5.3.1. Sizing of the connection cables:

Most photovoltaic systems operate at low voltage (12 to 48 V DC) and relatively high current. However, the losses in lines are proportional to the square of the intensity RI^2 where R is the resistance of the considered cable).

Whether it is the cable that connects the panel to the battery, or the one that connects the battery to the devices, the section must be calculated to limit line losses. These must be low compared to the power actually transmitted by the line, if possible lower than 04 or 05% of this power.

$$R = \rho \frac{L}{S} (\Omega) \quad \textbf{(3.17)}$$

Where: R is the resistance of the cable

L is the length of the cable

S is the cross-section of the cable

ρ is the resistivity of the cable

3.5.3.2. The battery panel electrical connection

For example, consider an installation supplying a 12 V nominal battery from a 12 V / 160 W panel power peak.

It is a question of calculating:

- The section of cable allowing to limit to 0, 48 V (4% of the nominal tension)
- The maximum voltage drop in the connecting cable,
- The panel and the battery being distant of approximately 15 meters.

The maximum current that will be delivered to the battery is therefore of the order of 10A (maximum 160 W) at an optimum voltage of about 14 V.

The resistivity of the copper is $1.8.10^{-8}\ \Omega\ /\ m$.

If ΔU max is called the maximum voltage drop, it is written as a function of the current I max:

$$\Delta U\ max = R \times I\ max \qquad (3.18)$$

R, I max being respectively resistance and the maximum current.

The resistance R is a function of the constituent parameters of the cable according to the formula:

$$R = \rho \frac{L}{S} \qquad \textbf{(3.19)}$$

$$The\ resistance = \frac{[resistivity(\Omega.m) \times length\ of\ cable(m)}{section(m2)}$$

From where: $$R = \frac{\Delta Umax}{Imax} = \rho \frac{L}{S} \qquad (3.20)$$

This allows determining of the cable section S:

$$S = \frac{Imax}{\Delta Umax} \times \rho l \qquad \textbf{(3.21)}$$

In the treated example S = 11.25 mm². It is therefore necessary to use cable of cross section at least equal to 12 mm². The section of the cable quickly becomes very important and therefore its price too. It is therefore necessary to make a compromise between a reasonable cost of the cable, and losses in line (so as not to over-size the panel).

3.5.3.3. The battery-appliances electrical connection

DC distribution:

The same calculation must be made for the section of the cable between the battery and the different devices to be powered.

It must take into account the design of the distribution: in the case of a single output of the battery, the devices are connected in parallel.

While in the case where the battery has several outputs (models that exist on the market), each of these outputs is connected to a device or series of devices. [6]

The total wiring is often longer, but the maximum current in each of the circuits is less, resulting in a smaller section, and ultimately a lower price.

Distribution from an inverter:

From this stage, alternating current 220 V is distributed. The distribution is then quite conventional, which means that the rest of the distribution process can be assimilated to other forms of distribution of the electric current, for example the processes used in the distribution of hydroelectricity

3.6. Method of designing and sizing large pv plants

For very large photovoltaic plants, a big difference can be seen in relation to the small individual photovoltaic plants mentioned above. For small photovoltaic plants, all the electrical energy produced is consumed at the same place of production, which is not the case for very large photovoltaic power plants whose electrical energy is supposed to take long distances to the places of consumption. The large photovoltaic plants are supposed to produce huge amounts of energy which are then injected into the electrical networks.

As for small photovoltaic plants, the implementation of very large photovoltaic plants requires a feasibility study and this time a study too deep than that made for small photovoltaic plant due to the components as huge and rigorous as for the previous cases. However, the steps of the reasoning remain almost the same in terms of sizing except that here we have to deal with huge quantities of components, namely the high number of solar panels, batteries, inverters, regulators, controllers; to name just that. When the PV generation is in excess of the real time local demand, the excess power is stored in batteries; if the batteries are also fully charged, the excess power is fed to the utility grid through a grid-connected inverter.

It should be noted that the largest photovoltaic installations can reduce the cost of the photovoltaic installation per watt of rated power installed[30] and that large-scale PV plants are composed of several thousands of PV panels, each being in the range of 150–350 W. The optimal values of the PV plant location, size, and time of investment, which comprise the optimization problem decision variables, are calculated such that the net present value of the investor’s profit is maximized [30].

The financial analysis of a large-scale PV plant is performed by calculating the expected power generation of the PV plant using an appropriate model of the PV modules and considering the capital investment cost, the annual operating and maintenance costs, and the performance derating factor of the PV system. Also, the internal rate of return and payback time period are used as metrics in order to explore the profitability of the PV installation.

However, both the cost of energy losses due to transformer overloads and efficiency, and the capital and lifetime operating costs of the transformer are considered during the design process. The impact of energy losses due to grid instability is also taken into account.

The effects of partial shading, PV module mismatch, cable losses, and power converter efficiency are also quantified in order to obtain the energy yield of the PV plant for each of the architectures under study.

Therefore, more sophisticated architectures have been developed where PV modules are arranged in strings, or even substrings, each one connected to the step-up transformer through a dedicated inverter, or a dedicated DC/DC converter and a centralized inverter. Conventional distribution transformers are widely used, either singly or paralleled, to connect the inverter to the main power line. The step-up transformer is a key element of a PV system, as it processes the whole generated energy.

Moreover, not only the efficiency and the cost are of primary concern, but also the influence of the transformer size either on the amount of energy delivered to the main utility, either on the stability of the network

In fact, while selecting a transformer rated power close to the PV plant peak power makes theoretically possible to fully transfer the captured solar energy to the utility network, such a design criterion will in practice lead to oversize both the transformer, the inverter and the power line. Moreover, a too large transformer would operate for long times at a reduced efficiency, while generating a largely unpredictable power injection on the main grid [6-9]. The last may lead to grid instabilities, causing frequent plant shutdowns, and requiring a remarkable reserve power to be provided by conventional generators. On the other hand, a too small step-up transformer would constitute a bottleneck, preventing an optimal exploitation of the solar energy.

3.6.1. Determination of the number of batteries for a photovoltaic solar power plant

For a solar photovoltaic installation, the use of batteries is an obligation. Indeed, to make electricity available every moment even during the night or when the sun is sailed, there must be a system of storage of the energy produced and this is possible thanks to the batteries. The objective being to be optimal in the production of the electrical energy, the number of batteries to be used must be determined on the basis of calculations.

Before you start:

- The energy that the installation will consume each day must be known.
- Know at least the voltage (usually 12V) and the capacity (often 50, 100 or 200Ah) of the batteries you will use. You can also do the math with several types of batteries and choose the most economical solution.

3.7. Applicatıon

As we have already determined, sothat households have the living standards that meet the Millennium Development Goals, a daily energy consumption of a modern neighborhood should be 383500 watts-hour/day.

The following example of a photovoltaic power station can be used to provide electricity in about 8 neighborhoods with 100 modern households each one.

Suppose we want to implement a photovoltaic plant that provides 3MWh / day and we choose to use 24V batteries of 200Ah capacity.

3.7.1. Determination of the desired autonomy

The storage capacity needed depends essentially on 2 parameters: the energy consumed per day and the autonomy of the system, that is to say the number of days that it will be able to support without sun. Autonomy generally varies between 3 and 15 days.

The number chosen depends on two factors:

- Weather conditions in the region where you are: are there periods of prolonged bad weather? If so, how many days can it last?
- The reliability you want for your system: Do you accept that power can be cut? If so after how many days without sun?

$$\boldsymbol{E_{ft}} = D_n * A_u \qquad \textbf{(3.22)}$$

Where: E_{ft} is the amount of energy consumed by your facility during the given time

D_n is the daily need

A_u is the autonomy

Given the region we are in, we can distinguish the days when the weather is bad.

So let us choose a higher autonomy to ensure the continuity of the activity: between 5 and 7 days

We therefore choose a weak autonomy, here 5days and then we get

$$3\text{MWh} \times 5\text{days} = 15\text{MWh}$$

Add losses

The electricity that comes out of the batteries does not come fully to your electrical devices: part is lost in the wires and during the continuous-AC conversion by the inverter. The amount of energy that will have to be returned by your batteries is therefore:

$$E_{Rb} = E_C \,/(1\text{-losses in line}) \qquad \textbf{(3.23)}$$

Where:E_{Rb} the amount of energy that will have to be returned by your batteries

E_C is energy consumed

If you do not know the loss values, you can use these average values:

Inverter efficiency = 0.9

(1 - Losses in line) = 0.97

Our installation must supply AC equipment, so it uses an inverter. The amount of energy to be returned is:

$$3/(0.9 \times 0.97) = 3.436\ MWh$$

However, given the maximum depth of discharge of the batteries, the batteries must not be deeply discharged to allow them to have a longer life: It is necessary to set a maximum depth of discharge. In general this depth varies from 30 to 80%. A good intermediate value is 50%, that is, you will only use half the capacity of your batteries.

For this example we are dealing with, the capacity of your batteries should therefore be:

$$C_B = E_R / Max_{dd} \quad \textbf{(3.24)}$$

Where: C_b is the capacity of the battery

E_R is the energy to be returned.

Max_{dd} is the maximum depth of discharge

For our installation we take a maximum depth of discharge of 50%, the capacity of the batteries must therefore be:

$$3.436 MWh/0.5 = 6.872\ MWh$$

3.7.2. Deduce the number of batteries

To change from a number in MWh to a number of batteries, multiply by 1000000 (to convert MWh to Wh) divide by the voltage at the battery terminals (to convert the Wh to Ah) then by the capacity of the batteries (in Ah) and round up to the next digit.

Example:

We use batteries whose voltage is 24V and the capacity 200Ah:

6.872MWh x 1000000 = 6872000 Wh

6872000/24 = 286333.333Ah

286333.333/200Ah = 1431.666

So we need 1432 batteries of 24V

3.7.3. Calculating total Watt-hours per day needed from the PV modules

After carefully calculating the electrical energy consumed by each device connected to the system, calculating the total number of watt hours requested from the photovoltaic modules becomes simple. Simply add up the total energy consumption of each device connected to the system without forgetting to add all the probable losses.

The formula for calculating

$$E_{Pm} = \Sigma\, E * 1.3L_t = \Sigma\, (P*t)*1.3L_t \qquad (3.25)$$

Where: E_{Pm} is a total watt hour from the photovoltaic modules

$\sum E$ is the sum of the amount of energy consumed by each device in the system

L_t is the total losses that could happen in the system installations

t is working time per day.

3.7.4. Sizing of the PV modules

Photovoltaic modules produce different amounts of power depending on whether their size and the material from which they are manufactured differ. Indeed, before pretending to know the sizing of the photovoltaic module, the determination of the total requirements in watt peak to be produced is an obligation. However, the power peak (Wp) produced is considerably influenced by the size of the photovoltaic module as well as the climate of the photovoltaic plant's location.

For this, given the variation of the climate and the location of the photovoltaic site concerned, we must consider the "panel generation factor" which is different in each site to reduce the risk of being wrong. It should be noted that this panel generation factor of the photovoltaic module is determined experimentally according to the region concerned. For example, the panel generation factor for Thailand is 3.43.

To determine the sizing of PV modules we may proceed as follows**:**

3.7.5. Calculating of the total Watt-peak rating needed for PV modules

During this step, the total peak power required for the PV panels must be determined to ensure the operation of the devices.

To do this, simply divide the total daily peak power of the site

(watts-peak / day) by the generation factor of the photovoltaic panels (add mathematical equation).

$$\mathbf{P_{Rp}} = \frac{\mathbf{P_{Wpd}}}{\mathbf{PV_{Gfp}}} \quad \textbf{(3.26)}$$

Where: P_{Rp} is the Rated Peak Power, P_{Wpd} is the daily peak power (watts-peak/day) and PV_{Gfp} the generation factor of the photovoltaic panels

3.7.6. Calculating of the number of PV panels for the system

A block diagram of the large PV plant that is considered in the proposed optimization process is illustrated in Fig 3.4. The PV modules are distributed in multiple PV inverters, and the generated power is injected into the electric grid at the point of common coupling (PCC) through an interconnection transformer and cable, respectively. The total number of PV modules which must be installed in the PV plant $\boldsymbol{N_{I,O}}$ is calculated according to the PV plant power rating $P_{plant, nom}$ (MW p) that is specified by the PV plant designer, as follows:

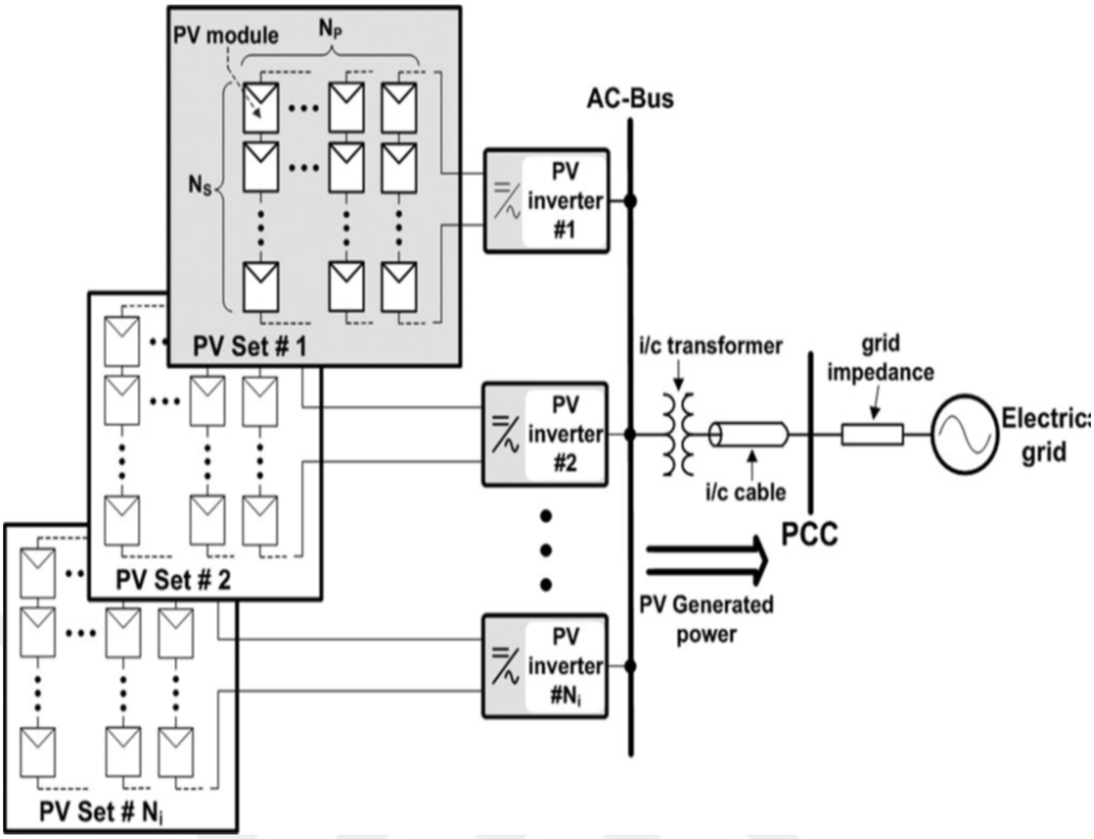

Figure 3.4: Block diagram of the large PV plant [31].

$$: N_{I,O} = \frac{P_{Plant,nom}}{P_{M,STC}} . 10^6 \quad (3.27)$$

Where :$P_{M,STC}$ (W) is the power rating of each PV module.

:$N_{I,O}$ The total number of PV modules

As shown in Fig. 3, the PV modules of the PV plant are distributed in PV sets, and each PV set is connected to a PV inverter. Each PV set consists of N_p PV strings ($N_p \geq 1$), while each string is comprised of Ns PV modules that are connected in series (Ns ≥ 1). The minimum and the maximum number of PV modules which can be connected in series in each PV string, Ns min and Ns max, respectively, are calculated according to the PV inverter dc input maximum power point (MPP) voltage level Vi, max (V) and the maximum permissible dc input voltage level, VDC, max (V), both specified by the PV inverter manufacturer, as it has been shown by different authors who worked on it such as: [38,39,40,41,42,43]

3.8. Transmission and distribution of electrical energy

After the operations of estimating the electrical energy to be produced in a photovoltaic power plant, after having minutely sized and implanted it, it is the time to transmit and distribute the electrical energy which, sometimes, must make long distances to reach the places of use. However, the types of electric transmission lines and the amount of electrical energy they transmit are determined according to the distance to be traveled.

During the transmission of electrical energy, the efficiency is better when this transmission is at high voltages. The greater the distance to which the electrical energy must be sent, the higher the electrical voltage in the transmission lines.

The use of these high voltages is linked to an economic objective. Indeed for a given power, the Joule line losses are inversely proportional to the square of the voltage:

$$P = {}^{K}/_{U^2} \qquad \textbf{(3.28)}$$

With: U = network voltage,

K = a constant function of the line.

In addition, the powers transported are such that the use of a low voltage would result in completely inadmissible cable sections.

Also, by taking into account the mathematical formulas of power as a function of voltage, current and resistance, we can admit the following statements:

$$P = UI \qquad \textbf{(3.29)}$$

$$U = RI \qquad \textbf{(3.30)}$$

$$I = U/R \qquad \textbf{(3.31)}$$

$$R = \rho \tfrac{L}{S} \qquad \textbf{(3.32)}$$

By replacing equation (3.30) in equation (3.29), we obtain

$$P = RI^2 \qquad \textbf{(3.33)}$$

Also by replacing equation (3.31) in (3.33), we obtain the new expression of power as

$$P = \frac{U^2}{R} \qquad \textbf{(3.34)}$$

Equation (3.32) in equation (3.34) gives as result

$$P = \frac{U^2}{\rho L} S \qquad \textbf{(3.35)}$$

With: P power to be transmitted

U The voltage in the transmission line

I the current

S the line section ρ the coefficient of line resistivity

From eqauation (3.35) we derive that the electric power transmitted by an energy transmission line is directly proportional to the product of the square of the voltage in line by the section of the line of the transmission; and is inversely proportional to the product of resistivity of the conducting wire by the length of the transmission line.

Equation(3.28) shows that joule losses decreasing very highly by voltage increasing.

We also note that during the transmission of electrical energy, the electrical current does not interest us; we focus to the voltage which must be raised according to the distance to travel in order to maximize the efficiency of the transmission line.

The use of high voltages is therefore imposed despite the isolation constraints that translate into higher hardware costs, the easiest solution being the use of overhead lines.

In any case, the choice of a transport voltage is above all a technical-economic compromise, depending on the powers to be transported and the distances to be covered.

The line losses are mainly due to the Joule effect, which depends only on two parameters: the resistance and the intensity of the current. The loss is given by the following relation: $P = RI^2$

The use of the high voltage makes it possible, with equivalent transmitted power (P = U.I), to reduce the current and therefore the losses.

Moreover, to reduce the resistance, at industrial frequencies, there are only two factors, the resistivity of the materials used to manufacture the transmission cables, and the section of these cables. For material of manufacture and equivalent section, the losses are therefore equal, in principle, for overhead lines and for underground lines [33].

Generally, the height of the pylons on which the electric cables of High-Voltage Line are suspended depends on the voltage to be transmitted. The more we have the voltage of the high line, the more we have the pylons which are high. A pylon supporting a line of 400 000 V can reach 90 m high [33].

However, the electrical energy is not used as it is transmitted at very high voltages. It must be lowered to be adapted to the different electrical appliances and machines that use it at low voltage (most often 220 -380V).

It should be noted that this operation of raising or lowering the electrical energy to obtain very high voltages, high voltages, averages or low voltage is possible thanks to the elevating or lowering transformers of the electrical energy.

Thanks to the Generator Step Up Transformer, the electrical energy produced is stepped up to high electrical voltages before traveling the distances to the various locations where it will be used. However, the electrical energy transits very high voltage lines to the low voltage ones thanks to Substation Step-Down Transformers. This step is the electrical distribution where customers receive electrical energy that they use according to their needs.

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

This thesis has been focused on Burundi's energy system. This small country of East Africa belongs to several economic communities. Due to its geographical location, Burundi has huge potential hydroelectric and large solar irradiation. However, despite all these assets, Burundi has a large lack of energy and continues to rank among the poorest countries in the world. In addition to being unevenly distributed, the burundian population is growing rapidly.Most Burundians live in the most remote areas.This is at the origin of a low rate of connectivity to the national power grid.

Indeed, to try to find a solution to this problem related to the lack of electrical energy, a deep analysis of the energy system of Burundi was done. This implies a brief history of Burundi, its geographical situation and its socio-economic context.

After this analysis, the finding was that the access to the national electricity grid is characterized by:

- Very low access to electricity:less than 5% of burundian people has accessto electricity. [7]
- Demand is so much higher than supply [8]. The population use firewood as the main source of energy for most artisanal or industrial thermal activities (brick making, bread making, etc.). The use of firewood is also the main fuel that the vast majority of the population uses for cooking.
- The supply of firewood covers only 2/3 of demand and deforestation following the search for firewood has accelerated.

Thus, given the geographical location and population growth of Burundi, the exploitation of renewable energy sources, in particular solar energy, has been considered in this thesis as a better solution to this lack of energy.

Indeed, an inventory of the daily energy consumption for a household and for a village or modern neighborhood was done as showen on table 3.1

Afterwards, a summary table of the different energy consumptions by categories of consumers meet in Burundi was done in order to establish how much will be the energy consumption in Burundi according to the period considered as showen by table 3.2

To meet at least the needs of different subscribers in electricity and to give access to electricity to as many Burundians as possible, an installed electrical power estimated at **345.7 GWh** could be implemented by 2023 while the estimated power of **617.9 GWh** could be installed for 2032**.** Going beyond, a nearby installed electrical power of **1234.2 GWh** could be implemented by 2045.

A photovoltaic plant that provides 3 MWh / day can supply electricity to about 8 neighborhoods, with 100 households each.

4.2. Recommendations

For a good implementation of the results obtained during this thesis, a series of recommendations has been formulated with regard to the Government of Burundi, to the economic operators working in Burundi, to the private as well as to the burundian researchers.

a) The government of Burundi:

- Try to harness as much as possible the energy potential of Burundi namly the huge available hyroelectric and photovoltaic energy resources.
- Update the national electricity grid in order to eradicate line losses during the transmission of electrical energy. These line losses are estimated at around 24%.
- Open up the energy field to different operators and economic partners so that there is competitiveness in energy production in Burundi.

- Encourage tree planting and forest protection to improve the production of firewood, which the supply is less than demand.

b) The economic operators working in Burundi:

- Become accustomed to energy self-sufficiency, especially through the technique of free energies such as the flywheel, bagasse as fuel and others.
- Invest in this energetic field which is considered as the engine of all economic development

c) Privates and households

- The private as well as the households who have the financial means are begging to implement micro solar photovoltaic in order to supply electricity and can be fed to the neighbors who do not have financial means.
- Have the habit of using energy saving devices to reduce daily consumption.
- Use improved stoves for cooking to minimize the demand for firewood.

d) The Burundian researchers.

- In addition to being very interesting, the energy field is a key area in development especially for developing countries like Burundi. I would be not logical if I said that all the cases of possible enhancement of energy in Burundi have been studied throughout this work. In the same way, other researchers should deeply investigate on other kinds of Renewable energy resources that should make Burundi to eradicate the Lack of energy and then allow too many Burundians to have access to the national electric Grid.

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