STUDIES ON SOLAR AND WIND HYBRID RENEWABLE ENERGY SYSTEM AND TO ANALYZE ITS PERFORMANCE FOR OPTIMIZED POWER OUTPUT

A Thesis Submitted towards partial fulfilment of the requirement of the Requirement for the degree

OF

MASTERS OF TECHNOLOGY

In

ENERGY SCIENCE AND TECHNOLOGY

Course affiliated to Faculty of Engineering & Technology

Under

Faculty of Council of Interdisciplinary Studies Law &Management

Jadavpur University

Submitted by

SOUVIK KHAN

[Exam Roll No. M4ENR19017]

[Class Roll No. 101630601012]

[Reg. No. 107953 of 2009– 2010]

Under the Guidance of

Prof. Ratan Mandal

School of Energy Studies

Jadavpur University

Kolkata 32

India

2019

CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "***Studies on Solar and Wind Hybrid System Renewable energy system and to analyze its performance for optimized power output*** " has been carried out by Souvik Khan in the partial fulfillment of the requirements for the degree of the Master of Energy Science and Technology from Jadavpur University, Kolkata is recorded as bona fide work that has been conducted under the supervision of Dr. Ratan Mandal. The contents embodied in the thesis have not been submitted to any other university for the award of any degree or diploma.

Dr. Ratan Mandal
Thesis Supervisor
School of Energy Studies
Jadavpur University
Kolkata – 700032

Dr. Ratan Mandal
Head of Department
School of Energy Studies
Jadavpur University
Kolkata – 700032

Dean
Faculty of Council of Interdisciplinary Studies Law &Management
Jadavpur University
Kolkata – 700032

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The foregoing thesis is hereby approved as a creditable study of an engineering subject and presented in a manner satisfactory to warrant acceptance as pre requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn there in but approve the thesis only for which it is submitted.

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I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his Master of Energy Science and Technology. All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

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Name: Souvik khan

Roll Number: 101630601012

Thesis Title**: *"Studies on Solar and Wind Hybrid System Renewable energy system and to analyze its performance for optimized power output"***

Signature:

Date:

ACKNOWLEDGEMENT

This thesis would not have been possible without the guidance and the help of several individuals during the preparation and completion of this study.

First and foremost, I would like to show my sincere and utmost gratitude to my supervisor ***Dr. Ratan Mandal, Associate Professor, School of Energy Studies, Jadavpur University, Kolkata, India*** for his kind and valuable advices during the completion of this research work.

I am grateful to my juniors, seniors and staffs in the Department of Energy Science and Technology, Jadavpur University, Kolkata, India for their kind cooperation and moral support.

It would be incomplete if I do not mention my affable gratitude and thankfulness towards my family especially to my parents without whose constant support and enthusiasm this thesis would not have been completed.

Souvik Khan
Department of Energy Science and Technology
Jadavpur University
Kolkata – 700032

Date:

DEDICATED TO

MY PARENTS,

FAMILY AND FRIENDS

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Abstract

The power supply at remote places at this era is a great challenge to us due to the environmental hazard. This paper relates to the optimization of an integrated hybrid system (solar Photovoltaic and Wind integrated). We need so many components regarding our experiment such as wind turbine (maximum power output is 400 W), solar photo-voltaic system (consisting of three panels), batteries etc. Our motive of the experiment is to find a suitable place on earth where we can get both solar and wind energy simultaneously. Normally in hilly areas we generally get both sunrays as well as wind but the only burden is the hills that means the installation of the integrated system results a high costing priority. Along with that if we consider any sea-shore there also we can get the sunrays as well as the wind flow. Moreover, if the tidal energy comes into picture then it is more efficient to install a hybrid system at sea-side rather than that of hilly areas.

We are regularly fed a certain amount of load connected to the batteries and check the performances of the charge stored in the batteries. On the basis of performance of the battery we can have an idea about the efficiency curve given by the manufacturer. And after that we can go to a conclusion about batteries that the charging and discharging phenomenon are occurred satisfactorily.

We fed an electrical load nearly equal to 520W for a certain time and draw the load curve from where we can get the number of units used to drive the system. Actually, these are the additional information regarding the experiment. Normally we need to optimize the system by taking all readings of battery voltage, current coming from the solar panel, current coming from the wind turbine in a sunny day and at night and need to find the time at which we can get maximum rate of charging the batteries.

In Jadavpur University, there are so many burdens on the way of wind speed and as the weather is too dusty here and for that reason, we are unable to get proper results of the experiment. The optimization needs proper results and proper weather condition to get the maximum power output (i.e. discharging of batteries) and as well as charging the two batteries.

Chapter 1

INTRODUCTION

1.1 Energy and its classification:

Energy, a great concern nowadays, is one of the most important factors in all type of progress of any country. Here, in the developing countries (rarely called third world countries), the energy sector assumes a keen importance to the financial investments regarding the increasing power to meet them.

Energy can be classified into several types based on the following criteria:

- Primary and Secondary Energy
- Commercial and Non-commercial Energy
- Renewable and Non-renewable Energy

1.1.1 Primary and Secondary Energy:

Primary energy sources, one type of energy, which are either found or stored in nature or in any natural substances. The most common primary energy sources are coal, oil, natural gas, and biomass. Coal is found in the nature in four different types depending on their efficiencies. Other primary energy sources are like nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to gravity etc. Primary energy sources are generally converted in industrial purpose into secondary energy sources like steam (temperature more than 100^0C) or electrical energy.

1.1.2 Commercial and Non-commercial Energy:

There are so many energy sources that are available in the present market for a constant price are known as commercial energy. The most important form of commercial energy are electrical energy, coal and refined petroleum products (which are in an endangered condition). The formation of commercial energy on the basis of the agriculture, transport, industrial and commercial development nowadays. We can see the examples of commercial energy are Electrical energy, lignite, coal, oil, natural gas etc. There are so may energy sources which are not available in the commercial market at any price are named as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung an agricultural waste and not bought at a price used especially in rural households that is to the remote area. Examples of non-commercial energy sources are Firewood in rural areas; solar energy for water heating, electricity generation, fish and fruits animal power for transport, threshing, lifting water for irrigation, crushing sugarcane; wind energy for lifting water and electricity generation.

1.1.3 Renewable Energy or Non-Conventional Energy:

Renewable energy is a special form of energy discussed in modern era which is obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power. The most important feature of renewable energy is that it can be installed without the any release of harmful pollutants. Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time. Actually, the renewable energy has a very large scope of future work because the raw material for the system is infinite in amount.

1.2 Global Energy Scenario

For 2017, global country level production data is preliminary and restricted to fossil fuels. Based on these data, production growth of fossil fuels increased after two years of decrease (+1.9% - Figure 1) [13]. This was driven by a surge in coal production after two years of decrease (+3.1% in 2017, -5.9% in 2016, -2.3% in 2015) [14]. Natural gas production continued to grow and at a higher pace (more than twice the 2016 growth rate, +3.6% in 2017). Crude oil production was fairly stable in 2017 (-0.2%), as opposed to +1.4% in 2016[15,16]. The increase in coal production was particularly strong in many regions: China (+54 Mtoe, +3.1%), OECD countries (+23 Mtoe, +2.8%) and other non-OECD Asia countries (+23 Mtoe, +3.9%). Natural gas production increased in all regions in 2017, particularly in non-OECD Europe and Eurasia (+42 Mtoe, +5.8%) and OECD (+25 Mtoe, +2.3%). As for crude oil, growth in OECD and Africa (+2.5% and +5.1% respectively in 2017, +47 Mtoe combined) [18] was offset by a decline in the Middle East, non-OECD Americas and non-OECD Asia including China (-1.4%, -3.9% and -3.6% respectively, so -51 Mtoe combined). The remainder of the article looks at the detail of 2016 world production and use, and 2017 OECD supply. World energy production was 13 764 Mtoe in 2016 - 0.3% [19] less than in 2015. Oil, natural gas and nuclear all grew at the same pace (+1.4%), setting new records in many countries. Fossil fuels accounted for 81% of production - a 0.6 percentage point decrease compared to 2015. Growth in oil and natural gas was entirely offset by the coal production's sharp decline for the second year in a row (-5.9% in 2016, after -2.3% in 2015),[20]

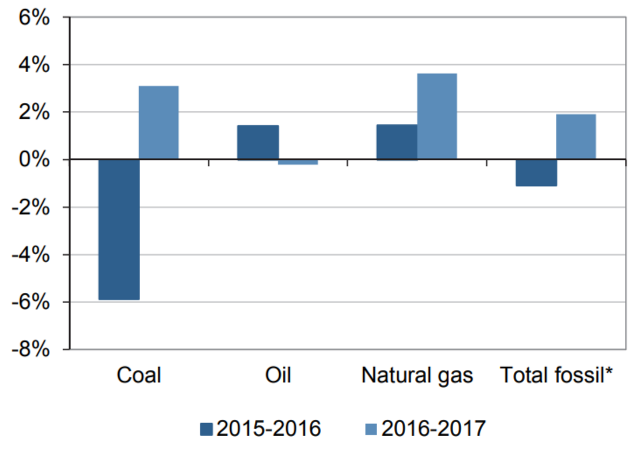

Figure 1. 1. Annual average change in global fossil fuels production by fuel

after 15 years of continuous growth. Together the production of these three fossil fuels decreased by 1.1% in 2016 (Figure 2).

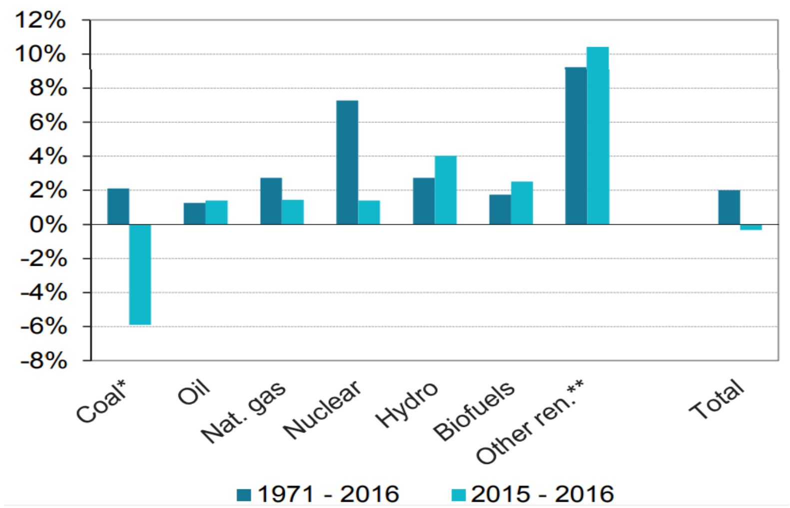

Figure 1. 2 Annual average change in global energy production by fuel

Among non-fossil sources, biofuels and waste slightly increased their share of the world energy production in 2016 (9.8% compared to 9.5% in 2015) [22], with reviving growth (+2.5% compared to +1.1% in 2015, +0.9% in 2014). Hydro sharply increased in 2016 (+4.0%) after having been flat in 2015 (-0.03%) due to comparatively bad weather conditions in some regions and the first decline in global production since 1989. Nevertheless, hydro provided 2.5% of global production in 2016, not much more than in 2015 (2.4%) [23]. Other renewable sources such as solar PV, wind, solar thermal, geothermal, kept on expanding at a fast pace (+31.1%, +14.2%, +3.2%, +4.0%, respectively) but still accounted for less than 2% of global primary energy production together. Finally, nuclear kept constant in 2016 compared to 2015, both in terms of its share of energy production (4.9%) and growth (1.4%) [23]. At a regional level, the OECD was the largest energy producing area just ahead of non-OECD Asia1 in 2016 as in 2015

(Figure 3). OECD economies produced 30% of global energy, whereas non-OECD Asia accounted for 28% (respectively 30% and 29% in 2015). Though production decreased in both regions (-2.4% in OECD, -2.7% in non-OECD Asia), they

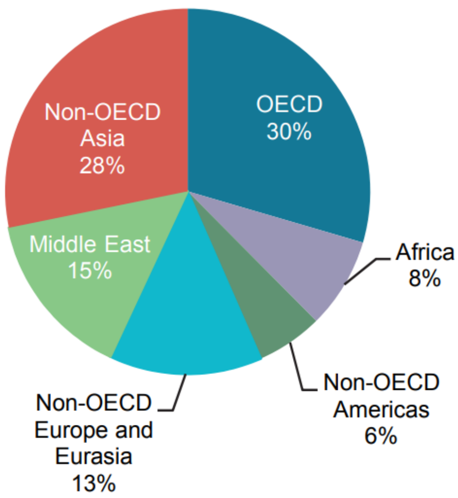

Figure 1. 3 Total production by region 2016 [16]

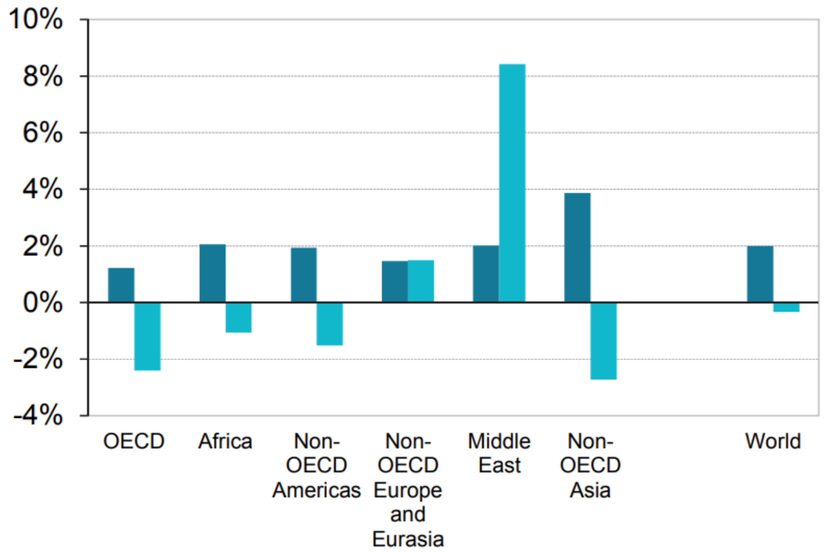

Figure 1. 4 Annual average change in energy production by region [17]

still each produced around 4 000 Mtoe, double the amount produced by the Middle East, the third biggest producing region (+8.4% in 2016 - Figure 4). The United States remained the biggest energy producer in OECD by far in 2016, with 1 915 Mtoe [23], even though its production fall was the largest in volume terms in the region (- 107 Mtoe). The decrease of the US production in 2016 was not offset by growth in Canada, Australia and Norway (+ 17.3 Mtoe together), respectively second, third and fourth biggest producers in OECD. Energy production grew in 20 of the 35 member countries of the OECD. OECD countries produced 4 064 Mtoe of energy in

2016. In non-OECD Asia, energy production significantly decreased (-2.7%), at 3 881 Mtoe in 2016,[24] in the wake of a strong decrease in China (-6.1%), that was not compensated by increases in the two next bigger producers India (+3.6%) and Indonesia (+1.9%). In China, energy production in 2016 amounted to almost 2 400 Mtoe (-6.1%)[25], the decline in coal production (-8.7%) and crude oil (-6.9%) being only partly compensated by growth in natural gas, hydro, nuclear and power renewables productions (+1.7%, +4.3%, +24.9%, and +18.2% respectively). In India, energy production increased by 3.6% in 2016, due to increases in coal (+2.9%) and biofuels and waste (+6.6%) [26]. In 2016, the Middle East ranked third, with 2 043 Mtoe of energy produced. Production of energy in the Middle East grew by 8.4%, following an increase of crude oil production in the top producing economies. With 1 862 Mtoe, non-OECD Europe and Eurasia produced 1.5% more energy in 2016 than in 2015. Africa produced 1 107 Mtoe in 2016, non-OECD Americas 806 Mtoe, a -1.1% and -1.5% decrease respectively. The IEA family (IEA member economies, Association and Accession countries) represented 53% of the global energy production in 1971[27], and 58% in 2016. Energy production is not evenly distributed across countries: for each fuel, less than five countries generally account for more than half of global production. China was not far from producing half of the world coal in 2016, and 29% of hydro. The United States and France combined produced almost 50% of all nuclear. Saudi Arabia, The Russian Federation and the United States contributed slightly less than 40% [25] of the world crude oil – these last two also accounting for 40% of the world natural gas.

1.2.1 Total Primary Energy Supply (TPES)

Between 1971 and 2016, world total primary energy supply (TPES) increased by almost 2.5 times (from 5 523 Mtoe to 13 761 Mtoe) [26] and also changed structure somewhat. While remaining the dominant fuel in 2016, oil fell from 44% to 32% of TPES. The share of coal has increased constantly between 1999 and 2011, influenced mainly by increased consumption in China: in 2011 it reached its highest level since 1971 (29%), peaking at 71% of TPES in China. It has declined since then and represented 27% of world TPES in 2016 (one percentage point less than in 2015). Meanwhile natural gas grew from 16% to 22% [30] and nuclear from 1% to 5%. Energy demand has evolved differently across the regions between 1971 and 2016. The OECD's share of global TPES fell from 61% in 1971 to 38% in 2016. It is now almost on par with non-OECD Asia, where energy demand grew seven-fold, and whose share of TPES almost tripled over the period. Though its share of global energy demand halved between 1971 and 2016, non-OECD Europe and Eurasia remained the third biggest energy consuming region, with more than 1 100 Mtoe TPES [31]. It was followed by Africa, where energy demand over the period has multiplied by four, reaching 820 Mtoe. Between 2015 and 2016, global TPES growth accelerated again, compared to the previous year: it increased by 89 Mtoe (+0.7%), reaching 13 761 Mtoe in 2016. During 2016[30] TPES increased mostly in non-OECD Asia excluding China, Africa, and non-OECD Europe and Eurasia (+3.3%, +2.7% and +2.4% respectively) [33]. It decreased by 1.7% in non-OECD Americas, by 1.1% in China, and was fairly stable (+0.1%) in OECD (Figure 5). The IEA family group accounted for 73% of TPES in 2016.

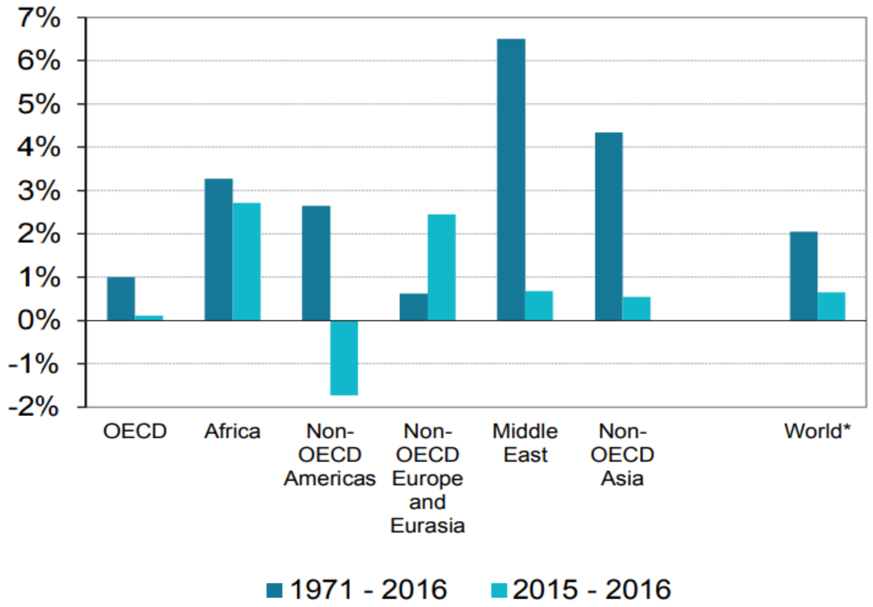

Figure 1. 5 Annual average change in TPES by region [161]

In 2016, the top five countries in terms of TPES accounted for less than half of the world GDP2, and world population (48% and 44% respectively) but consumed 52%[23] of total world energy. However, the relative shares of GDP, population and TPES of these five countries significantly varied from one to another However, energy intensities differed significantly. To produce the same amount of wealth, as measured by GDP in PPP, the Russian Federation consumed 2.6 times as much energy as Japan (the country with the lowest energy intensity of the five top energy consumers), and twice as much than India, in 2016[24]; naturally such comparisons reflect the importance of specific industries in each country. Though still dominant, power generation from coal has

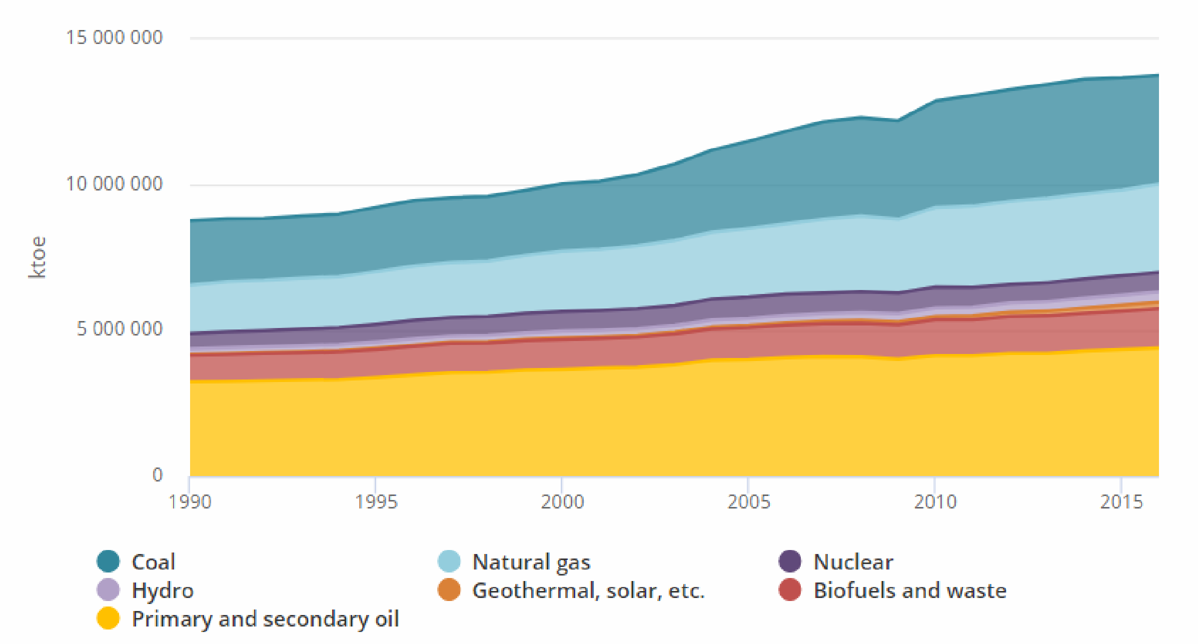

Figure 1. 6 Total Primary energy supply (TPES), World 1990 – 2016[18]

been decreasing for the three last years, reaching 38.4% of the electricity produced globally in 2016, its lowest share since 2001. Generation from gas grew slowly to reach 15% in 1990; since then steady increases have seen it grow to 23.2% in 2016[25]. This is a slightly smaller share than renewables (24.2%) which initially was dominated by hydro, but recent growth has come from the development of wind and solar PV. Nuclear production had steadily increased in the 1970s and 1980s, before plateauing at around 17% of electricity production and then declining since the 2000s to reach approximately 10%. Power production from oil peaked at almost 25% of power production in 1973[26], just before the oil crisis, and has been declining since then. From being the second fuel used for electricity production after coal, it has become the fifth, just above 3% of the global electricity generation in 2016. Whilst globally the use of oil for electricity generation has fallen sharply, it still accounts for over 70% of electricity generation in a number of countries including Lebanon, Iraq or Jamaica. Oil and natural gas combined provided 100% of power production in countries such as Bahrain, Qatar, Trinidad and Tobago and Brunei Darussalam [22].

1.2.2 Total Final Consumption (TFC)

Between 1971 and 2016, total final consumption (TFC) was multiplied by 2.25. However, the energy use by most economy sectors3 did not change and has been fairly stable for several years. Energy use in transport significantly increased, from 23% of TFC in 1971 to 29% in 2016 as well as in 2015.[30] Nevertheless, in 2016 industry remained the largest consuming sector, only one percentage point lower than in 1971 (37%). The residential sector ranked third in 2016 (22%).

Total final consumption has soared in non-OECD Asia including China since the early 2000s to account for 34% of global TFC in 2016[27], whilst the mainly increasing trend stopped in OECD with the 2008 economic global crisis, and total final consumption is oscillating around a plateau of yet over 3 500 Mtoe (38% of global TFC)[31]. The following sections briefly describe OECD trends up to 2017 and 1971-2016 energy trends in six different regions of the world: OECD, Africa, non-OECD Americas, non-OECD Asia, non-OECD Europe and Eurasia, and the Middle East.

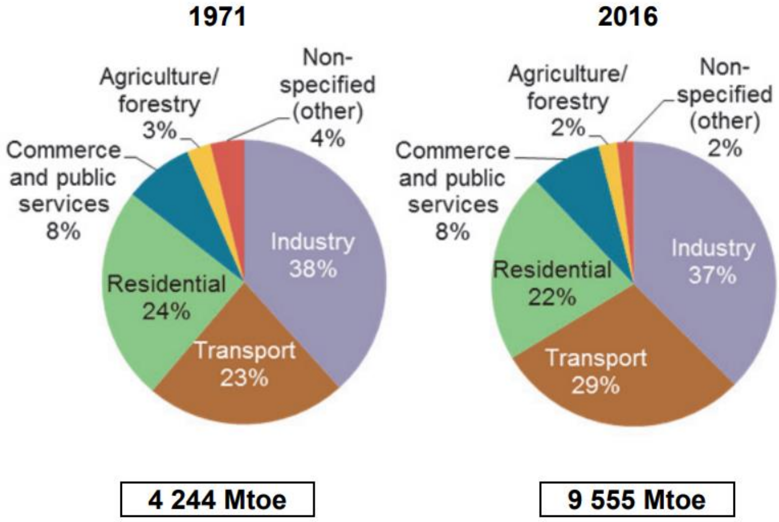

Figure 1. 7 Total final consumption by sector[20]

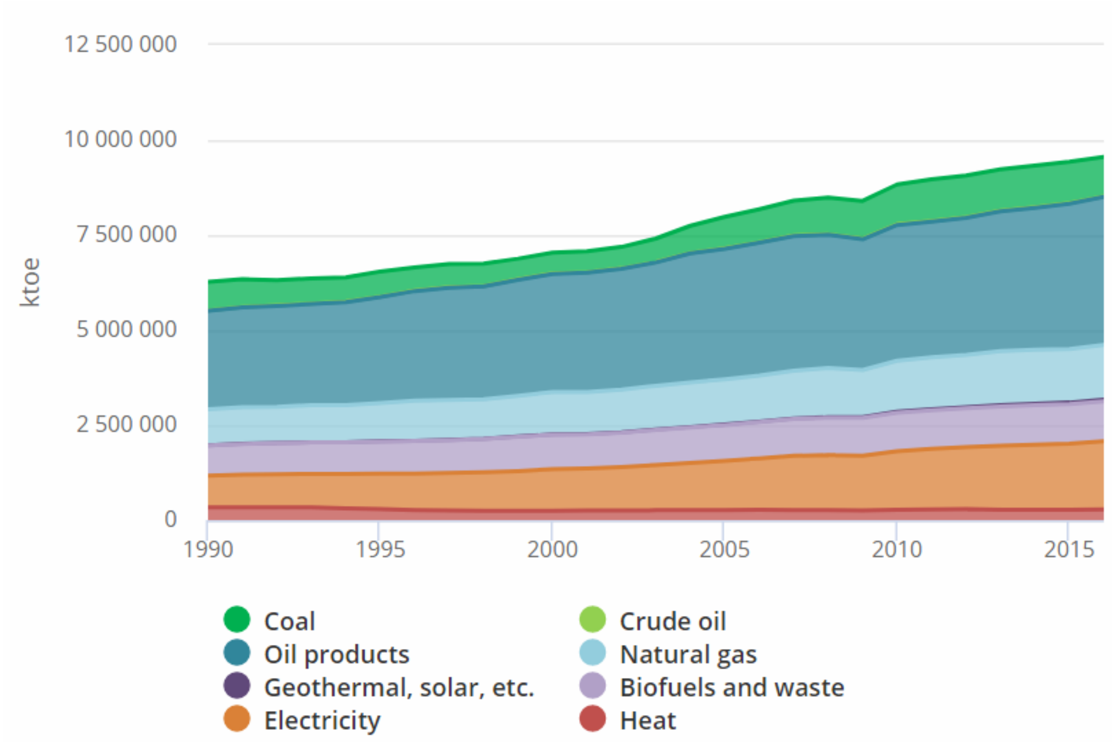

Figure 1. 8 Total Final Consumption (TFC), World 1990 – 2016 [24]

1.3 INDIAN ENERGY SCENARIO

India's energy consumption would grow by 4.2% p.a., faster than all major economies in the world. The Installed Capacity of the country as on 31.03.2016 [14] was 3,02,088 MW comprising of 2,10,675 MW thermal, 5,780 MW Nuclear, 42,784 MW hydro and 42849 MW renewable,

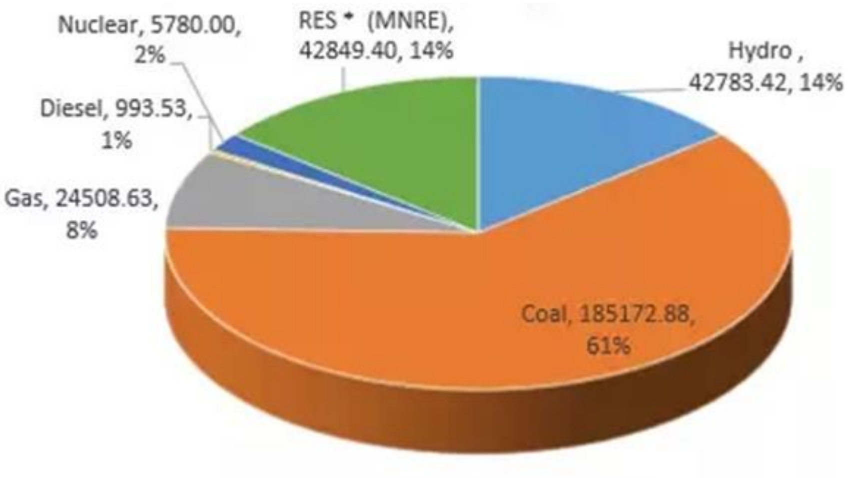

Figure 1. 9 All India Installed Capacity as on 31.03.2016[13]

The country has significant potential of generation from renewable energy sources. All efforts are being taken by Government of India to harness this potential. The Installed capacity as on 31st March, 2016 from renewable energy sources is 42,849 MW. The Total Renewable Installed Capacity comprises of 26,866.7 MW from Wind, 4,273.5 MW from Small Hydro Plants, 4,946.4 MW [25] from Biomass Power & Biomass Gasifiers and 6,762.9 MW from Solar power & Urban & Industrial waste. India ranks fourth in the world in terms of installed capacity of wind turbine power plants.

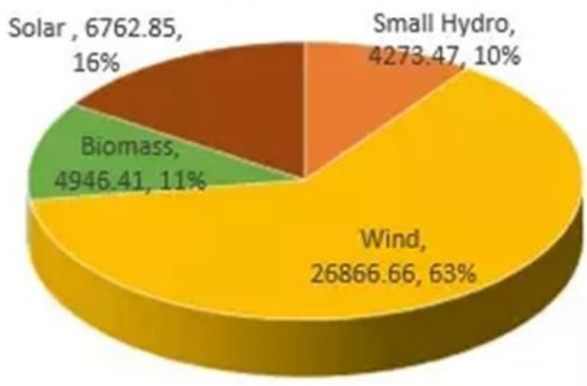

Figure 1. 10 All India Renewable Capacity as on 31.03.2016[13]

In India, as on 31.03.2016, the total RES capacity was 42,849 MW [27] out of total Installed Generation Capacity of 302,088 MW. This represents almost 14.2% of the total Installed Capacity. An Action Plan has been formulated by Government of India for achievement of a total capacity of 175,000 MW from Renewable Energy Sources by March, 2022.

The total estimated coal resources in the country is 315.149 billion tonnes [24] as per “The inventory of Geological Resources of Indian Coal” (as on 01.04.2017), prepared by the Geological Survey of India. The total coal extracted from the coalfields of India during 2016-17 is 655.31 million tones and since 1950 upto 2016-17 is around 14438.22 million tonnes. Every year about 3 to 5 billion tonnes of resources are being added through fresh exploration to the Coal Inventory of India.

Table 1. 1 Installed capacity of Grid-connected Renewable Power Plants (as on 31.03.2016)

Renewable energy source	**Installed capacity in MW**
Solar Power	6762.85
Wind Power	26866.66
Bio-Power & Waste Power	4946.41
Small Hydro Power	427347

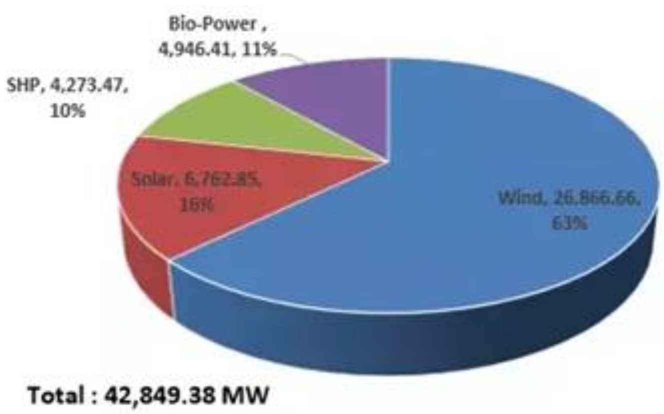

Figure 1. 11 RES installed capacity in MW as on 31.03.206[25]

A small Hydro-Electric Plant (130 kW) established near Darjeeling, West Bengal in 1897 ushered the beginning of hydro-electric power development in the country. Since then, development of hydro-electric power in the country has made rapid strides.

REGION	NO. OF	NO.OF UNITS	CAPACITY (MW)
NORTHERN	68	234	18302.27
WESTERN	2	101	7392.00
SOUTHERN	6	247	
EASTERN	19	6	4254.70
NORTH EASTERN		2	
ALL INDIA (TOTAL)	**1**	**676**	**42783.42**

Figure 1. 12 Region wise Summery of Hydro Electric Installed Capacity (Above 25 MW Capacity as on 31.03.2016) [25]

Figure 1. 13 Sector wise installed capacity and generation [25]

Out of total installed capacity of 3,02,088 MW as on 31st March 2016, a capacity of 24,508 MW (about 8.11%) is from gas-based power plants. However, capacity of 23,075 MW is being monitored by CEA.

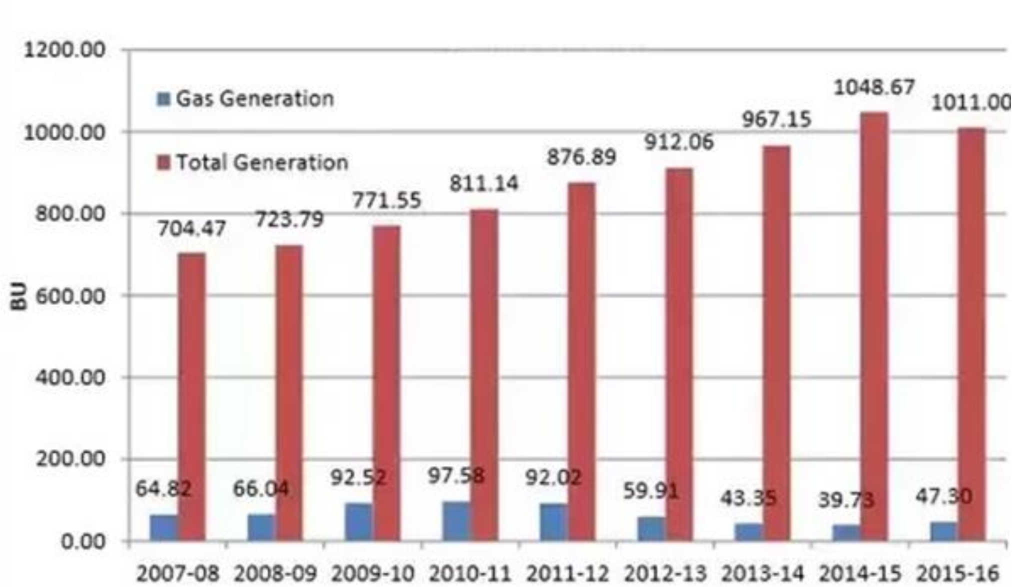

Figure 1. 14 Share of gas-based generation in total generation [22]

2.3 Coal is the main source of India’s energy sector. The All India Installed Capacity of the country is about 302,088 MW as on 31.03.2016, out of which about 185172.88 MW (61.3%) [22]is coal based. Of the total power generated in the country, 77.8 % comes from coal based thermal power stations even though they constitute only 61.3% of the total installed capacity. Coal based capacity of 50025 MW are in different stages of construction and are expected to be available during 2017-22

India's demand growth of 165%, nearly three times the overall non-OECD growth of 61%, also outpaces each of the BRIC countries: China (+41%), Brazil (+60%), and Russia (+6%) [19].

- India's share of global demand rises to 11% in 2040 from 5% in 2016, accounting for the second largest share of the BRIC countries.

- Demand for coal sees the biggest growth, expanding by 132% followed by renewables (+1409%), nuclear (+412%), hydro (+80%), gas (+185%) and oil (+129%) [17].

- India's energy mix evolves very slowly with fossil fuels meeting 82% of demand in 2040, down from 93% in 2016.

- The share of coal in the energy mix falls from 57% in 2016 to 50% by 2040, while the share of renewables rises from 2% to 13%.

- Power consumption more than trebles (+241%) and while coal remains the dominant fuel source, its share of generation drops from 77% in 2016 to 64% in 2040 as renewables rise from 5% to 23%.

- Energy in transport grows by 4.4% per year and oil remains the dominant fuel source with a 96% market share in 2040.

- Industry’s (combusted and non-combusted) share of energy consumed remains around 60% during the forecast.

- Energy production as a share of consumption increases from 56% in 2016 to 60% by 2040 while imports rise by 141%.

- A decline in oil (-24%) production is offset by increases in coal (+154%), gas (+99%), and non-fossil fuels by 544% [18].

- Coal remains the dominant fuel produced in India with a 63% share of total production in 2040. Renewables overtake gas and then oil by 2020 as the second largest source of energy production.

- Oil imports will rise by 175% and account for 65% of the increase in energy imports, followed by gas (+291%) and coal (+79%).

• By 2040, India's energy intensity of GDP is 37% lower than in 2016 while carbon intensity of energy use is down by 13% [17].

Energy efficiency improvements in India since 2000 prevented 6% of additional energy use in 2017. Movement of economic activity from energy-intensive industry sectors to less-intensive manufacturing and service sectors was almost entirely offset by increased energy use driven by factors such as changes in transport modes and occupancy levels as well as increased appliance ownership and building floor area.

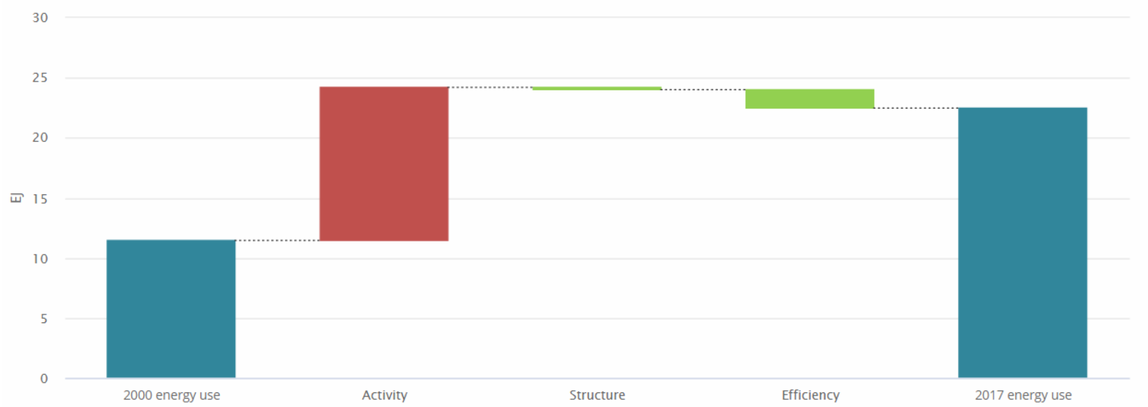

Figure 1. 15 Decomposition of Indian final energy use, 2000-2017[17]

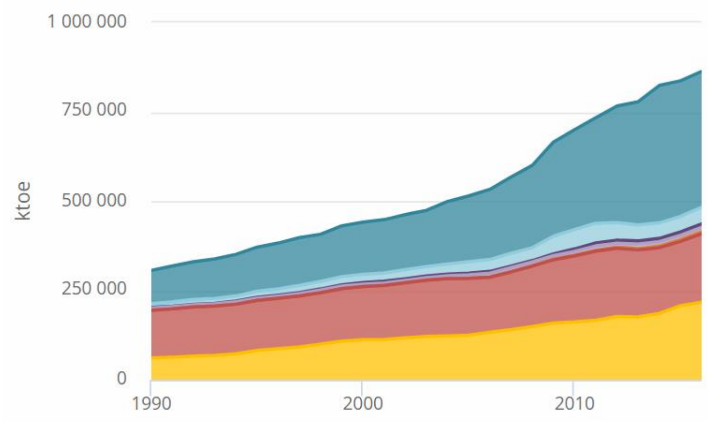

Figure 1. 16 Total Primary Energy Supply, India 1990 – 2016 [16]

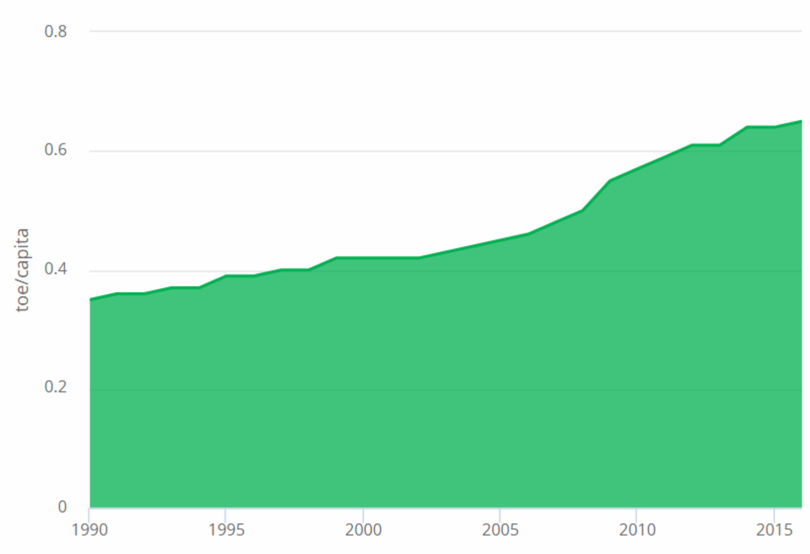

Figure 1. 17 Total Primary Energy Supply 1990 – 2016 [15]

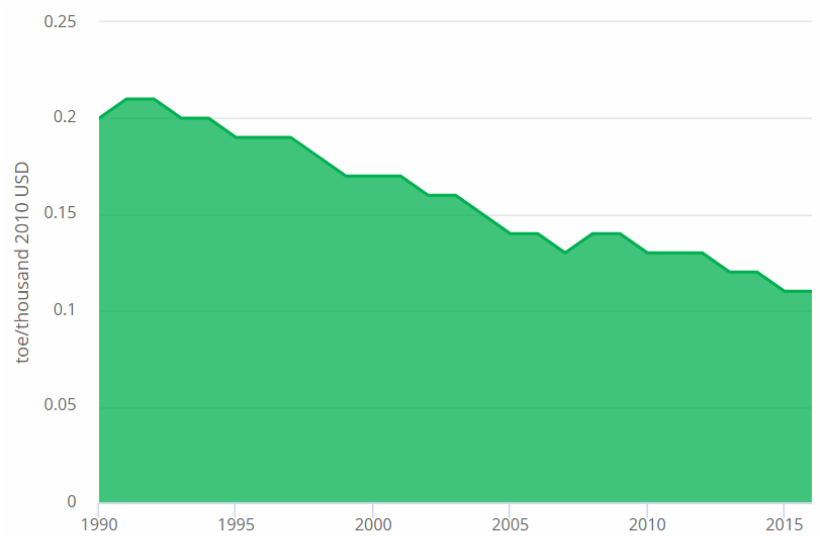

Figure 1. 18 Total primary energy supply (TPES)/GDP PPP, India 1990 – 2016 [15]

1.4 Aim and objective of the work

As we discussed before that there is a huge pressure on conventional energy resources and a big thrust is on renewable energy resources. SPV and wind turbine integrated technology is one of the promising technologies to be used in future to harvest energy as there are two types of energy but they store the heat and mechanical energy into electrical energy. As it is distributive in nature it can be implemented in small scale as well as in large scale also. Some of the drawbacks of this technology are it consumes large area, it has negative effect on dust deposition, it has negative effect on abnormal weather condition. Dust deposition issue is more prominent in case of small-scale plants. On the other hand, in small scale rooftop off-grid system the system becomes inoperative during islanding operation that means when there is absence of grid supply regardless of sunshine So the aim and objective of this study is to find out the drawbacks of the above mentioned problem and how these problems can be solved to harvest optimal energy.

There are so many objectives regarding the experiment. We are going to discuss a little bit about them.

1. We are going to take an overview of the discharging rate (rate of discharge) of the batteries. Batteries are first charged by the solar Photovoltaic and wind turbine system. And after that the batteries are discharged through the load for a certain period of time.
2. We need to see the energy consumption at the period of the experiment i.e. the total units generated by the battery. That is from how much charge we are going to supply the certain amount of constant load.
3. We need to take our eyes on the charging and discharging of batteries on various weather conditions. That means we need to check the weather condition daily and as per weather condition our output become authentic or not.
4. We need to optimize the system according to the data collected so far but the data should be in alliance with the weather condition.

1.5 Scope of the present Work

The present work is concentrated on the optimization of solar PV and wind integrated hybrid system. The Sun gives us a huge amount of energy i.e. enormous amount of static energy to the earth surface out of which a very small percentage is utilized and can be converted into useful energy and the rest part is wasted or radiated from the atmosphere. Solar PV and Wind integrated technology is one of the technically renowned technology by which we can capture the sun energy and can utilize it in useful form. Various research and development are still going all around the world to make the solar PV and wind integrated hybrid system more efficient reliable and cost effective. This work is also reflecting the same motive towards the advancement of solar PV and wind integrated hybrid system with several questions as well as solution in this renewable sector.

The scope of the present work is as follows:

(a) An experimental study has been conducted on renewable energy by collecting some data on different days (both days and nights) in several weather condition whereas the Sun and the Wind are the main sources of energy in our study.

(b) The performance analysis, energy calculation on the work period of solar PV and wind integrated off-grid system.

The entire work is presented in the form of a thesis consisting seven chapters. The present scenario of energy on the context of Indian as well as world context, the importance of solar energy for future and the aim and objective of the present work all are described in the first chapter.

A literature review of the earlier works has been done regarding this field has been described in the second chapter. A very small description of the theory related to the integrated solar photovoltaic and wind hybrid system has been provided in the third chapter. The fourth chapter consists of details of small application, of roof top off-grid hybrid system, which includes the description of existing setup and methodology used for the study. The results obtained in the present work accordingly its discussion is provided in the fifth chapter, and [the discussion is also done accordingly in the same. Conclusion of the thesis and the scope for future work has been provided in chapter six.

1.6 Conclusion

In this chapter the present energy scenario has been discussed. As the fossil fuel reserves are decreasing day by day alternating ways of energy generation are required. Solar energy has the potential to meet this requirement thus the present status of solar energy has also been discussed in this chapter. The aim and objective of the present work has been pointed out here. Also, a brief description of the contents of each chapter has also been provided here. The study regarding solar PV technology will be discussed in the next chapter.

Chapter 2

Literature Review

2.1 Introduction

In the modern era we are very conscious about the day by day decrement of the fossil fuel on the earth. We are using the fossil fuel for a long time but we are unable to regenerate it. There is no such alternative way to produce such an oil which is equally efficient like fossil fuel. We take fuel from the inner surface of earth and unable to refill the void space. Nowadays we are very conscious about the decrement of the level of fossil fuel; that means we need to think about the alternative way to generate electrical power without using the fossil fuel which is randomly used in the industries and power plants. In the 100% power generation of electrical power the steam power plant generates 80% of it in India. Actually, the main concern is that we need to reduce the 80% as much as possible then the power generation will be long lasting.

So, we need to think about the renewable energy nowadays. Renewable energy is that type of energy for which the main source of energy coming from an infinite source; that means we have no need to think about the deficiency of the input of the system. So, we are here to concentrate on the spread of the versatile use of renewable energy resources. There are so many drawback and constraints on the path of globalisation of use of renewable energy resources. In India it is very difficult to convince people to use renewable energy.

At present 1.3 billion people still has no access to electricity on the earth, of which 95% live in either remote areas or underdeveloped countries. Among the renewable energy technologies, solar photovoltaic (PV) and wind turbine (WT) have been considered as the most promising energy alternatives for remote or rural areas to meet their energy needs. Actually, underdeveloped areas are unable to afford the conventional electricity thus it is easy to reach to them for convincing the utilisation of the renewable energy.

The average energy used in India in 2017-2018 is 1149kWhr per capita and along with that we need to satisfy the challenge to meet with the stated value. But the main drawback is the output of the renewable energy sources is very less as compared with conventional power plant. The installation charge is very high in case of solar PV system that underdeveloped people cannot afford the charge. We will have a long-lasting output from a solar PV system as the running cost is nearly equal to zero. The only cost to run the system is the maintenance cost and nothing else.

2.2 Review Work:

1.The power supply of remote sites and applications at minimal cost and with low emissions is an important issue when discussingfuture energy concepts. This optimization [1] of an off-grid PV-Wind-Diesel system presents the modelling and optimization of a stand-alone hybrid energy system. The system consists of photovoltaic (PV) panels and a wind turbine as renewable power sources, a diesel generator for back-up power and batteries to storeexcess energy and to improve the system reliability(which is not there in our experiment). For storage the technologies of Lithium ion, lead-acid, vanadium redox-flow or a combination thereof have been considered. To beable to use different battery technologies at the same time, a battery management system (BMS) is needed. The presented BMS minimizesoperation costs while taking into account different battery operating points and ageing mechanisms.The system is modelled and implemented in Matlab/Simulink. As input, the model uses data of the irradiation, wind speed and airtemperature measured in 10 min intervals for 10 years in Aachen – Germany. The load is assumed to be that of a rural UMTS (Universal Mobile Telecommunications Service)/GSM (Global System Management for mobile communication) basestation for telecommunication. For a time frame of 20 years, the performance is evaluated and the total costs have been determined.Using a genetic algorithm, component sizes and settings have then been varied and the system re-evaluated to minimize the overall costs.

The optimization has been also done for a site in Quneitra – Syria[2]which has very good solar radiation that allows for the comparisonbetween two countries, as the weather data in the two countries differ greatly (different weather data).The optimization results show that using batteries in combination with the renewables is economical and ecological. However, thebest solution is to combine redox-flow batteries with the renewables. In addition, a power supply system consisting only of batteries, PV and wind generators may be applicable as well to satisfy the power demand.

The system consists of a load profile representing a base station, PV panels and a wind turbine as renewable power sources, batteries for storing excess energy and to improve the system reliability, as well as a diesel generator for backup power. The PV panels, the wind turbine and the three battery types are connected to a 48 V DC bus [1]. A diesel generator and the load are connected to a 230 V AC bus. The buses are joined through a bidirectional power converter. In order to use lithium-ion, lead-acid, vanadium redox-flow batteries or a combination of them simultaneously, a battery management system (BMS) is needed. It regulates the power flow by assessing the current state of health (SOH) and the state of charge (SOC) of the batteries and the diesel generator (in the below figure).

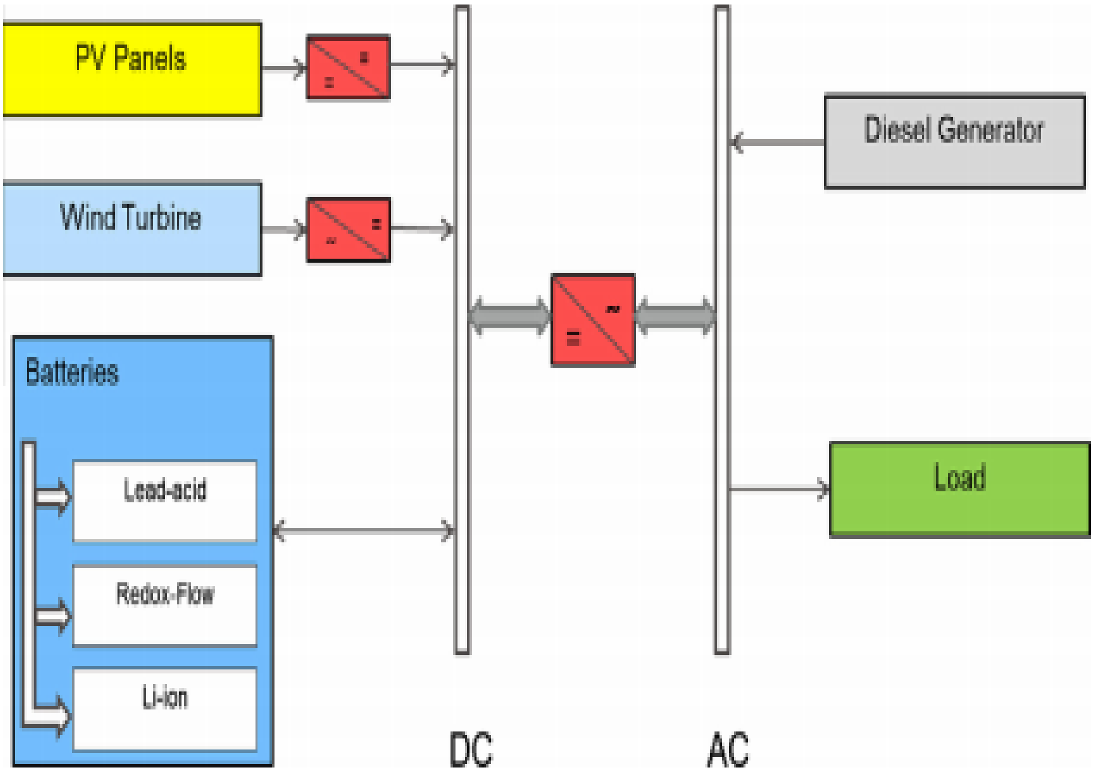

Figure 2. 1 System components and topology [1]

<u>System components</u> (a) The system model has been implemented with MATLAB/Simulink. Taking into account different battery operating points and ageing mechanisms, the BMS chooses the cost optimal storage technology. It also oversees the power flows within the whole system and triggers the diesel generator. The load is assumed to be that of a rural UMTS/GSM base station for tele communication. As further input, the model uses data of the insolation, wind speeds and air temperature for Aachen-Ho ̈rn,[3] Germany (50470 North, 6040 East, 222 m ASL) and for Quneitra – Syria (33080 North, 35490 East, 60 m ASL)(Ref 4).Using a 10 min interval, the system has been simulated for a time frame of 20 years. Then, system performance has been analyzed and total operation cost have been computed. Using a genetic algorithm, key parameters of the components and the system settings are then varied and the simulation has been repeated, with the goal to minimize overall cost. At each point in time, the load needs to be covered and therefore the equilibrium of generated, stored and used power needs to be:

$$P_{pv} + P_{wind} + P_{batt} + P_{dg} \geq P_{load} + P_{loss} \text{ ....}(1)$$

Here P_{pv} is the output power of the PV generator, P_{wind} is the output power of the wind generator, P_{batt} is the output power of battery, P_{dg} is the output power of diesel generator, P_{load} is the load connected to the off-grid system and P_{loss} is the overall system power loss. This is achieved by redirecting power from or into the batteries using the control strategy implemented in the BMS. Furthermore, the constraints for the model components need to be fulfilled. In the following sections, we discuss the components and the input and output data of the model separately.

(b) Using the temperature dependent Maximum Power Point algorithms and equations given by Sauer (1994) [4] the current and the voltage of one Photovoltaic module relative to the solar radiation and temperature have been determined. Other factors such as air density, dust have been neglected (that is also done in the experiment). Then the total power output has been computed according to an equation that is related to the algorithm used in the experiment. The equation consists of several number of constraints which are very much related to the experiment. At the maximum power point, we obtain voltage and current that are equally important for the experiment. Therefore, the total power output is essentially dependent on key optimization parameters module area (peak power) and the tilt angle as well as on the input data of the insolation. The panels have assumed a lifetime of20 years,[5] so they do not need to be replaced within the simulated time frame. The module current and the module voltage at different solar irradiance and different temperature are plotted below:

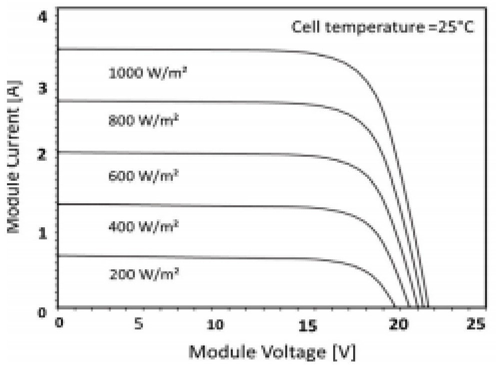

Figure 2. 2 The performance of the solar module at various level of irradiance at constant temperature 25°C (ambient temperature of the experiment) [4]

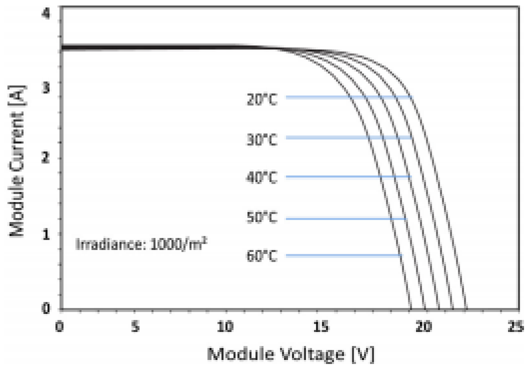

Figure 2. 3 The performance of the solar module at various level of temperature at constant irradiance 1000 W/m^2 (5)

(c) As a second renewable power source is there and that is the wind turbine coupled with a wind mill. According to the power transmission law we know that the power generated from the wind mill is proportional to the cube of the wind speed and the swept area of the rotor. And there are so many variables we need to consider for the generation of the electrical power such as aerodynamic efficiency, air density of the place, total efficiency of power generator and power converter combined and the nominal power of the wind generator. The experimental wind speeds used as the input data of the above 10 m above the ground [6]. Actually, the wind speed measured from any height from the ground is measured by the Kleemann and Meilβ (1993) such as:

$$\mathbf{V(h) = V_{10}(h/10)^{p}} \ldots\ldots\ldots\ldots\ldots (2)$$

In equation (2) V(h) is the velocity at height h from the ground and V_{10} is the velocity at a height of 10 meters from the ground and 'p' is the terrain roughness co-efficient generally used as a value of 0.3[1,12].

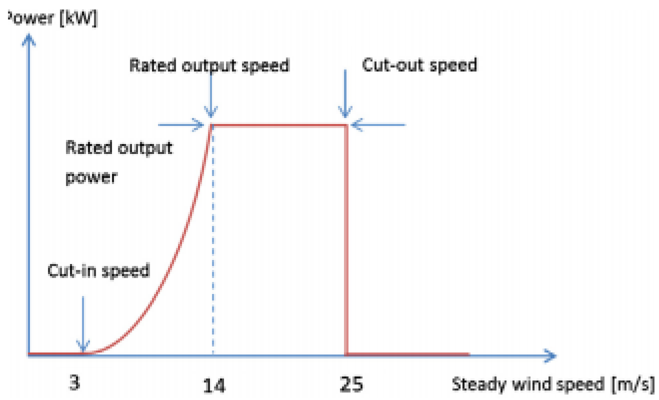

Figure 2. 4 Typical wind turbine power output with steady wind speed 9 [1]

The wind turbine will generate electrical power of some amount if the wind speed will exceed the value of 3 m/s which is the cut-in velocity of the wind generator. The output power is only then limited by the nominal power of the wind generator and if the wind speed exceeds 25 m/s then the output power will automatically become to zero and connected to a 48 V DC source [2].

4.A diesel generator is also introduced in the system which has certain amount of efficiency which is dependent upon the operation of the system [12,1]. The generator's efficiency depends strongly on the operation mode. All processes inside the generator are optimized for full load. Here, the maximum efficiency is 30% and the internal combustion is without residue. If the generator needs to deliver less than the rated power incomplete combustion can occur and efficiency decreases.

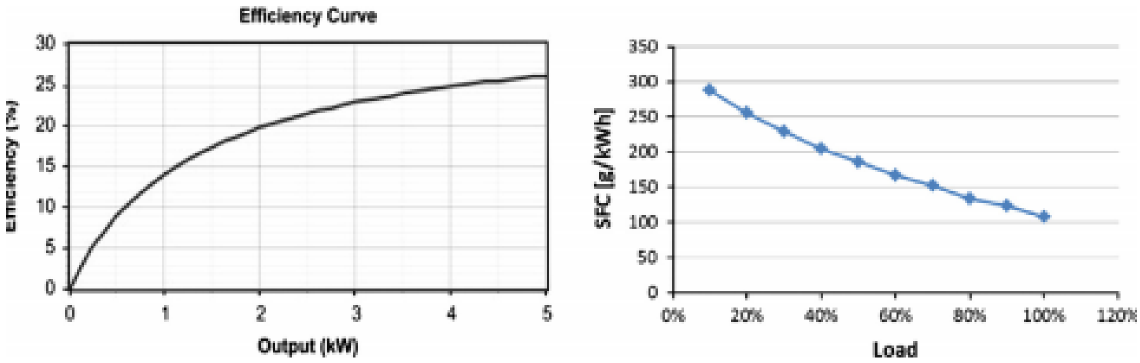

Figure 2. 5   Efficiency and specific fuel consumption of diesel generator [2]

We need to calculate the fuel consumption of the diesel generator and also calculate the efficiency at which the diesel generator is working. The main parameter of the diesel generator is the nominal power.

Since the diesel generator has been primarily used as backup power supply, the nominal power of the diesel generator needs to be at least the maximum load required by the system. However, the nominal power can also be larger in order to charge the batteries using the generator. The extension to which the batteries are charged by the diesel generator is determined by the part load factor. This factor is defined as the minimum power output as a percentage of the nominal power. It guarantees the operation of the generator above a minimum tolerated efficiency. Hence, along with the nominal power the part load factor can be optimized for the system. Also, to prevent frequent start-stop-cycles, a minimum runtime of the generator has been defined and optimized.

5. Three battery models are used in this simulation Pb-acid, Li-ion and vanadium redox -flow technologies simultaneously [7]. The battery voltage strongly depends on the state of charge

(SOC), the temperature and the state of health of the battery. Actually, the state of charge depends on the initial condition of the battery and the ambient temperature. Normally the state of charge depends on the effective current used to charge or discharge the battery and the battery capacity (calculated in Ah).Here, the effective current has been obtained from dividing the battery power by the voltage and taking into account electrical losses and additional losses due to gassing (lead-acid) or pumping losses (redox-flow).In general, the performance of a battery depends on its nominal capacity and on operational factors such as state of charge limits and charge rates. Therefore, these are the optimization parameters for each battery. For lead acid and lithium-ion technology the battery power has been directly correlated with the capacity. However, in case of the redox-flow battery the nominal power can be optimized independently from the capacity. Additionally, the performance of the battery is affected by its state of health. The state of health has been computed based on specific ageing data, the temperature and the actual usage of the battery. The peak power of the PV generator is 14.7 kWp (which is equivalent to about 114 m^2). Concerted to this, the nominal power of the PV converter is 5.9 kW.

Table 2. 1 Optimal configuration of hybrid system [2]

Parameter	Value
Peak Power of PV generator	14.7 KW
Nominal Power of DC-DC converter	5.9 KW
Inclination angle of PV pannel	390
Azimuth angle	-30
Peak Power of Wind Turbine	12.6 KW
Nominal Power of AC-DC converter	9.6 KW
Tower Height	17 m
Rotor Diameter	14 m
Battery Capacity -Lithium Ion	0
Battery capacity- Redox Flow	1460 Ah

For off-grid system we need not maintain the 50 Hz frequency as constant but while supplying to the household purpose we must maintain the frequency as 50 Hz (Indian standard). But in case of the on-grid system we should maintain the frequency as 50 Hz. (In case of any deviation we should inform).

Techno-economic optimization of hybrid photovoltaic/wind/diesel/battery generation in a stand-alone power system:

This paper focuses on development of optimal sizing model based on an iterative approach to optimize the capacity sizes of various stand-alone PV/wind/diesel/battery hybrid system components for zero load energy deficit. The suggested model takes into consideration the hybrid system sub-models, the Total Energy Deficit (TED), [6,5] the Total Net Present Cost (TNPC) and the Energy Cost (EC). The flow diagram of the hybrid optimal sizing model is also demonstrated. Exploiting the developed model, all configurations giving the rate of 0%of Total Energy Deficit (TED) are retained. Afterward, the optimal configuration is predicted on the basis of the minimum cost. Using solar radiation, ambient temperature and wind velocity data collected on the site of Gardai (Algeria), the optimized system is compared to other energy source choices. The optimization results show that a PV/wind/diesel/battery option is more economically viable compared to PV/wind/battery system or diesel generator (DG) only. We will consider the solar wind integrated system and after that we will also consider the diesel generator.

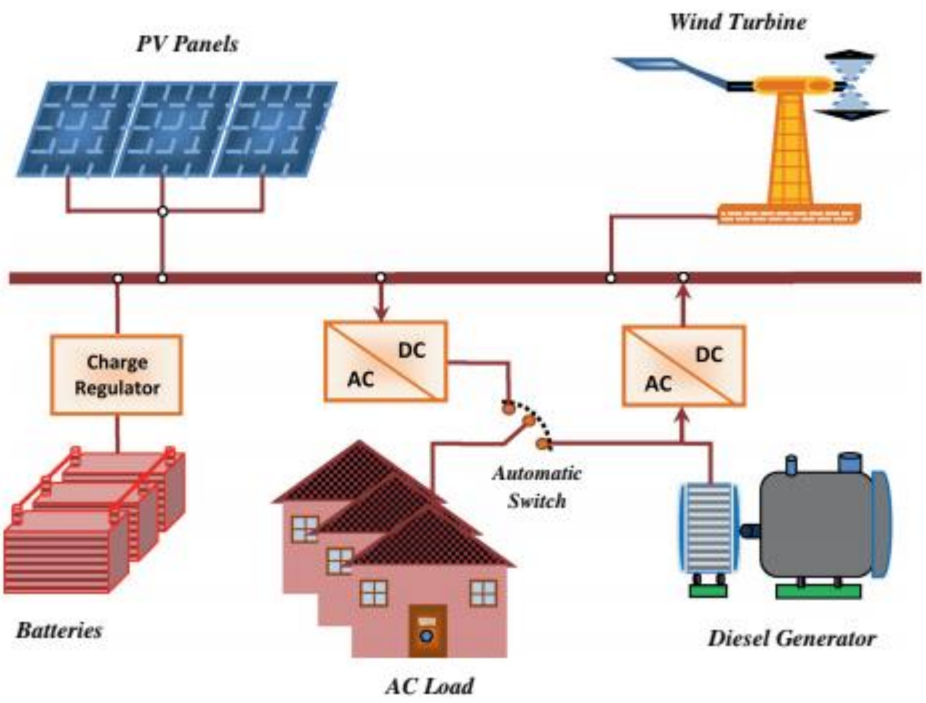

Figure 2. 6 Schematic diagram of stand-alone PV/wind/diesel hybrid system with battery storage [2]

The schematic diagram shows that PV panels and wind turbine are connected to a bus in which we need to improvise the diesel generator to supply electrical power to the bus (Though it is an off-grid stand-alone system).Batteries are charged through charge controller and discharged through inverter and supplied to the load(mainly in household purposes i.e. 50Hz 1 phase AC supply).

In this study, Fig. 1 shows the configuration considered in this paper. This configuration consists of PV subsystem, wind power subsystem, battery bank storage, charge controller, converter, diesel generator and an inverter which is used to interface the DC voltage to the consumer load AC requirements. The operation mode of the studied system is as follows: In regular operation, the hybrid system supplies the load demand. The excess energy from the PV and wind generators above the hourly demand is stored in the battery until the battery is entirely charged. When the energy required is greater than the energy generated, the battery bank will be used to insure the load demand. A diesel backup subsystem is in service at times when the hybrid system fails to meet the load and when the battery storage is exhausted. The battery storage can also be discharged if the water level of battery is not proper that means concentration of H_2SO_4 is either more or high in the battery bank.

The model consists of so many models like PV panel, wind turbine etc. We will discuss a little bit according to the results and discussion.

1. The first thing we need to discuss is about PV panel in the integrated system.Usually, in photovoltaic systems, a maximum power point tracking system is used and therefore the PV modules often operate at maximum power. For this purpose, the estimation of maximum power becomes an important parameter in modeling this system component. One of the most known models to describe the maximum output power of the PV module, in MPP conditions is given by Rosell and Ibanez in the year of 2006[8] :

$$\mathbf{P_m = D_1G + D_2T_c + D_3[\log G]^w + D_4T_c[\log G]^w \ldots\ldots\ldots(3)}$$

Here P_m is the maximum power generated by the PV panel under a certain weather condition. The coefficients $D_{1\text{-}4}$ and w must be determined by fitting the model to experimental data measured in one or more test sites. And along with-it Tc is the normal operating cell temperature which is given by the manufacturer. Actually, NOCT is calculated on the basis of the ambient temperature, wind speed and irradiance.

2. Electric power output of wind turbine at a particular location depends on wind velocity at hub height and turbine speed characteristics. Here we need to take some reference value of the wind speed e.g. let us suppose we are considering the wind speed at a height of 20 m[5,8] from the ground; now we need to know at what height we need the velocity of wind and by applying so

many formula(originally the formulas are invented from the power flow equation) invented so far. The graphical approach of power output vs wind speed is shown in the next page and along with it we can see that the power output is increasing as the speed of wind is increasing but after certain value of wind speed the electrical power output remains constant actually that is limited by the nominal power of the wind generator. However, we get the graphical approach of power output and wind speed.

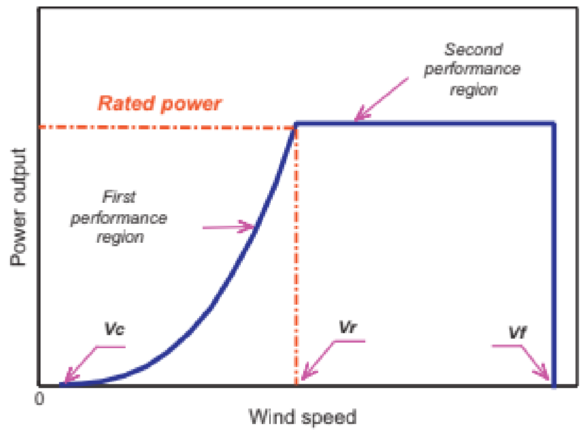

Figure 2. 7 Typical wind turbine power output with steady wind speed [1]

3. The diesel generator is also associated with the hybrid system and we need to examine out the fuel consumption of the diesel generator. The fuel consumption depends on the coefficients of fuel consumption curve given by the manufacturer. The diesel generator generates energy to meet the energy deficit to the ongoing system and the remaining energy is stored in the batteries.

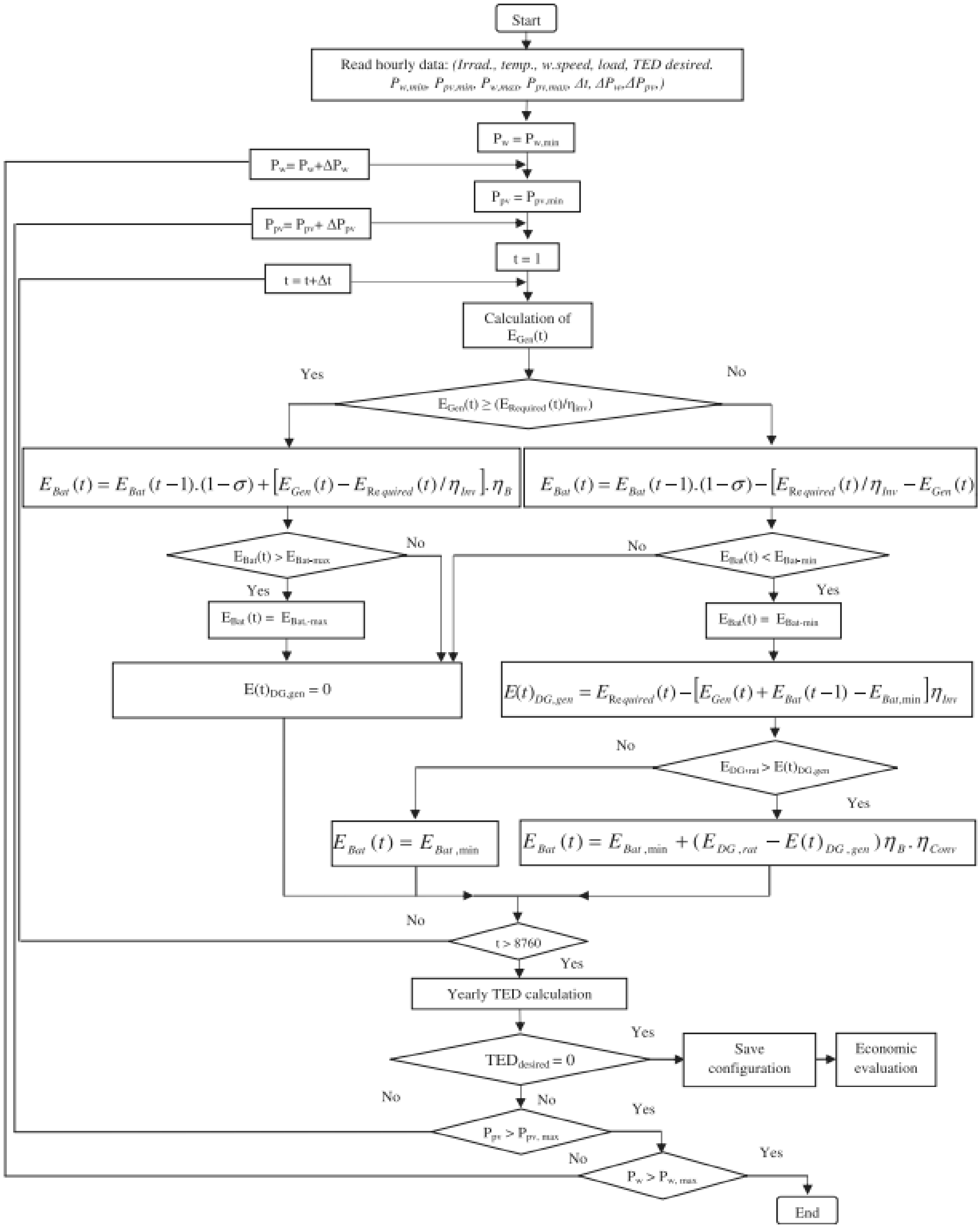

Figure 2. 8 The optimization process of the experiment [6]

In order to highlight the suggested methodology, a case study is conducted to investigate a stand-alone PV/wind/diesel hybrid system with battery storage, which is intended to supply a group of ten houses located in Ghardaı ̈a, Algeria ($32^0$29'N, $3^0$40'E, 450 m) [6]. The studied hybrid system components consist of PV subsystem, wind power subsystem, diesel generator, an inverter and battery bank storage.

The next figure shows the daily power consumption of Ghardaı̈a, Algeria. Actually, load curve shows that the total units of current consumed in that region.

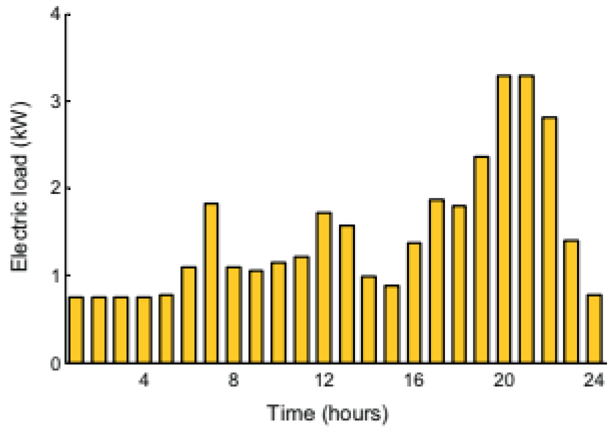

Figure 2. 9 Hourly load profile [7]

The total intention of this work is to minimize the system cost to get better future in the world of renewable energy. The intent of this work is to grow a global methodology for sizing optimization of stand-alone PV/wind/diesel hybrid system with battery storage that will be able to be used in applications such as rural electrification of remote sites. To reach this objective, we have developed a techno-economic approach described by two models: the reliability model developed beneath the Total Energy Deficit (TED) concept and the economic model based on the calculation of Total Net Present Cost (TNPC) and Energy Cost (EC). The combination of these two models can finally determine the optimal configuration leading to the total system autonomy in the most cost-effective manner.

Novel standalone hybrid solar/wind/fuel cell power generation system for remote areas

A novel standalone hybrid solar/wind/fuel cell power generation system is designed and constructed [10,11]. The contribution of this work is that the large-scale constructed hybrid system combines two renewable resources (solar and wind energy) with a FC system used as a standby power source to produce electric energy. Moreover, it maximally converts solar and wind energy into electric power because it uses a novel fast and highly accurate unified maximum power point tracking (MPPT) technique which concurrently tracks the maximum power points of both photovoltaic (PV) system and wind energy conversion system (WECS) implemented in the hybrid system [7,8,1]. Few hybrid solar/wind/FC power sources reported in the literature are simulated models, and moreover, there is not any new

MPPT consideration in them. It is experimentally verified that the constructed hybrid system efficiently produces electric energy for a remote area under different environmental conditions such as cloudy sky. The MPPT technique implemented in the standalone hybrid solar/wind/FC system is also compared to the state-of-the-art MPPT methods, the comparison explicitly demonstrates that the technique provides the highest MPPT efficiencies of 99.60% and 99.28% along with the shortest tracking convergence times of 12 milli-seconds and 15 milli-seconds respectively in PV systems and WECSs.

There are so many algorithmic approaches of the experiment that had been analyzed by Hasan Fathabadi and he has introduced a new approach to optimize the integrated system. On the basis of different MPPT techniques he gave an identical approach at 2015. For example, he has analyzed the OCV (Open Circuit Voltage) MPPT techniques given by Enslin et al,1995. It is a low accuracy offline method as we can only get open circuit voltage when the environmental condition varies over time. But Park and In-Kaun gave a modified OCV technique at 2004 though here also some drawback is present as per the author of the thesis. The SCC method is also a very well-known method in the case of renewable energy. The SCC method is firstly introduced by Masoum et al and Noguchi et al at 2002. But in this case also some improvisation is needed. Here another method is there i.e. OTC (optimal torque) which is given by Kumar and Chatterjee,2016. The other methods such as TSR (Tip Speed Ratio), PSF (Power Signal Flow), HCS (Hill Climbing Search) are also analyzed by the author of the thesis paper.

In this work, a novel standalone hybrid solar/wind/FC power generation system is designed and con-structed. It combines solar and wind energies with a FC system, and also uses a novel unified MPPT technique to maximally produce electric energy to supply power needs of a remote area. FC stacks are low-polluting and efficient electrochemical power sources that produce electric power through the chemical reaction between hydrogen and oxygen (Fathabadi, 2015), so a commercial FC stack has been used as a standby power source in the hybrid system. It is demonstrated that the constructed standalone hybrid solar/wind/FC power generation system maximally converts solar and wind energies into electric energy because of using a novel fast and highly accurate unified MPPT technique that concurrently tracks the MPPs of both PV array and WECS implemented in the hybrid power source. The unified MPPT technique does not need any sensor, and only uses the output voltages and currents of the PV array and WECS. It is also shown that the constructed power source produces enough electric energy to supply power needs under different environmental conditions such as cloudy sky, so there is no need to provide electric power by connecting to a local power distribution network or grid (Fathabadi, 2015). The rest of this paper is organized as follows. The design and implementation of the standalone hybrid solar/wind/FC power generation system and constructed system and experimental verifications are explained in the several parts of the paper.

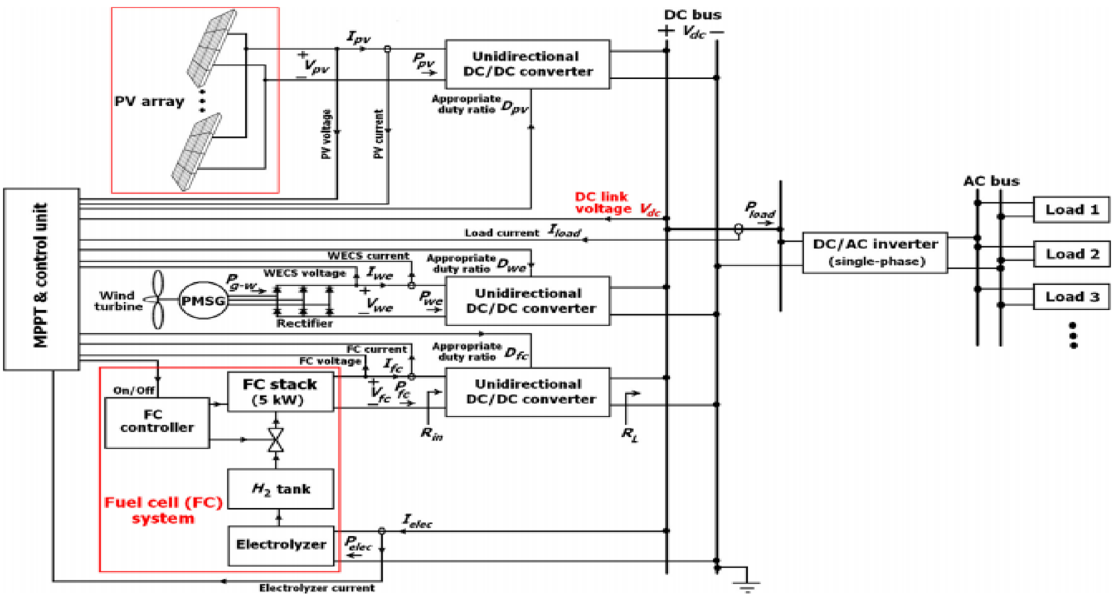

Figure 2. 10 Implementation and Configuration of a standalone hybrid system [8]

The figure shown above is the schematic diagram of the experiment completed by Fathabadi, 2015. Here we can see the MPPT and control unit had the control over the total system. The current directions are given from source to load and in the operation, we need DC-DC converter i.e. chopper to complete the source to load connection. The schematic of the chopper is given below:

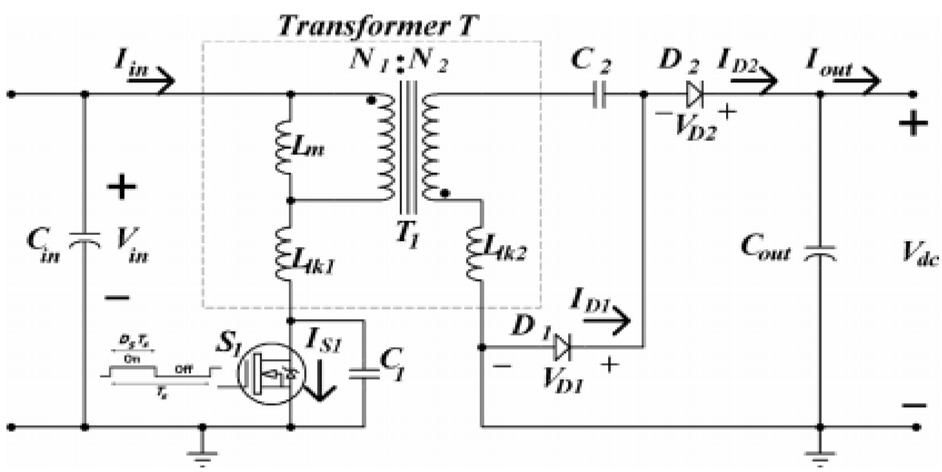

Figure 2. 11 DC – DC converter connected to PV array, WECS [9]

We can use buck or boost or buck-boost converter or chopper in the experiment to control the output voltage as well as the time period of the system.

Table 2. 2 Comparing different MPPT methods applicable to PV module from irradiance 0 to 1000 W/m^2[9]

Comparing different MPPT methods applicable to PV systems to the proposed unified MPPT technique in response to a solar irradiance step from 0 W m^{-2} to 1000 W m^{-2}.

MPPT method	Measured parameter(s)	Drawbacks & limitations	Tracking convergence time (ms)	MPPT efficiency (%)	Data type
OCV (Enslin et al., 1997)	Voltage	Offline, low accuracy	82	86	Simulation
Temperature method (Park and In-Keun, 2004)	Voltage & Temperature	Offline, low accuracy	80	83	Simulation
SCC (Masoum et al., 2002; Noguchi et al., 2002)	2 Currents	Offline, low accuracy, long convergence time	300	89	Simulation
Fuzzy logic (Salah and Ouali, 2011; Algazar et al., 2012)	Voltage & Current	Accuracy depends on selected roles	60	96	Simulation
Adaptive fuzzy (Guenounou et al., 2014)	Voltage & Current	Long convergence time	120	No report	Simulation
ANN Rizzo and Scelba, 2015	Voltage & Current	Long convergence time & requiring training data	820	No report	Simulation
P&O fixed step-size (Abdelsalam et al., 2011)	Voltage & Current	Occurring oscillation, low accuracy	76	88	Simulation
P&O variable step-size (Abdelsalam et al., 2011)	Voltage & Current	Low accuracy	15	96	Simulation
Three-point weighted (Jiang et al., 2005)	Voltage & Current	Low accuracy	47	96	Simulation
Dynamic P&O Ahmed and Salam, 2015	Voltage & Current	Long convergence time	1600	99.2	Simulation
Adaptive P&O (Ahmed and Salam, 2015)	Voltage & Current	Convergence time varies	⩾30	98.76	Simulation
PSO-ANFIS (Muthuramalingam and Manoharan, 2014)	Voltage & Current	Long convergence time	10,000–17,000	97–98	Simulation
P&O-ANFIS (Muthuramalingam and Manoharan, 2014)	Voltage & Current	Long convergence time, low accuracy	12,000–19,000	85–97	Simulation
IC (Liu et al., 2008)	Voltage & Current	Occurring oscillation, low accuracy	81	95	Simulation
Variable step-size INR (Mei et al., 2011)	Voltage & Current	Long convergence time	⩾150 ⩾ 500	99.5 No report	Simulation Experimental
Modified IC (Tey and Mekhilef, 2014)	Voltage & Current	Long convergence time	⩾200	No report	Simulation
ESC (Brunton et al., 2010; Lei et al., 2011; Bazzi and Krein, 2011)	Voltage & Current	Low accuracy	33	97	Simulation
Scanning technique (Kotti and Shireen, 2015)	Voltage & Current	Long convergence time	2000	No report	Experimental
Hybrid prediction-P&O (Jiang et al., 2014)	Voltage & Current	Long convergence time	⩾3000	No report	Experimental
Auto-scaling variable step-size IC (Chen et al., 2014)	Voltage & Current	Large number of calculations, long convergence time	⩾520	No report	Simulation
GA (Daraban et al., 2014)	Voltage & Current	MPPT efficiency varies, long convergence time	⩾600	96–99	Simulation
Predictive (Bouilouta et al., 2013)	Voltage & Current	Low accuracy, long convergence time	245	95.8	Simulation
This work	Voltage & Current	–	12	⩾99.60	Experimental results

These algorithms are very vital to analyze the experiment done by the author and in between them which one is experimental and which one is simulation we need to find out. From the above chart we can easily say that the maximum efficiency, comes into picture regarding this experiment, which is above 99.6% and that is exceeding all the experimental data in the given table. So we can easily say that the process followed by the experiment is most efficient to get power output at minimum cost.

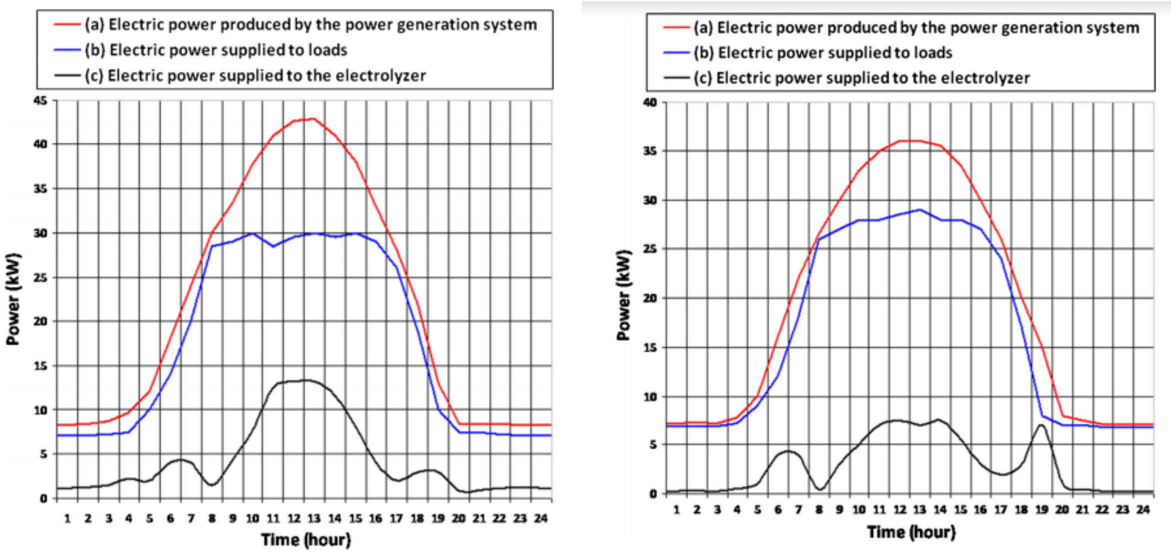

Figure 4. 1 Different powers measured in sunny day in Summer and Spring [7]

These are the two figures taken in a sunny day in summer season and spring season respectively. We can see the deviations in all the three electrical power line. And from these graphs we can get the MPPT efficiencies in different time format. As per the experimental result we can have the MPPT efficiencies are 99.6% and 99.28% respectively [7] for summer and spring season.

In this study, a novel standalone hybrid solar/wind/FC power generation system was designed and constructed. The outcomes of this work can be summarized as below:

a. During a sunny day, the hybrid system produces enough electric power to satisfy the load demand, and the extra power produced by the system is supplied to the electrolyzer to produce H_2.

b. During a cloudy day, the PEM FC stack is turned on by the control unit whenever the PV system and WECS do not produce enough electric power to be supplied to loads.

c. The novel MPPT technique implemented in the constructed hybrid power source provides the highest MPPT efficiency (99.60%) along with the shortest tracking convergence time(12 ms) in PV systems[11]

d. The MPPT technique provides the highest MPPT efficiency(99.28%)[8]along with the shortest tracking convergence time(15 ms) in WECSs. The constructed hybrid power generation system is standalone, so it can be widely used in remote areas where there is not any power distribution network. As future work, the grid-connected version of the hybrid system applicable to the areas where a local grid exists can be implemented by adding a bidirectional three-phase DC/AC inverter to the system.

In the above experiment we see that the author introduces a 3- phase system into the system. But our experiment is related to the single-phase system in which no phase overlapping is there and as we know in household purpose; we generally use the single-phase system.

Renewable hybrid system size optimization various electrochemical energy storage technologies

A.Kaabeche and Y. Bakelli [10] introduce a new approach to optimize the system parameters considering the various electrochemical energy storage technologies. The main objective of the proposed article is the establishment of rules and tools for energy management optimization as well as the sizing of an autonomous wind and solar production system using an electrochemical storage device. The optimization criterion is techno-economic in order to minimize the energy produced cost, while considering the reliability level required by the consumer. Four most recent nature inspired algorithms have been employed to solve this complex optimization problem. This included ant lion optimizer algorithm (ALO), grey wolf optimizer algorithm (GWO), krill herd algorithm (KH) and JAYA algorithm, which is used for the first time in renewable systems sizing. Thus, the conducted methodology permits to determine the optimal system configuration, by minimizing the unit electricity cost (UEC) for a specified loss of power supply probability (LPSP) while counting the excess energy. Three electrochemical battery technologies including, lead-Acid (LA), lithium-ion (Li-ion) and Nickel-Cadmium (Ni-Cd) have been considered in this study. In order to predict the future performance of the studied system, various sensitivity analyzes have been carried out taking into account, the impact of the lifetime, the depth of discharge (DOD) and the relative cost of diver’s battery technologies on the UEC. The simulation results demonstrate the supremacy of the JAYA algorithm against the other algorithms. JAYA converges [12,13] towards the optimal solutions for three battery technologies. It also shows that a 50% reduction in battery cost will reduce the cost of EUC by 30%, which would allow Li-ion batteries to become as competitive as LA batteries in terms of cost. Other similarly interesting results on the effect of DOD on UEC have been found. For DODs of 50% and 80% corresponding respectively, to Ni-Cd and Li-ion technologies, the UEC produced by the PV/Wind/Ni-Cd and PV/Wind/Li-ion systems becomes as attractive as that produced by the PV/Wind/LA system.

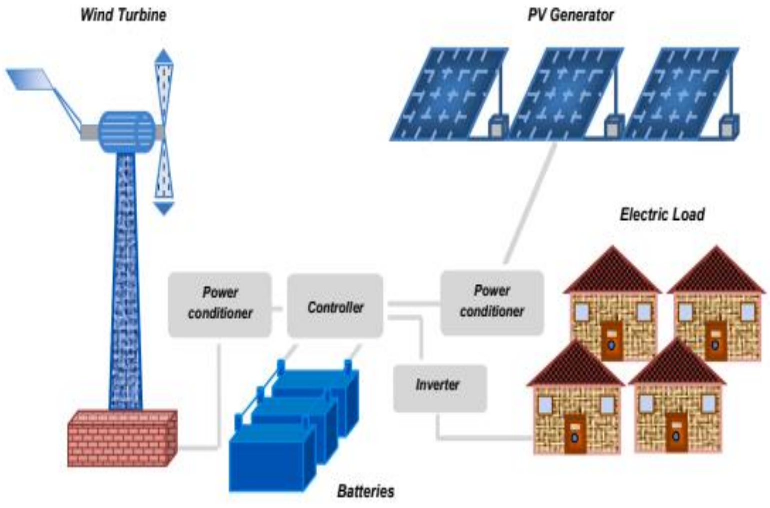

Figure 2. 12 Schematic diagram of grid independent solar PV/Wind/Diesel system [9]

The schematic diagram shows the total experimental setup. Here we can see one power conditioner is used. Power conditioner improves the quality of power to give into an electrical equipment. Actually, from wind turbine and solar PV we are getting static energy and we need to upgrade the quality of the power. After conditioning the power, it is taken into the charge controller.

This experiment tells a very big scenario that how we can minimize the overall system cost by improvising the optimized hybrid system. Below is the overview of global irradiance, wind speed and temperature on the earth on that year the experiment was done:

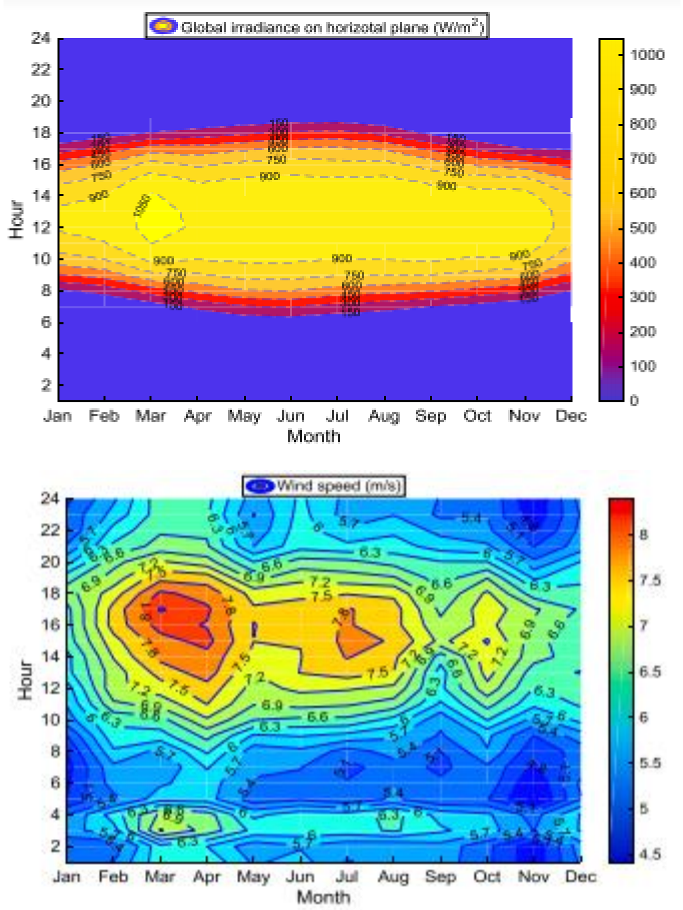

Figure 2. 13 Meteoroological conditions for optimal design solar irradiance and Wind speed [10]

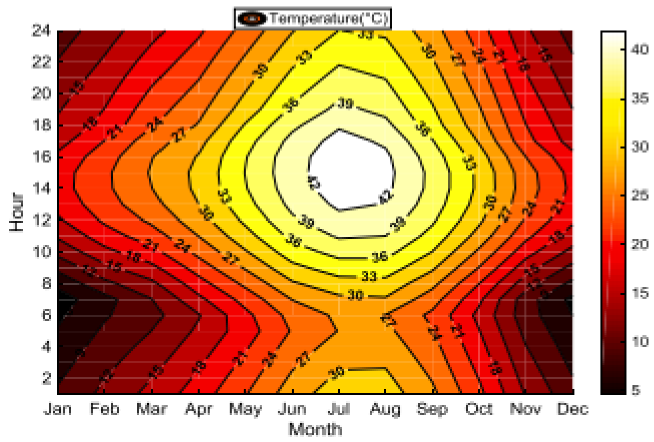

Figure 2. 14 Meteoroological conditions for optimal design ambient temperature [10]

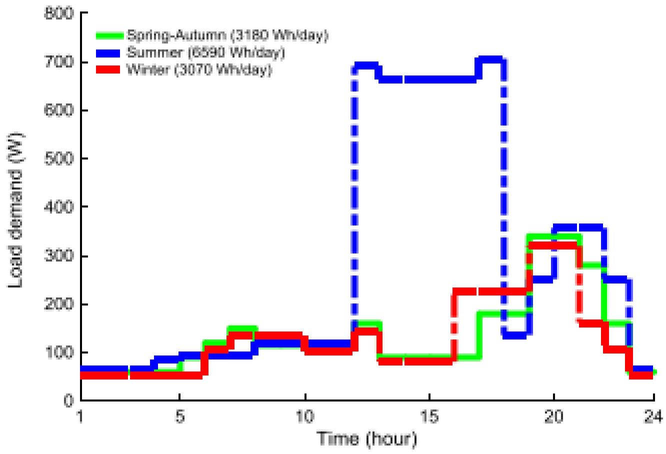

Figure 2. 15 Seasonal hourly load profile[9]

After observing the diagram of global irradiance, wind speed and temperature with respect to the time in month over a year we can assume the type of data produced by the experiment. Accordingly, the load demand and time are shown at different periods of the year (like summer, winter, spring-autumn). This article presents rules and tools for energy management optimization as well as the sizing of an autonomous wind and solar production system using an electrochemical storage device. For this purpose, we have used optimization techniques based on meta-heuristics usually employed to solve complex optimization problems. Among the most recent ones we have used, ALO algorithm, GWO algorithm, KH algorithm and Jaya algorithm, which is used as a frontrunner in renewable systems design. Thus, the conducted methodology makes it possible to determine the optimal system configuration, by minimizing the UEC for a desired LPSP. Three electrochemical energy storage technologies, namely: Lead-Acid (LA), Lithium-ion (Li-ion) and Nickel-Cadmium (Ni-Cd) have been considered in this study. In order to showcase the settled approach, a case study is lead to examine a hybrid PV/wind system that is intended to meet a group often households, situated in Adrar (27°52′N, 0°16′W, 262 m above the Sea) [11]. This region is located in the southwest of Algeria characterized by a hot desert climate typical of the hyper-arid Saharan zone, with a hot long summers and warm short winters. The input data of the developed algorithm comprise essentially, the meteorological data relating to the Adrar site, the technical and economic characteristics of individual system components and the average seasonal daily consumption characterized by a basic load and peak power especially for summer profile relating to the use of low consumption solar climbers. Our Implementation as a scope of research area of solar PV and wind hybrid system is that we can analyze the performance of battery and day by day the load fluctuation on the certain amount of load. So, we will analyze the efficiency of battery as well as the fluctuation of load.

Chapter 3

General Theory of Solar Photovoltaic Technology and Wind Turbine

3.1 Introduction

The Earth receives about 1353 W/m^2 of total solar irradiation before entering our environment and along with it we can say that the solar constant has come from the total solar radiation on earth. There are so many wastages of the solar energy in the environment itself. As so many layers are there above the earth and they especially ozone layer consumes a certain amount of solar energy from the solar radiation.

Along with the solar PV system we have a wind turbine system and as we know that the wind speed varies from time to time on a particular place. If the place is congested by buildings, malls etc. then it is too tough for wind to come into picture and rotate the turbine.

3.2 Components of a Photovoltaic plant:

As we have seen before, a photovoltaic plant is consisting of different elements to enable the conversion of solar energy into electrical energy. Most importantly we can see that a photovoltaic plant not always consists of these elements, it may dispense with one or more of these items, taking into account the type and size of the fed charges, as well as the nature of energy sources where the plant is situated.

3.3 Collection system

This system consists of a set of photoelectric cells, also called photocells or solar cells. Solar cells are the most basic unit of a solar photovoltaic system. A solar cell is an electronic device which directly converts text into electricity. Light shining on the solar cell produces both a current and a voltage to generate e power. This process requires firstly, a material in which the absorption of light raises an electron higher energy state, and secondly, the movement of this higher energy electron from the solar cell external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic RY conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a p-n junction.

These electronic devices are generally made of silicon, the second most abundant substance in the Earth. The cell size comes under range between 1 and 10 cm of diameter, and that can transform light energy (photons) into electrical energy (electrons) by the photovoltaic effect. It is important to notice that it accepts both direct and diffuse radiation and can generate electricity even on cloudy days. These cells are manufactured of a material which benefits from the photoelectric effect. Electrons, excited by the light, move through the silicon.

Certain chemical elements added to the composition of silicon. can set the path to follow the electrons on these free electrons are captured, the result is an electric direct current that can be used as electricity from a power between 1 and 2 W.

Silicon or other semiconductor materials used for solar cells can be single crystalline, polycrystalline and Amorphous. The key difference here in these materials is the degree to which the semiconductor has a regular, perfectly ordered crystal structure, and therefore semiconductor material may be classified with respect to the size of the crystals making up the material.

- Single Crystalline: Crystalline silicon is very efficient plated on the surface of solar panel so that the acceptance of solar rays increases. Single crystalline exhibits a very nice performance but the main drawback is the high cost. Firstly, silicon is heated and get molten and after cooling it becomes in a single crystal form. It has good performance having efficiency between 14 to 16%.

- Multi-Crystalline: When a single crystalline structured semiconductor material is separated by grain boundaries. Actually, the grain boundary reduces the cost and quality that of single-crystalline structure. But it reduces the performance of the solar panel and that is one of the drawbacks of the multi-crystalline structure.

- Amorphous: It is the non-crystalline structure of the silicon semiconductor. Actually, while in preparation of crystalline semiconductor, the molten silicon gets no crystallization that's why an amorphous substance we get. The efficiency of amorphous semiconductor is varied from 5 to 7%.

Photovoltaic cells for solar energy are called a photovoltaic module. A PV module consists of a number of interconnected solar cells (typically 36 connected in series) encapsulated into a single, high longevity, unit which is stable. The key purpose of encapsulating a set of electrically connected solar cells are there to protect the people a and their interconnecting wires from the typically harsh environment in which they are used and also that the user is protected from electrical shock. For example, solar cells, since they are relatively tiny and are prone to mechanical damage unless protected. In addition, the metal grid on the top surface of solar cell and the wires interconnecting the individual solar cells may be corroded by water or water at boiling point. The two key functions are to prevent mechanical damage to the solar cells and to prevent water from corrosion of the electrical contacts.

3.4 Solar photovoltaic module

There we can find so many PV modules exist and the module structure is often different for different types of solar cells or for different applications. For example, amorphous silicon solar cells are often encapsulated into a flexible PV array, while bulk silicon solar cells for remote power applications are usually rigid with glass front surfaces.

The front surface of a PV module must have a high transmission coefficient and rate of transmission in the wavelengths which can be used by the solar cells in the PV module. For silicon solar cells, the top surface must have high transmission of light in the wavelength range of 350 nm to 1200 nm[11]. In general, our minimum and maximum range of sight having range from 380 nm to 760 nm. In addition, the reflection from the front surface would be low. As we see theoretically this reflection could be reduced by applying an anti-reflection coating to the top surface, in practice these coatings are not robust enough to withstand the conditions in which most PV systems are used. An alternative technique to reduce reflection is to roughen or texture the plane. However, in this case the dust and dirt is more likely to attach itself to the top surface, and less likely to be dislodged by wind or rain. These modules are not therefore "self-cleaning", and the advantages of reduced reflection are quickly outweighed by loses incurred due to increased top surface soiling.

We can see there are so many choices for a top surface material including acrylic, polymers and glass. Tempered, low Fe-content glass is generally used as it is low cost, strong, stable, highly transparent to water and gases and has good self-cleaning characteristics.

An encapsulant is used to provide adhesion between the solar cells, the top surface and the rear surface of PV module. The encapsulant should be stable at elevated temperatures and

High UV exposing place. It should also be optically transparent and should have a low thermal resistance. EVA (ethyl vinyl acetate) is the most commonly used encapsulate material. EVA comes in thin sheets which inserted between the solar cells and the top surface and the rear surface. This sandwich is then heated nearly equal to150º C to make polymerization of the EVA and for bonding the module together.

The key characteristics of the rear surface of the PV module are that it must have low thermal resistance and that it must stop the incoming of water or water vapour. In most modules, a thin polymer sheet typically, Tedlar, is used as the rear surface. Some PV modules, known as bifacial modules are designed to accept light from either the front or the rear of the solar cell. In bifacial modules both the front and the rear must be optically transparent.

The final constructional component of the module is the edging or framing of the module. A conventional PV module frame is typically made of Al (atomic number 13). The frame structure should be free of projections which may result in the lodgement of water, dust or other matter.

Photovoltaic modules consist of a network of solar cells, as a circuit connected in series to increase the output voltage to the desired value (usually 12V or 14V), while connecting also multiple networks in parallel to increase the electric current to be able to be provided to the device.

The set of PV modules is called photovoltaic or solar panel or an array. The photovoltaic modules that create an array can be connected to each other in series, parallel or mixed, to obtain the voltage needed by the system. This makes photovoltaic systems to be able to suit any installation, large or small.

Type of power they provide is direct current (DC), so if you need alternating current (AC) or increase voltage, it will have to be added an inverter and/or a power converter.

Regarding the installation of these panels on any space on earth, it should be taken several considerations. Firstly, it is to be noted that throughout the year, the angle of sunlight varies, and that is why we must ensure that the direction of the light vector is parallel to normal vector of the panels. Thus, in the northern hemisphere, the panels are placed facing true south with an inclination to the horizon that corresponds to the angle to obtain the maximum sunrays, while in the southern hemisphere, the panels are oriented towards the geographical north-east.

The panels can be mounted on the roof of a house or anywhere it is suited. The place to be chosen must be free of any shadow that is there should not any burden panels and sunrays. Otherwise this would reduce significantly the performance of the panel. As a general rule, the panels are oriented so that the collecting surface is perpendicular to the midday sun the month in which maximum gain is desired, depending on the latitude and longitude to implement. Thus, the amount of daily energy provided by solar panels varies depending on the orientation, location, climate and season.

Moreover, the panels must be installed with a minimum distance from any area of approximately 50 cm permit an adequate airflow through the bottom, which prevents overheating that could reduce their performance.

There is another factor that might reduce its performance is dirt, as it is one of the obstacles on the way of sunlight. We know photovoltaic modules require little maintenance; it is needed a periodic cleaning. The depth of the effect depends on the volume of waste, so the layers if dust minimize the intense radiation in a uniform way, they are not dangerous and the power reduction is not usually important, while the waste from the birds show more serious problem. The action of rain may in many reduce the need for cleaning the photovoltaic modules. The cleaning operation is simply washing with proper treated water modules and a mild detergent (easily available in the market). Not considering these general rules, can reduce the efficiency of the module and along with it can reduce the lifetime of the equipment.

We can arrange solar panels parallel to each other or may be series with each other. And in this discussion for parallel connection the voltage of the panel will be constant and for series connection the current will be same.

The I-V characteristic of a solar cell and set of solar cells are given below, where we can easily analyse the type of power output for each case:

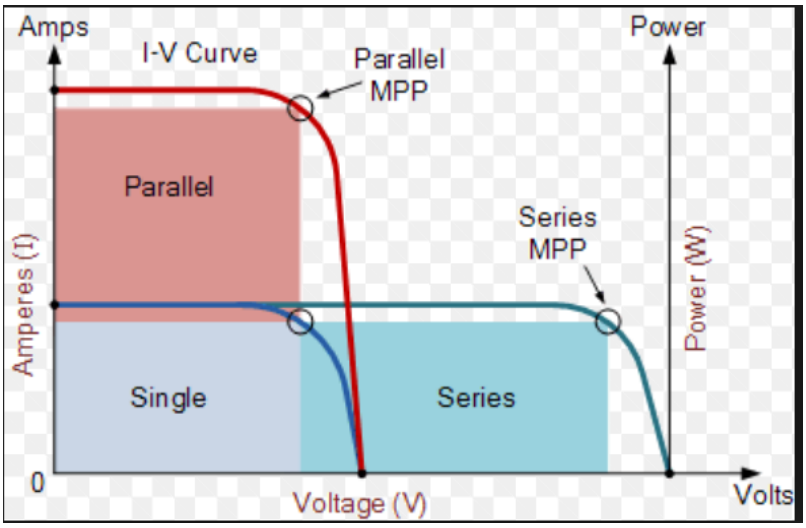

Figure 3. 1 I-V characteristic of the solar cell and set of solar cells

3.5 Wind Turbine:

A wind turbine made up of two major components and having looked at one of them, the rotor blade design in the previous tutorial, we can now look at the other, the wind generator which is the electrical machine used to generate electrical power. A low rpm electrical generator is used for converting mechanical energy into electrical energy.

- Electricity generation: Wind turbine generator or WTG's is the device by which the rotational energy converts into mechanical energy then the mechanical energy is converted to electric energy. If the load is more than that of the generation then the loss on the performance takes place and the continuation of the of the incident will harm the WTG. The type of WTG required for a particular location depends upon the energy contained in the wind and the characteristics of the machine.

- The Power vs Wind Speed graph for normal WTG is given below:

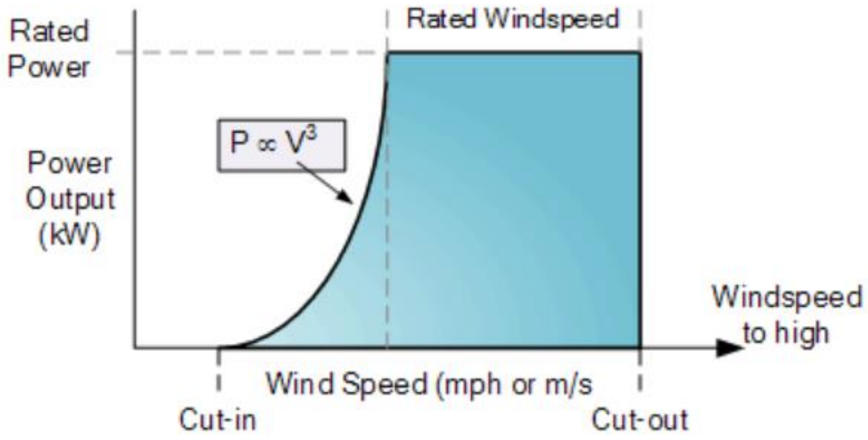

Figure 3. 2 The Power versus Wind speed graph for normal WTG

The power related to wind speed V like this:

$$P \propto V^3 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

It refers to $P = KV^3$ where K is a constant that depends on the environmental condition.

3.6 Storage system (Battery)

Solar cells, modules, panels, and arrays convert incident sunlight into de, but none of them can store the generated electricity. On the other hand, sunlight is available only for a certain fraction of the 24-hour daily cycle. If the electricity is required on demand any time of the day, then one must use energy storage apparatus to meet an isolated PV system, as this is the one responsible for storing dc power produced by the generator.

There is another reason for the use of energy storage in a PV system. A PV system with no energy storage supplies variable energy to the blond. In many applications, the load may not be able to withstand a changeable supply. In addition, if for some reason, the load is temporarily increased, the PV system without storage may be unable to serve it.

Battery storage is somehow at expensive but it offers the advantage of speed, modularity and transportability. The battery or chemical storage batteries are indispensable in almost all forms of application Battery storage is bank is a device capable of converting chemical potential energy into electrical energy. They are consisting of two electrodes immersed in an electrolyte where chemical reactions occur due to loading or unloading.

If the photovoltaic plant is properly sized, its mission is reliability. Its function is to supply the expected power consumption during periods when there is not enough solar energy to generate electricity voltaic modules. The sizing of the battery bank is based on the number of days of autonomy battery and it is expressed in Ampere-hour.

3.7 Control system (Charge controller)

The charge controller, charge regulator or battery regulator is an electronic device whose function is to limit the rate at which electric current is added to or drawn from electric batteries. It prevents charging and may protect against overvoltage, which can reduce battery performance or lifespan, may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or controlled discharges, depending on the battery technology, to protect battery life.

3.8 Power conversion system (DC-AC inverter):

The function of the inverter or converter is to transform the direct current generated by photovoltaic panels into alternating current, with the magnitude and frequency desired by the user. The output from the inverter can be injected to the electrical grid through their respective transformers used in electrical installations or can be used to feed the local loads or both.

These inverters have a microprocessor to ensure a sinusoidal curve with minimal distortion. Its operating principle is based on the use of electronic devices operating as switches which allows interrupting the current and reverse polarity he main characteristics of an inverter are determined by the input voltage generated by the panels. The inverter must be adaptable to the generator. Solar inverters also function as maximum power point trackers (MPPT)The main specification that has to be seen in a solar inverter is the maximum power, the output waveform, the operating frequency and efficiency, The efficiency of the inverter is defined as the ratio on the electric power delivered by the inverter to be used (output) and the extracted electricity of the generator (power input). Unlike solar panels, inverter efficiency is not constant and depends on the system load. For loading rates near to the rated power, efficiency is higher than for low loading rates.

There are different types of inverters available in the market, with different degrees of complexity and highly variable performance. Depending on the type of the loads to be fed, the simple square wave inverters, or the sinusoidal wave inverters can be used. Another important electrical parameter for inverters is the rate of harmonic distortion both for voltage and current. The less this distortion better will be the performance of the inverter.

3.9 Application of solar photovoltaic energy: photovoltaic plant

PV solar energy allows a large number of applications because it allows powering at the off

buttons, and injecting all the energy produced to the electricity grid for its distribution to the users.

3.9.1 Stand-Alone solar photovoltaic plant:

In isolated environments, which require little electrical power and network access is difficult, like

her stations or communications repeaters, solar panels are used as a viable economic alternative. To understand the importance of this possibility, it should be noted that approximately one-quarter of the world's population is lacking access to electricity.

As, it is commonly applied to feed many devices as autonomous or Semi-autonomous items,

watches to satellites, sensors, transmitters, and calculators, etc. They can also be used in rural electrification or isolated dwelling or livestock farm applications, telecommunications repeaters, autonomous lighting, signposting and alarms or other professional applications with the help of

age system if necessary: regulators and batteries. The process would begin with the generation of energy in photovoltaic modules at low voltages and currents. The level of the current and voltages depends on the number of modules used in series and parallel. Next it would go to the battery (or a set of batteries) where the generated electrical energy is to be stored, with the use of the regulator to avoid damaging the accumulation system. Finally, depending on the required load current, DC or AC will flow through an inverter, to get the energy in the form desired by the user.

3.9.2 Grid connected solar Photovoltaic system:

While solar Photovoltaic plant or system are connected to grid, it is called on-grid solar Photovoltaic plant or system. As the PV cells are directly connected to grid we have to maintain the set up without any damage of any equipment.

Solar panels generate electricity but in charge form so we need to invert it to AC, so that the grid will collect AC power from inverter and the frequency of overall system should be constant. A constant number of solar PV panels connected to utility grid can supply a certain number of load, but in case the load is increased then the remaining power is fed from grid to the consumer.

Chapter 4

Details of the small application of integrated wind solar PV system On The top of the roof:

4.1 Introduction:

Nowadays a variety of solar apparatus are popular because of the reduced part of the fossil fuel. Now a growing citizen is aware to use the solar apparatus as well as the advantage of wind energy. To make less pollution on the area people use the renewable energy.

4.2 The Technology:

We have a setup on the roof top of the building, School of Energy Studies, Jadavpur University. The energy stored by the solar PV as well as the wind turbine is static in form of electrical energy. Actually, the integrated system collects charge in the battery as DC form of electrical energy. Now the inverter converts the DC to AC and supply the load connected in the stair case of the department. The frequency is said to be constant while supplying to load i.e. 50 Hz.

4.3. Benefits and Considerations:

4.3.1 Low Amount of Carbon Emission:

- Prevents 150 pound of coal from being mined.
- Keep 105 gallons of water from being consumed during conventional electricity production.
- Refrain from SO_x and NO_x from the environment.

4.3.2 Less Pressure on The Power Grid:

It is a very disgraceful point to say that the integrated system could have supply a near about 520 W for a very less amount of time. So, the conventional energy gets saved for that particular time period.

4.3.3 Maintenance:

We need to maintain the solar PV panel and wind turbine by observing that any obstacle comes into picture. That means if any of them is unable to generate electricity when their favorable environmental condition is there. Along with it we need to maintain the batteries by putting distilled water over a time. If any irregularities are there in pouring water in the batteries, they will not be charged properly.

4.4 Existing Setup:

We have a setup of integrated or hybrid solar and wind system in our department. The system design and component specification will be discussed later.

4.4.1 Location of the Hybrid system:

The hybrid system is installed in the building of School of Energy Studies, Jadavpur University , Kolkata – 700032. The latitude and longitude of the place are: 22.5ºN and 88.36ºE respectively. The location are shown below:

Location of the hybrid system

4.4.2. Various Components:

There are so many components regarding the experiment as follows:

4.4.2.1. Solar Panels:

There are 3 solar panels connected together. Each of them having rated maximum power output is 105 W. They also have the voltage and current at maximum power are 18.65 V and 5.64 A respectively. The open circuit voltage is 22.72 V and the short circuit current is 5.98 A which is nearly equal to 6 A. And along with it the maximum permissible system voltage is 600 V. The solar panels are mounted on the south direction to get the maximum solar input in the daytime.

Figure 4. 2 The solar panels on the roof top

Figure 4. 3 The specification of solar panel

4.4.2.2. Wind Turbine:

The WT integrated with WTG have a capacity to produce 400 W in maximum power point. The size of the blade is nearly 1.8 feet and is mounted to the topmost part of the building and south-faced.

Figure 4. 4 Wind mill

4.4.2.3. Solar inverter:

Our inverter and embedded charge controller are from Geetanjali Solar, Suncraft Energy.The inverter gives us input AC voltage, output AC voltage (while it is on), battery voltage, frequency etc. The charge controller is embedded in the inverter which control the charging of the batteries.

Figure 4. 5 Inverter

4.4.2.4. Ammeters:

There are two ammeters connected in between the solar PV and battery and wind turbine and the battery. Actually, they are not the part of the system component. They have a range of 0-50 a AC/DC. One ammeter is connected to solar PV panel and the other is with the wind turbine.

Figure 4. 6 Ammeters

4.4.2.5. Fuse:

We have an HRC fuse which has the high rapturing capacity between the connection between solar and the battery. The rating of the fuse pickup current is 125 A and AC voltage of 415 V. The frequency is 50 Hz for the overall time.

Figure 4. 7 HRC fuse

4.4.2.6. Batteries:

We have two batteries connected in parallel to each other each are bought from Sola-Tubular company. The DC voltage of battery is 12 V and it varies while the battery gets charged or discharged simultaneously. The specification of the batteries are 120 Ah, C_{10} .

Figure 4. 8 Batteries

4.5 Conclusions:

This chapter concludes about various benefits, apparatus details and the benefits of the solar and wind hybrid system.

Chapter 5

RESULTS AND DISCUSSION

We have an integrated system of solar Photovoltaic and wind turbine connected to two 12 V ,120 Ah batteries. And along with it the batteries are connected to the 7 lights in the staircase of our department, School of Energy Studies, Jadavpur University, Kolkata 700032.

We have 3 solar panels each having a maximum power generation capacity of 105 W. So we get total power of 315 W, when they all operated under maximum power generation condition. Along with the solar PV system we get the wind turbine which has a generation of 400 W at peak power generation condition.

So all total we get 715 W at maximum power generation condition for both solar PV and wind turbine. But we are running a load nearly equal to 520 W for a time span and if we discharge more from the batteries then the inverter gets overloaded and gets heated soon. The graphical approach between load versus time and load versus battery voltage while discharging of batteries.

These figures are shown below and after analysis of the data stored, we get that on 25th April 2019 at 2.13.30 p.m. we get the highest current input to the battery from solar panel nearly 8.7 A that means the battery gets charged in a faster rate. But on that same time, we did not get any result on ammeter connected with wind turbine. Our motive is to find out the point or time on which the optimum output is taken from solar PV and wind turbine system separately.

But if we have a look on 24th May 2019, we can see that we got current readings from both wind and solar PV systems. On the same day we got sunny weather as well as the wind speed also above the cut-in voltage.

So, we can say at the weather condition as that of on 24th May 2019 is the perfect weather to get the optimized result. But in the whole span of my experiment we are able to get result very few days from both renewable systems. It is very difficult to optimize the power output with the help of few results.

On 20th May 2019 we get highest reading on ammeter connected to the wind turbine. We get nearly equal to 4 A reading from the ammeter coming from wind turbine. But at night the reading is taken (Actually permission to continue experiment is given by our professor) and at that time there is no sunlight so we get 0 A on ammeter connected to solar PV system. So, in this case we are unable to do the optimization as one result is blank.

Furthermore, we can see that on clean sunny weather and wind speed at least nearly equal to 10 m/s results in the optimization of solar PV and wind hybrid system.

We have given graphs of load versus time and load versus battery voltage for each day of experiment and along with what are the parameters which are needed to score. We can have a look on the tables namely 5.1, 5.2, 5.3.

From the graphs we can easily observe the rate of discharge of the batteries from open circuit (OC) condition to that of connected to load. The voltage gradually decreases while discharging through the load. In some cases, shown in the figures in this chapter that the discharge is not identical for all of the day. Hence, we can get an overview on the performance of the battery.

Along with that we observe the load curve in the work period. We can calculate the total energy produced in unit by the dc batteries through the inverter. We can have an overlook on the area of load curve. The areas are more or less same in all the days of experiment. So, we can say after the performance analysis of the system that the battery supplies to the load identically in all those days (from April 17,2019 to May 27,2019).

Following are the tables of the selected dates discussed before and the graphs regarding the experiment:

Thursday, April 25, 2019, 12:00 pm — 6:00 pm
Temperature: 36 / 34 °C, Solar irradiance: 5.32 kWh/m²
Haze. Humidity: 54%, Barometer: 29.72 "Hg, Wind direction: SSE, Wind:15 km/h.

Table 5. 1 **Collected results**

AC IN (V)	AC OUT (V)	LOAD (W)	BATTERY VOLTAGE (V)	FREQUENCY (Hz)	TIME (hh:mm:ss)	I_S (A)	I_W (A)
0	NOT SPECIFIED	0	13	50	14:05:18	7.1	0
1	229	0	12.5	50	14:02:40	7.1	0
2	230	0	12.4	50	14:00:02	7.1	0
1	230	526	12.4	50	14:01:50	7.2	0
1	230	520	12.2	50	14:02:40	8	0
1	230	521	12.1	50	14:03:30	8	0
1	230	521	12.1	50	14:04:20	8.1	0
1	230	520	12.1	50	14:05:10	8.3	0
1	230	520	12	50	14:06:00	8.3	0
1	230	519	12	50	14:06:50	8.4	0
1	230	522	12	50	14:07:40	8.4	0
1	230	522	12	50	14:08:30	8.5	0
1	230	522	12	50	14:09:20	8.5	0
1	230	522	11.9	50	14:10:10	8.6	0
1	230	525	11.9	50	14:11:00	8.6	0
1	230	523	11.9	50	14:11:50	8.7	0
1	230	524	11.9	50	14:12:40	8.6	0
1	230	523	11.9	50	14:13:30	8.7	0
1	230	526	11.9	50	14:14:20	8.6	0
1	230	527	11.9	50	14:15:10	8.6	0
1	230	528	11.9	50	14:16:00	8.5	0
1	230	528	11.9	50	14:16:50	8.5	0
1	230	528	11.8	50	14:17:40	8.5	0
1	230	529	11.8	50	14:18:30	8.5	0
1	230	529	11.8	50	14:19:20	8.5	0
1	230	529	11.8	50	14:20:10	8.5	0
1	230	530	11.8	50	14:21:00	8.5	0
1	230	529	11.8	50	14:21:50	8.5	0
1	231	530	11.8	50	14:22:40	8.4	0
0	230	0	12.8	50	14:23:30	8.7	0
0	NOT SPECIFIED	0	13	50	14:24:20	8.7	0

Friday, May 24, 2019, 12:00 pm — 6:00 pm
Temperature: 37/ 33 °C, Solar irradiance: 5.32 kWh/m^2
Scattered clouds. Humidity: 63%, Barometer: 29.57 "Hg, Wind direction: S, Wind: 21 km/h.

Table 5. 2 **Collected results**

AC IN (V)	AC OUT (V)	LOAD (W)	BATTERY VOLTAGE (V)	FREQUENCY (Hz)	TIME (hh:mm:ss)	I_S (A)	I_W (A)
0	NOT SPECIFIED	0	15	50	16:15:00	1.6	1
2	73	0	14.7	50	16:15:45	1.6	1
1	229	0	14.7	50	16:16:30	1.6	1
1	229	0	14.7	50	16:17:15	1.6	1
0	228	519	12.2	50	16:18:00	1.6	1
0	229	517	11.9	50	16:18:45	1.6	1
1	230	516	11.9	50	16:19:30	1.6	1
0	230	516	11.5	50	16:20:15	1.6	1
0	230	515	11.4	50	16:21:00	1.5	1
0	230	515	11.4	50	16:21:45	1.5	1
0	230	515	11.4	50	16:22:30	1.5	1
0	230	516	11.3	50	16:23:15	1.5	1
0	230	517	11.4	50	16:24:00	1.5	1
0	230	513	11.2	50	16:24:45	1.5	1
1	230	513	11.2	50	16:25:30	1.5	1
2	230	511	11.2	50	16:26:15	1.5	1
2	230	0	12.3	50	16:27:00	1.5	1
1	230	0	12.4	50	16:27:45	1.5	1
0	NOT SPECIFIED	0	12.5	50	16:28:30	1.5	1

Monday, May 20, 2019, 6:00 pm — 12:00 am
Temperature: 34/ 29 °C, Solar irradiance: 5.32 kWh/m²
Passing clouds. Humidity: 81%, Barometer: 29.7 "Hg, Wind direction: S, Wind: 18km/h.

Table 5. 3 **Collected results**

AC IN (V)	AC OUT (V)	LOAD (W)	BATTERY VOLTAGE (V)	FREQUENCY (Hz)	TIME (hh:mm:ss)	I_S (A)	I_W (A)
0	NOT SPECIFIED	0	15.8	50	19:06:25	0	4
1	230	0	15.7	50	19:07:36	0	4
1	231	524	12.8	50	19:09:00	0	4
0	230	520	12.7	50	19:10:13	0	4
0	229	520	12.6	50	19:11:26	0	4
1	230	521	12.6	50	19:12:39	0	4
1	230	518	12.4	50	19:13:52	0	4
0	230	514	12.3	50	19:15:05	0	4
0	230	517	12.1	50	19:16:18	0	2
0	230	518	120	50	19:17:31	0	2
0	230	518	11.9	50	19:18:44	0	2
0	230	520	11.9	50	19:19:57	0	2
0	230	515	11.6	50	19:21:10	0	2
1	230	516	11.6	50	19:22:23	0	2
2	230	514	11.6	50	19:23:36	0	2
1	230	518	11.5	50	19:24:49	0	1
1	230	518	11.5	50	19:26:02	0	1
0	230	515	11.2	50	19:27:15	0	1
0	229	520	11.2	50	19:28:28	0	1
0	230	0	12.5	50	19:29:41	0	1
0	NOT SPECIFIED	0	13.8	50	19:30:54	0	1

2. Another important overview of the load curve at an interval of 10 days. We have seen there is very less variation of the of the different load curves drawn on the figure. There is one abrupt change on the graph and that is at the starting of the experiment (happened in one day only). This thing can happen because of high inductive load is connected somewhere in the circuit or due to the wrong display of inverter.

There are two load curves one taken on daylight another is at night. The load curve at night also not varied from one to another. So, we can have an overlook on them:

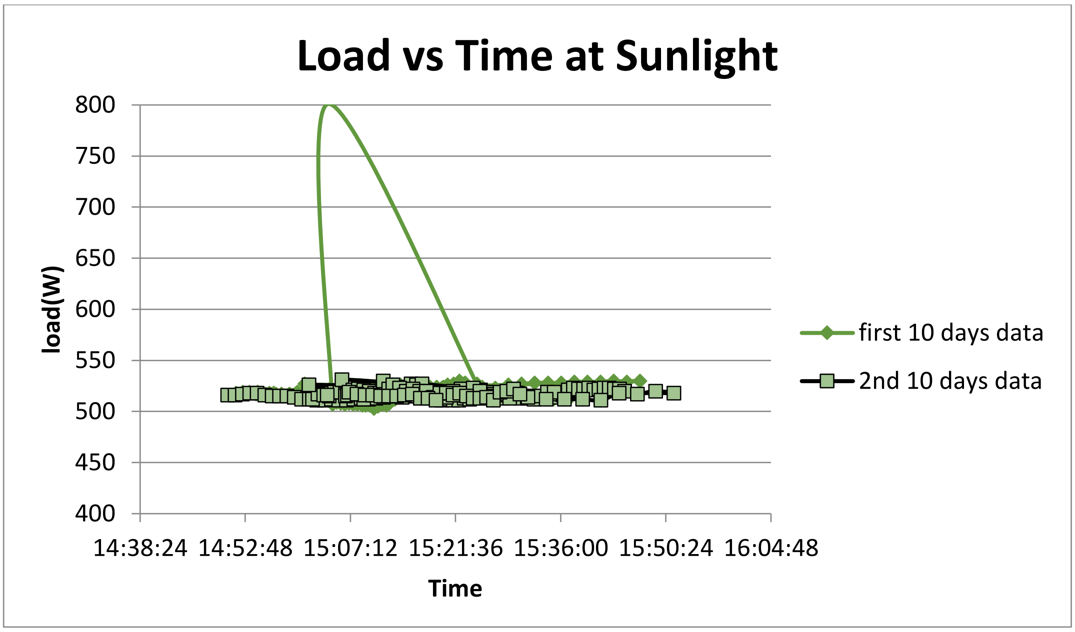

Figure 5. 1 Load vs Time at the presence of the Sunlight

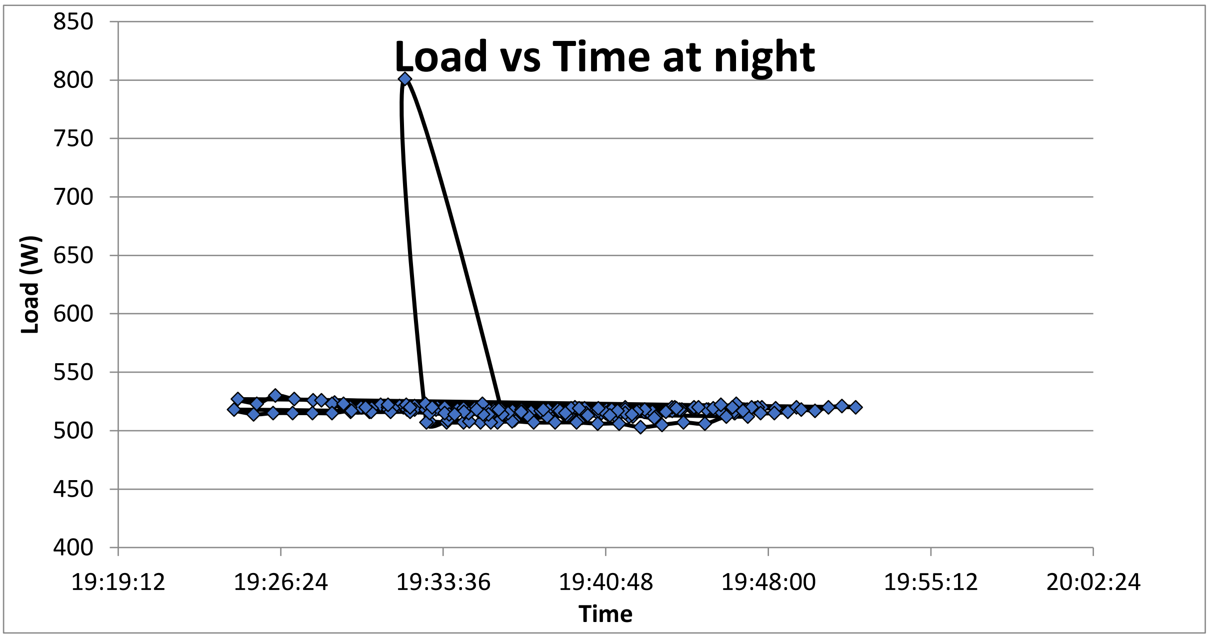

Figure 5. 2 Load vs Time at night

3. The battery voltage plays an important role in this experiment. We can analyze the performance of the battery. There is no record of data of charging of battery at day and night. We only analyze the discharging of battery with respect to time. As we see in the below figure (randomly taken one day's battery discharge data), firstly battery remains at very high potential before discharging. While the battery gets connected to the load then the previous open circuit condition will change to short circuit condition. And at the last of the experiment while the load is disconnected from the battery as well as inverter the battery voltage suddenly increases due to open circuit condition.

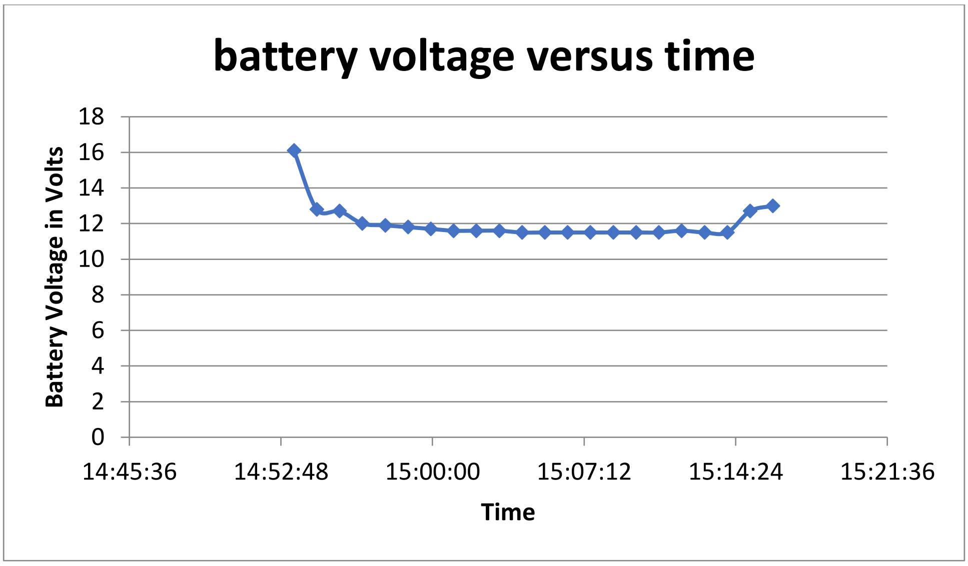

Figure 5. 3The discharging of battery with respect to time

4. Lastly, we are calculating the energy delivered by the battery to the load. The is not taken for same time every day, that's why we have plotted it on the graph day by day with respect to time. Here we can see that the energy versus time graph is increasing according to the time of loading. It means when we switch on the supply from battery to load for a very short time period, the energy will be generated in less amount and vice versa. These smooth graph shows the performance of the battery is good so that for higher time higher energy is produced. The charging and discharging of battery depend on the efficiency and performance of battery.

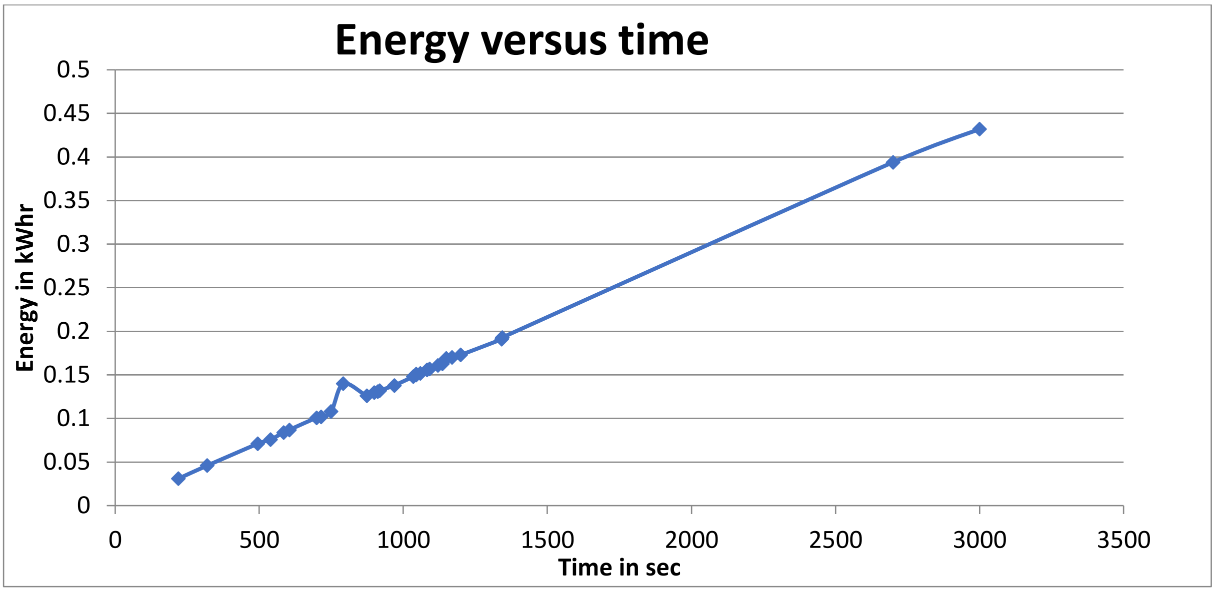

Figure 5. 4 Energy versus Time graph

Chapter 6

6.1 Conclusion

a. We have an overview on the discharge of the batteries and have recorded the graph between load in Watts versus battery voltage in volts. The graphs are drawn in wrong direction actually the voltage will get low while the discharge is ongoing. But we get the drops of voltage from open circuit (OC) to connected with the load at stairs.

b. The energy consumption can also be calculated from the area of the load versus time graphs shown in the chapter 6. Actually, the unit is kWhr, so the total numbers of units are the area under the load versus time graph.

c. The Sun is present throughout the day an no hazy weather is preferable for the experiment because the weather condition affects the solar irradiance as well as the wind speed so we need to take a remote place where solar and wind integrated system can be established.

d. Our drawback of the experiment is that we cannot optimize the integrated system properly due to the irregularities of data.

e. No disorder in environment is preferable for the experiment and if there then we need to take necessary action against it.

f. A major drawback there and that is harmonics. While we are converting a DC energy to AC, we need to take help of the inverter (embedded PWM techniques) there are so many harmonics such as 3^{rd},5^{th},7^{th} etc gets into our conventional system and it is too harmful for the system.

6.2 Future Scope of work:

a. We can install solar PV and wind integrated system in a remote place to get the optimized output. On hilly areas where there is no electricity. But we need to aware of the natural calamities occurred on earth such as earthquake, flood etc.

b. Another scope of work is that we have done our experiment for a certain load but if there is a variable load then we need to do the modulations so that the frequency remains same.

c. For household purpose (generally uses single phase connection) rather than our stair lights we could have installed the integrated system with the total building but it is different from the BIPV (Building Integrated Photovoltaic system). Because in BIPV there is no connection of wind turbine, so we can implement our hybrid system instead of BIPV for total building operation.

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