HYBRID WIND SOLAR ELECTRIC POWER SYSTEM

BY:
WALAA ELSHAFEE MALIK ELAMIN
INDEX NO. 084085

Supervisor
Dr. Kamal Ramadan

REPORT SUBMITTED TO
University of Khartoum
In partial fulfilment of the requirement for the degree of
B.Sc (HONS) Electrical and Electronic Engineering
(CONTROL ENGINEERING)
Faculty of Engineering
Department of Electrical and Electronic Engineering

July 2013
Declaration of originality

I declare that this report entitled “Hybrid Wind Solar Electric Power System” is my own work except as cited in the references. The report has not been accepted for any degree and is not being submitted concurrently in candidature for any degree or other award.

Signature : _________________________
Name : ____________________________
Date : ____________________________
ACKNOWLEDGEMENT

Unlimited praise for Allah as the number of his creatures, the gratification of himself, the weight of his throne and the extension of his words.

All the thanks and respect for the great women, my mother Alawia Hashim for always being there for me.

I would like to present my deep thanks to my supervisor Dr. Kamal Ramadan for his encouragement, patience, continuous support and great supervision.

Many thanks and best wishes for 084 batch, my partner Hiba Faisal and to my 074 friends.
DEDICATION

To my father’s soul
ABSTRACT

The hybrid system is a very useful system in the electrical power generation for the isolated small networks and for the grid tied systems, it combines two or more power sources to work concurrently or when just one is available according to a pre specified scenario.

In this project we proposed a hybrid system that combines wind and solar energy and have a storage unit along with a backup diesel generator, which is a good combination to use for a small network to ensure a steady and continuous supply for the load at all times and under different weather conditions.

This project aims to construct this kind of hybrid system for an isolated small network and supply the load with either wind energy, solar energy or battery unit with standby diesel generator and the coordination of these different resources is done by the microprocessor as the brain of the system and outputs to relays that connect the desired energy source.

The system was simulated for the different scenarios that could happen in cases of one unit is out and others in or vice versa and the impact that this would have in the stability of the small network.

The project objectives have been met using the software simulations and the results was satisfactory and analyzed for the instability and control system design.
للمستخلص

النظام الهجين هو نظام مفيد جداً في توليد الطاقة الكهربائية للشبكات الصغيرة المعزولة والأنظمة مربوطة الشبكة، فهو يجمع بين اثنين أو أكثر من مصادر القوة للعمل معاً في وقت واحد أو اثنين معاً (المحرك فيها) وفقاً لسيناريو ما محدد مسبقا. في هذا المشروع اقترحنا نظام هجين يجمع بين طاقة الرياح والطاقة الشمسية وله وحدة تخزين جنبًا إلى جنب مع مولد ديزل احتياطي. وهذا النظام مزيج جيد لاستخدامه في شبكة صغيرة لضمان وجود إمدادات ثابتة ومستمرة للتحميل في جميع الأوقات وتحت مختلف الظروف الجوية. ويهدف هذا المشروع لبناء هذا النوع من النظام الهجين لشبكة صغيرة معزولة وإمداد الحمل إما بطاقة الرياح أو الطاقة الشمسية أو السطحية أو وحدة بطارية مع مولدات الديزل، وتنسيق هذه الموارد المختلفة من قبل المعالج والمخرجات المطلوبة من مصدر الطاقة المطلوب. تم محاكاة النظام لجميع السيناريوهات المتوقعة في وجود إحدى الوحدات وخروج الأخرى والعكس، وللتأثير الناتج في استقرار الشبكة الصغيرة. وقد تم الابتعاد بأهداف المشروع باستخدام برامج المحاكاة وكانت النتائج مرضية كما تم تحليلها لحالة عدم الاستقرار وتصميم نظام التحكم.
Table of Contents

Declaration of originality.................................................................................................................. ii
ACKNOWLEDGEMENT .......................................................................................................................... iii
1 DEDICATION ........................................................................................................................................ iv
ABSTRACT ................................................................................................................................................ v
المستخلص ................................................................................................................................................ vi
List of figures........................................................................................................................................... x
List of tables........................................................................................................................................... xii
List of equations ....................................................................................................................................... xiii
List of abbreviations ............................................................................................................................. xiv

CHAPTER ONE  INTRODUCTION ............................................................................................................. 1
1.1 Overview ............................................................................................................................................... 1
1.2 Problem Statement ............................................................................................................................... 1
1.3 Project motivation ............................................................................................................................... 2
1.4 Objectives ........................................................................................................................................... 2
1.5 Methodologies .................................................................................................................................... 2
1.6 Report layout ....................................................................................................................................... 2

CHAPTER TWO LITREATURE REVIEW ................................................................................................. 4
2.1 Energy Overview ................................................................................................................................ 4
2.1.1 Introduction .................................................................................................................................... 4
2.1.2 Non-renewable resources ............................................................................................................ 4
2.1.3 Renewable resources ................................................................................................................... 5
2.2 Solar Systems ...................................................................................................................................... 5
2.2.1 Photovoltaic Systems .................................................................................................................... 5
2.2.2 PV System Components ............................................................................................................. 5
2.2.3 Advantages of PV System ........................................................................................................... 6
2.2.4 Disadvantages of PV System ....................................................................................................... 7
2.3 Wind Systems ..................................................................................................................................... 8
2.3.1 Wind Resource ........................................................................................................................... 8
2.3.2 Wind Energy Systems ................................................................................................................ 9
2.3.3 Wind System Components ................................................................. 9
2.3.4 Advantages of Wind System ............................................................. 10
2.3.5 Disadvantages of Wind System ........................................................... 11
2.4 The Electrical Grid ................................................................................. 11
2.4.1 Electrical Grid Definition ................................................................. 11
2.4.2 Electrical Grid’s Components .............................................................. 11
2.5 The Hybrid Systems .............................................................................. 12
2.5.1 2.5.1 Introduction ............................................................................... 12
2.5.2 Hybrid System’s Components ............................................................. 12
2.5.3 Advantages of Hybrid Systems .............................................................. 13
2.5.4 Grid Connection Power Electronic Equipments .................................. 13
2.6 Energy potential in Sudan ........................................................................ 15
2.6.1 Energy growth ................................................................................... 15
2.6.2 Solar .................................................................................................... 16
2.6.3 Wind .................................................................................................... 16
2.7 Summary .................................................................................................. 17
3 Chapter Three METHODOLOGY ............................................................... 18
3.1 Introduction.............................................................................................. 18
3.2 Methodology and Flow Chart ................................................................. 18
3.3 Models ..................................................................................................... 20
3.3.1 PV Systems ......................................................................................... 20
3.3.2 Wind Systems ..................................................................................... 24
3.4 Proposed analysis of data ........................................................................ 26
3.4.1 Load flow analysis .............................................................................. 26
3.4.2 Transient stability analysis ................................................................. 26
3.5 Summary .................................................................................................. 27
4 Chapter four Design of Hybrid system control ......................................... 28
4.1 Introduction ............................................................................................. 28
4.2 Decision Makers (Microcontroller) .......................................................... 28
4.2.1 A microcontroller has seven main components .................................. 29
4.3 Code Vision AVR Compiler ..................................................................... 29
4.4 Proteus simulator ........................................................................................................... 30
4.4.1 Major features of PROTEUS VSM include .......................................................... 31
4.5 Relays .......................................................................................................................... 31
4.6 Control Circuit Design ............................................................................................... 32
4.6.1 All generation sources are off .................................................................................. 32
4.6.2 Only Wind is connected .......................................................................................... 33
4.6.3 Only solar is connected ........................................................................................... 35
4.6.4 When solar and wind both are available .................................................................. 37
Shown in figure (4-10). ...................................................................................................... 37
4.6.5 Only the battery is connected .................................................................................. 39
4.6.6 Only the diesel generator is connected .................................................................... 40
4.7 Discussion .................................................................................................................... 41
5 Chapter 5 Hybrid Wind-Solar System Simulation ......................................................... 43
5.1 Introduction .................................................................................................................. 43
5.2 Adopted Software ........................................................................................................ 43
5.2.1 ETAP ® .................................................................................................................. 43
5.3 Testing the impact of Hybrid system on existing network ........................................ 46
5.3.1 System Modification ............................................................................................... 46
5.3.2 Steady-State Stability Simulation and Results......................................................... 47
5.3.3 Transient Stability Analysis ..................................................................................... 53
5.4 Discussion of the results ............................................................................................. 57
6 Chapter six Conclusion and future work .................................................................... 59
6.1 Conclusion ................................................................................................................... 59
6.2 Future work ................................................................................................................ 59
Bibliography ..................................................................................................................... 60
Appendix A: microprocessor control code ................................................................. A-1
Appendix B: Atmega16 Microcontroller Pin description ................................................. B-1
List of figures

Figure 2-1 Wind System .................................................. 9
Figure 3-1 Flow Chart of the process .................................. 19
Figure 3-2 Typical PV GRID-TIE system .......................... 20
Figure 3-3 Typical PV grid tie with battery ......................... 22
Figure 3-4 Typical PV stand alone system ......................... 23
Figure 3-5 PV direct ....................................................... 24
Figure 3-6 Connection of Stand-alone Wind System .......... 24
Figure 3-7 Grid-Tied Wind System with battery .................. 25
Figure 3-8 Grid-Intertied wind without battery backup ........ 26
Figure 4-1 Atmega16 Microcontroller ................................ 29
Figure 4-2 Code Vision AVR ........................................... 30
Figure 4-3 Proteus ........................................................ 31
Figure 4-4 Relay .......................................................... 31
Figure 4-5 All sources off .............................................. 33
Figure 4-6 Wind without excess power ............................. 34
Figure 4-7 Wind with excess power .................................. 35
Figure 4-8 Solar without excess power ............................. 36
Figure 4-9 Solar with excess power .................................. 37
Figure 4-10 Wind and Solar without excess power .............. 38
Figure 4-11 Wind and Solar with excess power ................. 39
Figure 4-12 Battery ....................................................... 40
Figure 4-13 Diesel Generator .......................................... 41
Figure 5-1 ETAP modes ................................................. 44
Figure 5-2 Edit Mode ..................................................... 44
Figure 5-3: IEEE 9- Bus Basic System ............................... 46
Figure 5-4: The PV/Wind Hybrid System ......................... 47
Figure 5-5 Steady State Stability Results (Case-1) ............... 48
Figure 5-6 Steady State Stability Results (Case-2) ............... 49
Figure 5-7 Steady State Stability Results (Case-3) ............... 50
Figure 5-8 Steady State Stability Results (Case-4) ............... 51
Figure 5-9 Steady State Stability Results (Case-5) ............... 52
Figure 5-10 Steady State Stability Results (Case-6) ............. 53
Figure 5-11 Transient Stability Results (Case-1) .................. 54
Figure 5-12 Generator Power Angle (Case-1) .................... 54
Figure 5-13 Transient Stability Results (Case-2) .................. 55
Figure 5-14 Generator Power Angle (Case-2) .................... 55
Figure 5-15 Transient Stability Results (Case-3) ............... 56
Figure 5-16 Generator Power Angle (Case-3) .............................................................. 56
Figure 5-17 Transient Stability Results (Case-4) ....................................................... 57
Figure 5-18 Generator Power Angle (Case-4) ............................................................ 57
List of tables

Table 5-1 ETAP Study Modes .................................................................45
Table 5-2 Steady State Stability Results (Case-1) .....................................48
Table 5-3 Steady State Stability Results (Case-2) .......................................49
Table 5-4 Steady State Stability Results (Case-3) .....................................50
Table 5-5 Steady State Stability Results (Case-4) .....................................51
Table 5-6 Steady State Stability Results (Case-5) .....................................52
Table 5-7 Steady State Stability Results (Case-6) .....................................53
List of equations
Equation 2-1 Wind Power........................................................................................................8
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>VAC</td>
<td>Voltage Alternating Current</td>
</tr>
<tr>
<td>WT</td>
<td>Wind Turbines</td>
</tr>
<tr>
<td>KWh</td>
<td>Kilo Watt hour</td>
</tr>
</tbody>
</table>
CHAPTER ONE
INTRODUCTION

1.1 Overview

It is increasingly becoming accepted that renewable energy has a decisive place in the future energy system and that the “future” may not be very far away, considering not just issues of greenhouse gas emissions and the finiteness of fossil and nuclear resources, but also their uneven distribution over the Earth and the increasing political instability of precisely those regions most endowed with the remaining non-renewable resources.

Hybrid systems by definition contain a number of power generation devices such as wind turbines, photovoltaic, micro-hydro and/or fossil fuel generators. Hybrid power systems range from small systems designed for one or several homes to very large ones for remote island grids or large communities.

Hybrid power systems are seen as a way to provide power to the many remote communities in the developing world where the costs for large scale expansion of electrical grids are prohibitive and the transportation costs of diesel fuel are also very high.

The use of renewable power generation systems reduces the use of expensive fuels, allows for the cleaner generation of electrical power and also improves the standard of living for many people in remote areas.

1.2 Problem Statement

The rate at which the energy is being produced and consumed can damage our world in many ways, so designing a system that combines multiple renewable and non-renewable resources is the best solution, wind and energy individual electric power systems would not give a continuous supply because they are changing with the weather...
conditions, so a system that combines both sources and save energy when they are absence to ensure a continuous supply of power is required.

1.3 Project motivation

To insure sufficient and continuous supply for the load with a clean, regenerated power sources.

1.4 Objectives

The objectives of this project are:

1- Design and simulate a control scheme for the hybrid wind solar system with battery and backup generator.

2- Study the stability of this system for different load and supply cases.

1.5 Methodologies

- ETAP software.
- Code vision compiler.
- Proteus simulator.

1.6 Report layout

This report is organized in 6 chapters:

Chapter 2 (Literature Review): This chapter presents the solar and wind energies and systems in general with a general view of the hybrid system.

Chapter 3 (Models and Methodology): This chapter handles the methodology of the project and the models of PV and wind energy systems.

Chapter 4 (design of hybrid system control): This chapter carries out the overall design and the simulation of the control scheme.

Chapter 5 (Hybrid Wind-Solar System Simulation): This chapter includes the simulation of the hybrid system and discusses the load flow and transient stability analysis.
Chapter 6 (Conclusion and Future Work): This chapter is a conclusion and recommendations for future work.
2.1 Energy Overview

2.1.1 Introduction

The term “Energy” is defined as the ability of producing work. Energy is a compound word and comes from the Greek words: en + ergon, which mean work inside a body. The normal technical definition is that energy is the capacity or ability to do work. A more scientific definition of energy was given by the famous physicist Max Planck:

“The ability of a system to produce outside activity”.

Energy is something that we cannot touch, see, smell or hear. People and civilizations couldn’t survive without it. The energy is an essential part of our daily life. Nothing could happen without energy. We depend on the hundreds of different ways which it appears in nature. Our organisms need energy to move and our machines need energy to function as well. [1]

2.1.2 Non-renewable resources

Sufficient, reliable sources of energy are a necessity for industrialized nations. Energy is used for heating, cooking, transportation and manufacturing. Energy can be generally classified as non-renewable and renewable. Over 85% of the energy used in the world is from non-renewable supplies. Most developed nations are dependent on non-renewable energy sources such as fossil fuels (coal and oil) and nuclear power. These sources are called non-renewable because they cannot be renewed or regenerated quickly enough to keep pace with their use. Industrialized societies depend on non-renewable energy sources. Fossil fuels are the most commonly used types of non-renewable energy. The three main types of fossil fuels are coal, oil, and natural gas.
2.1.3 Renewable resources

An alternative to the nuclear and fossil fuel power is renewable energy technologies (hydro, wind, solar, biomass, geothermal, and ocean). Large-scale hydroelectric projects have become increasingly difficult to carry through in recent years because of competing use of land and water. Relicensing requirements of existing hydro plants may even lead to removal of some dams to protect or restore wildlife habitats. Among the other renewable power sources, wind and solar have recently experienced a rapid growth around the world. Having wide geographical spread, they can be generated near the load centers, thus simultaneously eliminating the need of high voltage transmission lines running through rural and urban landscapes. [2]

2.2 Solar Systems

2.2.1 Photovoltaic Systems

A system used to transform solar radiation directly into electricity. At the heart of a solar power system, also known as solar electric system, are solar cells which are interconnected to form solar module (solar panels) and solar array. The size and configuration of a system depend on its intended task. Modules and arrays cube used to charge batteries, operate motors, and to power any number of electric loads. With the appropriate power conversion equipment, solar power system can produce alternating current (AC) compatible with any conventional appliances, and can operate in parallel with, and interconnected to. Among the components of a complete solar power system may be a DC-AC power inverter, a battery bank, a system and battery controller, auxiliary energy sources and sometimes the specified electrical load (appliances).

2.2.2 PV System Components

PV system basics:

- Panels: PV panels are the single biggest expense of a PV system. Their placement and mounting affect the system performance more than any other facet of the job.

- Mounting equipment: Mounting PV panels is of critical importance. First, it is needed to mount the panels where they'll get maximum sunshine over the course of a
year. But the more difficult problem is to mount them with enough integrity that they'll stay put for 25 years or more.

- **DC-to-AC inverters:** Inverters take the low-voltage, high-current signals from the PV panels and convert them into 120VAC (or 240 VAC), which is directly compatible with grid power. From a reliability standpoint, they are generally the weak link in any PV system, so quality is a must.

- **Disconnect switches:** Disconnect switches are of critical importance, and they need to be mounted within easy reach.

### 2.2.3 Advantages of PV System

1. The fuel for photovoltaic, sunlight, is practically infinite, free, and easily accessible.

2. Photovoltaic panels are extremely reliable and require low maintenance even in harsh conditions.

3. Photovoltaic systems are very versatile as they are suitable for loads of any size; they can provide a couple of watts for small loads like lanterns or electronic gadgets, a couple of kilowatts for loads like heavy machinery and households, or a couple of megawatts for solar power stations.

4. Photovoltaic systems are versatile also in the sense that they can be stand-alone, local grid, central grid-connected or even hybrid (in conjunction with other technologies like wind or hydro) systems.

5. Photovoltaic systems are an ideal choice and turn out to be cheaper for remote applications away from the grid as infrastructure costs of electricity transmission can be avoided.

6. Photovoltaic systems work best when we need energy the most, i.e. during peak energy demand period of the day. This reduces infrastructure costs for fossil-based generation plants as they have to be designed to meet peak demands, while they run to meet that demand only for a short period of time.

7. Photovoltaic systems are modular, where additional power generating capacity can readily be added.
8- Photovoltaic systems last at least thirty years as typically there are no moving parts involved in electricity generation; consequently, they don’t create any noise pollution.

9- Photovoltaic conversion does not involve any polluting emissions, combustion, radioactivity, high temperature and pressure process or disposal or raw materials.

10- Photovoltaic systems have a very short lead time for installation.

11- Photovoltaic has a high rate of public acceptance and an excellent safety record.

12- Photovoltaic is a green technology and has the potential to play a major role in controlling greenhouse gases and global warming.

13- Photovoltaic industries create jobs in addition to energy, and help the economic development of societies. [3]

2.2.4 Disadvantages of PV System

1- The main disadvantage of photovoltaics is its relatively high initial cost compared to many other large-scale electricity generating sources. However, the cost of solar electricity has dramatically reduced over the last couple of years with advances in technology. Moreover, the cost of photovoltaics will further reduce as more and more systems will be deployed (economies of scale) and an infrastructure starts revolving around it.

2- Even though the sunlight reaching earth carries 6,000 times greater energy than the global requirement, the power density of sunlight is relatively low. This means that photovoltaic tends to be less suited for applications that are physically small compared to the energy they require.

3- The output of photovoltaic systems is variable depending on the availability of solar radiation. Areas with greater cloud cover and shorter days will experience lower power generations, and such systems have to be designed accordingly.

4- Photovoltaic energy is typically stored in batteries, which increases the costs and maintenance of such systems. However, there is a tremendous thrust to improve energy storage technologies such as solar-hydrogen systems.
5- Photovoltaic modules are typically only 13-18% efficient; this low efficiency is one of the dominant causes for the high cost. Again, this technology is aggressively pursued to further photovoltaic cell and system efficiency.

6- In spite of the popularity of the concept of photovoltaics, there is a vast lack of knowledge, and hence, faith in this technology. Confidence in this technology will be gained with education and examples. [3]

2.3 Wind Systems

2.3.1 Wind Resource

Wind energy is derived fundamentally from solar energy via a thermodynamic process. Sunlight warms the ground causing air above it to rise. The ensuing pressure differential causes air from elsewhere to move in, resulting in air motion (wind). Different regions on earth are heated differently than others—primarily a function of latitude. Air motion is also affected by the earth’s rotation.

The net effect is that certain parts of the world experience higher average winds than others. The regions of highest winds are the most attractive for extracting its energy: Theoretically, the power which can be extracted from the wind is proportional to the cube of the velocity. The power that can be extracted in practice, however, is somewhat less than proportionally related to the cube of velocity, according to equation (2-1).

$$p = C_p \frac{1}{2} \rho A V^3$$

Equation 2-1 Wind Power

Where

P= power extracted

$C_p$= power coefficient

$\rho$= air density

A= area swept by the wind

V= wind speed
From the previous equation it is seen that the power in the wind is proportional to:

- The area of windmill being swept by the wind.
- The cube of the wind speed.
- The air density - which varies with altitude.

2.3.2 Wind Energy Systems

Converting the energy in wind into a socially useful electrical or mechanical form involves many types of processes which all have their own particular characteristics. Some of these processes are well developed, others less so. Figure 2-1 shows the wind system.

![Wind System](image)

**Figure 2-1 Wind System**

2.3.3 Wind System Components

2.3.3.1 Turbines

Most small WTs manufactured today are horizontal-axis, upwind machines that have two or three blades. These blades are usually made of a composite material, such as fiberglass.

The turbine's frame is the structure onto which the rotor, generator, and tail are attached. The amount of energy a turbine will produce is determined primarily by the
diameter of its rotor. The diameter of the rotor defines its "swept area," or the quantity of wind intercepted by the turbine. The tail keeps the turbine facing into the wind.

2.3.3.2 Towers

Because wind speeds increase with height, a small wind turbine is mounted on a tower. In general, the higher the tower, the more power the wind system can produce.

Relatively small investments in increased tower height can yield very high rates of return in power production. For instance, to raise a 10-kilowatt generator from a 60-foot tower height to a 100-foot tower involves a 10% increase in overall system cost, but it can produce 25% more power.

Most turbine manufacturers provide wind energy system packages that include towers. There are two basic types of towers: self-supporting (free-standing) and guyed.

There are also tilt-down versions of guyed towers. Most home wind power systems use a guyed tower, which are the least expensive and are easier to install than self-supporting towers. However, because the guy radius must be one-half to three-quarters of the tower height, guyed towers require enough space to accommodate them.

While tilt-down towers are more expensive, they offer the consumer an easy way to perform maintenance on smaller light-weight turbines, usually 10 kilowatt or less. Tilt-down towers can also be lowered to the ground during hazardous weather such as hurricanes. Aluminum towers are prone to cracking and should be avoided.[4]

2.3.4 Advantages of Wind System

1- The wind is free and with modern technology it can be captured efficiently.
2- Once the wind turbine is built the energy it produces does not cause greenhouse gases or other pollutants.
3- Although wind turbines can be very tall each takes up only a small plot of land. This means that the land below can still be used. This is especially the case in agricultural areas as farming can still continue.
4- Many people find wind farms an interesting feature of the landscape.
5- Remote areas that are not connected to the electricity power grid can use wind turbines to produce their own supply.
6- Wind turbines have a role to play in both the developed and third world.
7- Wind turbines are available in a range of sizes which means a vast range of people and businesses can use them. Single households to small towns and villages can make good use of range of wind turbines available today. [5]

2.3.5 Disadvantages of Wind System

1- The strength of the wind is not constant and it varies from zero to storm force. This means that wind turbines do not produce the same amount of electricity all the time. There will be times when they produce no electricity at all.

2- Many people feel that the countryside should be left untouched, without these large structures being built. The landscape should left in its natural form for everyone to enjoy.

3- Wind turbines are noisy. Each one can generate the same level of noise as a family car travelling at 70 mph.

4- Many people see large wind turbines as unsightly structures and not pleasant or interesting to look at. They disfigure the countryside and are generally ugly.

5- When wind turbines are being manufactured some pollution is produced. Therefore wind power does produce some pollution.

6- Large wind farms are needed to provide entire communities with enough electricity. [5]

2.4 The Electrical Grid

2.4.1 Electrical Grid Definition

An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. Grid Tie means that the system is hooked into the utility company. Off the grid means the system is not connected to the utility company. [6]

2.4.2 Electrical Grid’s Components

1- Power stations that produce electricity from combustible fuels (coal, natural gas, biomass) or non-combustible fuels (wind, solar, nuclear, hydro power).
2- Transmission lines that carry electricity from power plants to demand centers.

3- Transformers that reduce voltage so distribution lines carry power for final delivery. [6]

2.5 The Hybrid Systems

2.5.1 Introduction

Hybrid power systems combine two or more energy conversion devices, or two or more fuels for the same device, that when integrated, overcome limitations inherent in either. Hybrid Power Systems incorporate several electricity generating components with usually one major control system which enables the system to supply electricity in the required quality. Figure (2-2) shows the hybrid connection.

Components for electricity generation can utilize renewable energy sources like wind turbines, photovoltaic, solar thermal, hydro power, wave power or biomass power stations. [7]

![Wind/Solar Hybrid Power System](image)

Figure 2-2 Wind-Solar Hybrid System

2.5.2 Hybrid System’s Components

The wind-solar hybrid system mainly consists of one or two aero generators along with PV panels of suitable capacity, connected with charge controller, inverter, battery bank, etc. to supply AC power.
1- PV Module (PV Array): A number of PV panels connected in series or/and in parallel giving a DC output out of the incident irradiance. Orientation and tilt of these panels are important design parameters, as well as shading from surrounding obstructions.

2- Wind turbine: This is installed on top of a tall tower, collects kinetic energy from the wind and converts it to electricity that is compatible with a home’s electrical system.

3- Hybrid controller: are designed to integrate all three (the DC power from the solar array, the AC/DC or three-phase AC from the wind turbine, and the power from the backup).

4- Battery bank: can be a single battery or multiple batteries connected together to create essentially one large battery of the required voltage and amp-hour capacity. In some ways the battery configuration and capacity are the most important electrical power decision to make, and a wise choice can help guarantee a steady supply of electrical power as well as a system that is simple to operate and maintain.

5- Inverter: A power converter that inverts the DC power from the panels into AC power. [8]

2.5.3 Advantages of Hybrid Systems

1- Hybrid systems can address limitations in terms of fuel flexibility, efficiency, reliability, emissions and / or economics.

2- Achieving higher reliability can be accomplished with redundant technologies and/or energy storage. Some hybrid systems typically include both, which can simultaneously improve the quality and availability of power.

3- Hybrid systems can be designed to maximize the use of renewables, resulting in a system with lower emissions than traditional fossil-fueled technologies.

4- Hybrid systems can be designed to achieve desired attributes at the lowest acceptable cost, which is the key to market acceptance. [9]

2.5.4 Grid Connection Power Electronic Equipments

DC-AC/AC-DC converters are used to solve connection problems of hybrid resources to grid. The main concern is differences of wind speed and frequency of system which forces us to use some interference equipments to change the frequency and keep it in the adequate boundaries provided by operator.
The inverters/converters are used in connection of wind energy systems to grid to facilitate the frequency variations smoother.

Rectifiers and inverters are used in to change the frequencies and enhance amplitude of grid connection voltage as well. Since both voltage and frequency of connection should stay stable, these AC-DC-AC connections in wind turbines and DC-DC-AC connections in photovoltaic cells are used.

These converters used include a few circuits for rectifiers, inverters in AC sides and harmonic and ripple filters. So the output voltages are kept constant and provided by outcome of rectifiers, the filters in the DC section eliminate harmonics and provide a smoother outcome and the voltage levels and waveform states are controlled in the inverter parts of the system.

The important point on connection of wind turbines in systems is that phase, amplitude of voltage, frequency and many other factors should meet the system specifications that wind or solar system wants to be connected to as hybrid resources.

These parameters are determined and changed by using power electronic equipments used in system, hence the role of these devices become more important.

AC inverters have the duty of changing the DC power (including both current and voltage) to AC power which can be used in purposes of real usages in domestic or industrial section.

DC converters have the duty of changing amplitude of voltage in photovoltaic (Solar) systems and hence it acts as transformer but for DC sources.

The rectifier in the system plays an extra-ordinary role to make the voltage of output stable and consequently cause it to be ready to be used as inverter inputs.

All these in photovoltaic systems matter since the appliances are using alternative current sources and active power generated by solar cells are of direct current type. In addition, even for wind turbines which can provide an alternative current the changes and variations in frequency should be monitored in details and in cases of any frequency deviation, the AC-DC-AC converter system should come into effect. [10]
2.6 Energy potential in Sudan

- Sudan is an agricultural country with fertile land, plenty of water resources, livestock, forestry resources and agricultural residues. *Figure (2-3)* shows the daily load curves for different seasons in different years.[11]

![Figure 2-3 Daily Load Curves](image)

2.6.1 Energy growth

![Figure 2-4 Electricity Generation Growth](image)
Figure (2-4) shows electricity generation growth since the year 2002 and till 2012.

2.6.2 Solar

Average solar insolation in the country is roughly 6.1 kWh/m²/day, indicating a high potential for solar energy use. Figure (2.5) shows the solar map in Sudan. [12]

![Solar Map of Sudan](image)

Figure 2-5 GHI

2.6.3 Wind

Average wind speeds are estimated at 3-6 m/s; higher speeds have been recorded along the Red Sea coast. Figure (2.6) shows wind resource in Sudan. Wind energy in Sudan is currently used for pumping water from deep and shallow wells to provide drinking water and irrigation through the use of wind pumps.[12]
2.7 Summary

Each kilowatt-hour (kWh) generated from renewable resources saves the environment from the burning of fossil fuels. The coal fired and the natural gas fired power plants produce 1.05 Kg and 0.75 Kg carbon dioxide, respectively, to generate 1kWh electricity.

Renewable sources are safe and unlimited in the sense that there is no possibility of reserves being run down. With some exceptions, proposed renewable energy sources are local and so cannot be exploited by a foreign power as has happened with oil over many years. Furthermore renewable sources can add diversity to energy supply and almost none of them releases gaseous or liquid pollutants during the operation.
CHAPTER THREE
METHODOLOGY

3.1 Introduction

To overcome the limitations inherent in the stand alone PV system and stand alone wind system, achieve high reliability electric power generation system and produce energy at low cost; a hybrid wind solar system should be designed, the two sources will comply and support each other, supplying a battery unit with the excess power and have a backup diesel generator in the case of bad weather conditions.

In this chapter a methodology of the work done through this project would be made clear including the flow of the process, followed by the different models of these types of systems according to its connection to the grid or a small network or standing alone. A complete description of the proposed analysis of data will be presented.

3.2 Methodology and Flow Chart

Results and objectives of this project presented in two main areas, the control section and the power analysis section. Control section started with considering all the different situations that could be considered for such a hybrid system, deciding the suitable control component to use for coordinating the supply of the electric power, knowing the suitable type of input that it could understand and how to make use of the output for the better understanding of the process.

In this project only simulation for the process is made, readings and data taken from the wind system and the diesel generator are an AC power, and data from the PV and battery are DC power, so the power of the PV and battery are first inverted to an AC power. Having all sources with the same type of power, the microcontroller Atmega16 will be used to coordinate the work, microcontroller could only handle 5 volt so the huge power from the different sources will be stepped down very much to match with the microcontroller, process start with checking the availability of the wind energy which
have the highest priority to supply the load if it has enough power, supplying the load will be followed by calculating the excess power remaining to decide if the battery should be charged or not. If the wind energy wouldn’t be enough then the solar energy will be the next option to use if it is available and enough for the load, same checking for the excess power will be made. Another option that is available is to use both sources together if the combination is enough, and the battery might be supplied too. Either of the two sources not available or not enough, the battery unit or the diesel generator - if the battery is empty - maybe used. Flow chart of the process is shown in figure (3-1).  

Code Vision compiler was used for debugging the code written for the control and coordination using the automatic program generator wizard, then PRTOTEUS was used for simulating the process using AC power generators representing inputs from the different sources and LEDs were used to indicate each operation.

Figure 3-1 Flow Chart of the process
On the other side, the power analysis of the system which was made by ETAP Software mainly concentrate on the impact of the absence (i.e. reject) or present of any source of the sources mentioned.

First a load-flow study was done for different combinations of sources simply by opening or closing the circuit breakers followed by each source. The results of power flow, busses voltages, busses angles and line losses were compared.

Moreover, the transient stability study was done for the same cases by simulating the rejection of any source by a three-phase fault in its bus. The transient stability curves of power angle, speed and power of the generator were plotted and compared too.

3.3 Models

3.3.1 PV Systems

3.3.1.1 GRID-TIE (BATTERY FREE)

The simplest and most cost effective PV design for most sites is the "Grid-Tie" (sometimes referred to as inter tied or utility-interactive) system. This system does not provide backup power during a power outage (even if the sun is shining) but for sites with reliable grid power, this is usually the logical system choice. A typical PV Grid-Tie system with no battery is shown in figure 3-2.
There are no batteries to store excess power generated--the electric utility essentially stores it for you through a system called "net-metering." DC (direct current) generated by the PV panels is converted into AC (alternating current) power by the inverter (exactly the same high quality AC current delivered to your site by the utility-provided power grid). Output from the inverter is connected to your existing distribution panel (breaker panel) which feeds the rest of your site. While the system is generating electricity, power needs are provided by the PV system (up to its capacity), reducing or eliminating the power you would have drawn from the utility grid at that time. During periods when your grid-tie system is generating even more energy than your site requires, any excess is fed back into the grid for others to use and the electric utility company "buys" it from you at the retail rate. They provide credits to your account for all the power that is pushed back into the grid through the meter. And your meter will literally run backwards! When your site needs to draw more energy than it is producing (say, during cloudy conditions or at night), electricity is provided by the power grid in the normal manner and is first paid for by your accumulated credits.[13]

3.3.1.2 GRID-TIE WITH BATTERY BACKUP

The Grid-Tie with Battery Backup system can also push excess electricity produced to the electric utility grid but has the added feature of batteries in order to power some selected backup loads when the grid is down. A typical PV Grid-Tie system with battery backup is shown in figure 3-3.

The "Grid-Tie With Battery Backup" PV system incorporates one or more special AC circuits which are not directly connected to the electric grid like the rest of the building, but are always powered through the inverter and/or charge controller. These circuits may power a refrigerator, selected lights, computers or servers any devices the owner deems essential.
Figure 3-3 Typical PV grid tie with battery

The "dual function" inverter can supply the utility grid with any excess power produced by the system like the "grid-tie" inverter, plus the inverter works with the PV modules and battery bank (through the charge controller) to provide AC power to the backup circuits when the grid is down. The charge controller manages the battery voltage, keeping them fully charged when the grid is live, and preventing them from being depleted when the system is drawing power from them. [13]

3.3.1.3 STAND-ALONE

The Off-Grid or Stand-Alone PV System incorporates large amounts of battery storage to provide power for a certain number of days (and nights) in a row when sun is not available. The array of solar panels must be large enough to power all energy needs at the site and recharge the batteries at the same time. Most Off-Grid systems benefit from the installation of more than one renewable energy generator and may include Wind and/or Hydro power. A gas generator is often employed for emergency backup
power. You may have seen mini versions of the stand-alone system on remote road signs and radio towers. A typical Stand-Alone System is shown in Figure 3-4. [13]

![Typical PV stand-alone system](image)

**Figure 3-4 Typical PV stand alone system**

### 3.3.1.4 PV DIRECT

PV Direct systems are usually very simple systems where the photovoltaic panel is connected directly to a motor or pump which matches the voltage and amperage output of the panel. When the sun shines and the PV panel produces electricity, the device runs—when the sun is not available, the device stops. This system is often used for livestock where a well-pump lifts water out of the ground to a watering trough in remote locations. Other applications include solar powered attic fans, irrigation systems and small day-time garden waterfalls or fountains. A typical PV Direct System is shown in Figure 3-5. [13]
3.3.2 Wind Systems

3.3.2.1 Stand Alone Wind

A simple stand-alone wind system using a constant speed generator is shown in Figure 3-6. It has many features similar to the pv stand-alone system. For a small wind system supplying local loads, a permanent magnet DC generator makes a wind system simple and easier to operate. The induction generator, on the other hand, gives AC power. The generator is self-excited by shunt capacitors connected to the output terminals. The frequency is controlled by controlling the turbine speed. The battery is charged by an AC to DC rectifier and discharged through a DC to AC inverter.

The wind stand-alone power system is often used for powering farms. [2]
3.3.2.2 Grid-tied Systems with Battery Backup

Grid-tied wind systems with battery backup are connected to the local utility company's grid as a primary power source, while they also charge battery banks with wind-derived electricity. Once the battery banks are filled, the excess electricity is transferred via power lines to the utility company for energy credits, which are applied as discounts to the owner's electric bill. These systems can pay for themselves in utility bill credits while offering the owner emergency battery-stored electricity during utility company power outages due to storms or utility grid malfunctions. [14]. A typical Grid-Tied system with battery backup is shown in Figure 3-7.

![Grid Intertied Wind with Battery Backup](image)

Figure 3-7 Grid-Tied Wind System with battery

3.3.2.3 Grid-tied Systems without Battery Backup

Grid-tied wind energy systems are connected directly to the power grid without backup battery banks. The electric utility company serves as the primary electric power source while the wind-generated electricity is sent via power lines to the electric utility company for credit toward the electric bill. The elimination of batteries, which are costly and require maintenance, make this system a more cost-effective option. On the down side, when the electric utility grid goes down due to storms or malfunction, so does the system. [14]. A Typical Grid-Tied wind without battery backup is shown in figure 3-8.
3.4 Proposed analysis of data

3.4.1 Load flow analysis

Load flow analysis is probably the most important of all network calculations since it concerns the network performance in its normal operating conditions. It is performed to investigate the magnitude and phase angle of the voltage at each bus and the real and reactive power flows in the system components.

Load flow analysis has a great importance in future expansion planning, in stability studies and in determining the best economical operation for existing systems. Also load flow results are very valuable for setting the proper protection devices to insure the security of the system. In order to perform a load flow study, full data must be provided about the studied system, such as connection diagram, parameters of transformers and lines, rated values of each equipment, and the assumed values of real and reactive power for each load.

3.4.2 Transient stability analysis

The stability of a system refers to the ability of a system to return back to its steady state when subjected to a disturbance. As mentioned before, power is generated by synchronous generators that operate in synchronism with the rest of the system. A generator is synchronized with a bus when both of them have same frequency, voltage
CHAPTER THREE
METHODOLOGY

and phase sequence. We can thus define the power system stability as the ability of the power system to return to steady state without losing synchronism. Usually power system stability is categorized into Steady State, Transient and Dynamic Stability.

Steady State Stability studies are restricted to small and gradual changes in the system operating conditions. In this we basically concentrate on restricting the bus voltages close to their nominal values. We also ensure that phase angles between two buses are not too large and check for the overloading of the power equipment and transmission lines. These checks are usually done using power flow studies.

Transient Stability involves the study of the power system following a major disturbance. Following a large disturbance the synchronous alternator the machine power (load) angle changes due to sudden acceleration of the rotor shaft. The objective of the transient stability study is to ascertain whether the load angle returns to a steady value following the clearance of the disturbance.

The ability of a power system to maintain stability under continuous small disturbances is investigated under the name of Dynamic Stability (also known as small-signal stability). These small disturbances occur due random fluctuations in loads and generation levels. In an interconnected power system, these random variations can lead catastrophic failure as this may force the rotor angle to increase steadily.

3.5 Summary

From the above rehearsal of the steps done through this project, all the work done had been concluded with sufficient details including the software used and the procedure. The next chapters will explore what had been discussed here and present the steps to start the project till the end of the story.
Chapter four
Design of Hybrid system control

4.1 Introduction

Control of the hybrid system guarantees that your load will have efficient power all the time and that the power wouldn’t exceed the limited value so as the load won’t be harmed, so coordinating between the different sources of power in an efficient way will result in a satisfactory operation.

The values of different energy sources will enter the control element along with the load value; the control element will decide which source will be used and then open or close the final control device accordingly.

4.2 Decision Makers (Microcontroller)

A microcontroller is a computer-on-a-chip used to control electronic devices. It is a type of microprocessor emphasizing self-sufficiency and cost-effectiveness, in contrast to a general-purpose microprocessor. A typical microcontroller contains all the memory and interfaces needed for a simple application, whereas a general purpose microprocessor requires additional chips to provide these functions.

A microcontroller is a single integrated circuit with key features such as: central processing unit, input output interfaces such as serial ports peripherals such as timers and watchdog circuits, RAM for data storage, ROM for program storage, clock generator and resonator or RC circuit.

Microcontrollers also usually have a variety of input/output interfaces. Serial I/O (UART) is very common, and may include analog-to-digital converters, timers, or specialized serial communication interfaces.

A microcontroller helps the designer be more creative by providing him with some kind of bridging mechanism to interact with the electrical hardware components that he will attach to it.
Physically, a microcontroller is an integrated circuit with pins along each side. The pins presented by a microcontroller are used for power, ground, oscillator, I/O ports, interrupt request signals, reset and control. In contrast, the pins exposed by a microprocessor are most often memory bus signals (rather than I/O ports), microcontroller is shown in figure (4-1).

![Atmega16 Microcontroller](image)

**Figure 4-1 Atmega16 Microcontroller**

4.2.1 A microcontroller has seven main components

- Central processing unit (CPU).
- ROM.
- RAM.
- Input and Output.
- Timer.
- Interrupt circuitry.
- Buses. [15]

4.3 Code Vision AVR Compiler

There are several ways that the programmer can write, compile, and download a program to the ATmega16 microcontroller. There are many different text editors, compilers, and utilities available for many different languages (C, BASIC, assembly language, etc.)
Figure 4-2 Code Vision AVR

CodeVisionAVR –figure (4-2)- is C cross compiler, Integrated Development Environment and Automatic Program generator designed for the Atmel AVR family of microcontrollers.

The C cross-compiler implements nearly all the elements of the ANSI C language, as allowed by the AVR architecture, with some features added to take advantage of specificity of the AVR architecture and the embedded system needs.

The compiled COFF object files can be C source level debugged, with variable watching, using the Atmel AVR studio debugger.

The integrated development enviroment (IDE) has built-in AVR chip in-system programmer software that enables the automatical transfer of the program to the microcontroller chip after successful compilation/assembly. [16]

4.4 Proteus simulator

ISIS provides the development environment for PROTEUS VSM (figure 4-3). This software combines mixed mode circuit simulation, micro-processor models and interactive component models to allow the simulation of complete micro-controller based designs.

ISIS provides the means to enter the design in the first place, the architecture for real time interactive simulation and a system for managing the source and object code associated with each project. In addition, a number of graph objects can be placed on the
schematic to enable conventional time, frequency and swept variable simulation to be performed.

![Proteus Schematic Capture](image.png)

**Figure 4-3 Proteus**

4.4.1 Major features of PROTEUS VSM include

- CPU Models available for popular microcontrollers such as the PIC.
- Interactive peripheral models include LED and LCD displays, a universal matrix keypad, an RS232 terminal and a whole library of switches, pots, lamps, LEDs etc.

4.5 Relays

![Relay](image.png)

**Figure 4-4 Relay**
A relay is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used. Relays, shown in figure (4-4) are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. [17]

4.6 Control Circuit Design

The circuit designed next is constructed using microcontroller (Atmega16), this circuit is used to control the operation and switching for isolated network which is consists of solar, wind, battery and standby generator.

Operation Scenarios as Follows

4.6.1 All generation sources are off

Both load and battery are not supplied; this is shown in figure (4.5).
Figure 4-5 All sources off

All the AC inputs are zero or less than the load, this is a blackout case when no source is connected several sources are connected but its not enough and both the load and battery are not supplied, no lamp is lightning while the load has an AC value.

4.6.2 Only Wind is connected

4.6.2.1 Just enough to supply the load, no excess power

Shown in figure (4-6).
The wind power is available and its just enough for the load, the blue LED indicates that the wind relay is connected and just the load is supplied.

4.6.2.2 Only the wind with excess power

It is enough to supply both load and battery, shown in figure (4-7).
The blue LED indicates that the wind relay is connected and the green LED indicates battery is being charged, which means excess power from wind.

4.6.3 Only solar is connected

4.6.3.1 Only enough to supply the load

Shown in figure (4-8) no excess power.
The green LED indicating only solar relay is connected and its enough just for the load, no charging of the battery.

4.6.3.2 Only solar is connected with excess power

Enough to supply both load and battery, shown in figure (4-9).
Figure 4-9 Solar with excess power

The highest green LED indicates that the solar relay is connected and the low LED indicates that there is a power excess and the battery is charging.

4.6.4 When solar and wind both are available

4.6.4.1 No excess power

Shown in figure (4-10).
Figure 4-10 Wind and Solar without excess power

This is the case when solar alone or wind alone is not enough but combining both sourced will give the enough power for the load, the blue LED indicates that wind relay is connected and the green LED indicates solar relay is connected.

4.6.4.2 With excess power

Shown in figure (4-11).
Figure 4-11 Wind and Solar with excess power

The individuals are not enough but combined sources gives the required power and there is some excess power to charge the battery indicated by the low green LED.

4.6.5 Only the battery is connected

Shown in figure (4.12).
Solar and wind are both not available to use, then we will discharge our battery, indicated by the blue LED, and only the battery relay will be connected, indicated by the yellow LED.

4.6.6 Only the diesel generator is connected

Shown in figure (4.13).
Figure 4-13 Diesel Generator

The two sources is not available and the battery is empty, the backup diesel generator will work and will only supply the load, indicated by the yellow LED that only diesel relay is connected. No charging for the battery will take place.

4.7 Discussion

The above simulation of the control system considered all sources as an AC sources, although both the solar and the battery gives DC voltage but we assumed its inverted before entering the system for control.

The input to the microcontroller should be small values in order to be handled; this is done by connecting step down transformers not shown in the simulation.
As the relay is applicable for small power applications it’s the perfect choice to use for the output from a microcontroller and it will derive the large power circuit that supplies the load, the connection between load and different sources.

Results obtained by the simulation were as required and the system will be stable and most of the time supplied with power, and it will save energy (charging) every time when there excess power.
Chapter 5
Hybrid Wind-Solar System
Simulation

5.1 Introduction

This chapter shows how the Hybrid Wind-Solar System was implemented and simulated detailing the adopted software program, connections and simulation results.

5.2 Adopted Software

Power systems analysis and simulation software are ubiquitous in electrical engineering practice. Initially, they were used to quickly solve the non-linear load flow problem and calculate short circuit currents, but their use has been extended to many other areas such as power system stability, protection and coordination, contingency / reliability, economic modeling, etc.

The most common software packages used for power systems analysis are MATLAB, ETAP, PSAT, DIGSILENT, etc. In this project ETAP is used to simulate the PV/Wind Hybrid system.

5.2.1 ETAP ®

ETAP ® is the most comprehensive electrical engineering software solution for the design, simulation, operation, and automation of generation, transmission, distribution, and industrial power systems.

ETAP allows to easily create and edit graphical one-line diagrams (OLD), underground cable raceway systems (UGS), three-dimensional cable systems, advanced time-current coordination and selectivity plots, geographic information system schematics (GIS), as well as three-dimensional ground grid systems (GGS).
5.2.1.1 ETAP Modes

In general, ETAP has three modes of operation under Network Systems; Edit, AC Study, and DC Study. The AC Study mode consists of analyses such as Load Flow, Short Circuit, Motor Acceleration, Transient Stability, and Protective Device Coordination as shown in figure 5.1.

![Figure 5-1 ETAP modes](image)

(i) Edit Mode

In this mode ETAP provides a graphical editor to construct the one-line diagram as shown in figure 5.2. One can graphically add, delete, move, or connect elements by using the one-line diagram Edit toolbar; zoom in or out; display grid on or off; change element size, orientation, symbol, or visibility; enter properties; set operating status; etc.

![Figure 5-2 Edit Mode](image)
(ii) Study Modes

Study modes enable the user to create and modify study cases, perform system analysis, view alarm/alert conditions, and view output reports and plots. When a study mode is active (selected), the toolbar for the selected study is displayed on the right side of the ETAP window. The used study modes and associated study toolbars are shown in table 5.1.

Table 5-1 ETAP Study Modes

<table>
<thead>
<tr>
<th>Study Mode</th>
<th>Toolbar Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Flow</td>
<td><img src="image" alt="Load Flow Toolbar" /></td>
</tr>
<tr>
<td>Transient Stability</td>
<td><img src="image" alt="Transient Stability Toolbar" /></td>
</tr>
</tbody>
</table>
5.3 Testing the impact of Hybrid system on existing network

The Wind – Solar Hybrid system was tested on IEEE 9-Bus test system which consists initially of nine busses, three generators with total capacity of 519.5 MW & a total load of 330.618 MW. The IEEE 9-Bus test system is shown in Figure 5.3.

![Figure 5-3: IEEE 9-Bus Basic System](image)

5.3.1 System Modification

The IEEE 9-Bus system in figure 5.3 was modified to represent the PV/Wind Hybrid system shown in Figure 5.4.

The new system consists of two generators – Gen1 which operates as a voltage controlled generator- the backup generator-and Gen2 which represents the battery bank since it operates as a swing generator to supply the load in case of no enough power from other sources - and a combination of wind turbines represented by one 163.2 MW wind
turbine connected to bus-7 and a PV panel represented simply by a battery (2552 AH, 143 V) which connected to the bus-9 through an inverter.

Figure 5-4: The PV/Wind Hybrid System

Wind and Solar systems were assumed to be working at their full capacity and Gen2 was assumed as a swing generator to represent the battery bank.

The system under study will be operated under different combinations of the four sources; Gen1, Solar panel, wind turbine and battery bank.

The operating condition of the system is controlled by the control circuit of chapter Four.

5.3.2 Steady-State Stability Simulation and Results

The steady-state stability analysis was studied for the network assuming that the diesel generator act as a backup generator as the cases shown in chapter four.

5.3.2.1 Case-1: The Load was supplied by WTG and Battery Bank

The steady state stability analysis of this case is shown in figure (5-5) and table (5-2).
Chapter 5
Hybrid Wind-Solar System Simulation

Figure 5-5 Steady State Stability Results (Case-1)

Table 5-2 Steady State Stability Results (Case-1)

An over-voltage error occurred at the wind turbine bus and one transmission line was over-loaded.

5.3.2.2 Case-2: Only Solar System with the battery bank is available
Steady State Stability Results are shown in figure (5-6) and table (5-3)
The results in this case indicated that the solar system can operate alone with the battery bank with a good voltage profile.

5.3.2.3 Case-3: Wind and Solar only
Steady State Stability Results are shown in figure (5-7) and table (5-4)
The voltage profile results in this case were almost the same as case-1 when one over-voltage bus and one over-load error.

5.3.2.4 Case-4: Wind, Solar and Battery were ON
Steady State Stability Results are shown in figure (5-8) and table (5-5)
The over-voltage error also appeared in the bus of the wind turbine as the previous cases.

### 5.3.2.5 Case 5: Battery only

Steady State Stability Results are shown in figure (5-9) and table (5-6).
The voltage profile results were not acceptable

5.3.2.6 Case-6: Diesel Generator only
Steady State Stability Results are shown in figure (5-10) and table (5-7).
In this case the generator was supplying the load alone with a good voltage profile but with one over-loaded line.

5.3.3 Transient Stability Analysis

The rejection of any source was simulated as a three phase fault in its bus in order to study the transient stability in such cases.

The transient stability analysis was studied for the network when the diesel generator (i.e. Gen1) was working as a main source not as a backup.
5.3.3.1 **Case 1: Solar System was down**

Transient Stability Results and generator power angle are shown in figure (5-11) and figure (5-12).

![Figure 5-11 Transient Stability Results (Case-1)](image)

![Figure 5-12 Generator Power Angle (Case-1)](image)

It is clear that the rejection of the solar system doesn’t have any negative impact on the system since the wind generator, battery bank and the diesel generator can supply the load.

5.3.3.2 **Case-2: Both Wind and Solar were OFF**

Transient Stability Results and generator power angle are shown in figure (5-13) and figure (5-14).
Figure 5-13 Transient Stability Results (Case-2)

Figure 5-14 Generator Power Angle (Case-2)

5.3.3.3 Case-3: Wind was OFF

Transient Stability Results and generator power angle are shown in figure (5-15) and figure (5-16).
Chapter 5
Hybrid Wind-Solar System Simulation

Figure 5-15 Transient Stability Results (Case-3)

Figure 5-16 Generator Power Angle (Case-3)

From the power angle curve in Figure 5.16, it is clearly noticed that the machine will lose its stability soon since the solar and the generator are not enough to supply the load.

5.3.3.4 Case-4: Wind, Solar and the battery were OFF (Only the generator was ON)

Transient Stability Results and generator power angle are shown in figure (5-17) and figure (5-18).
5.4 Discussion of the results

As seen in the results, in some cases there were some buses suffered from over-voltage conditions. This could be solved by using load tap-changer transformers or there is large number of over-voltage busses, reactors could be connected in order to improve the voltage profile.

Also in some cases an over-load condition appeared in a line. To avoid this case simply a new line could be connected in parallel with the existing line (i.e double line scheme) such that the power flow could be divided between them.
The ETAP 7 does not have a solar panel icon so that it was represented by battery which considered by the ETAP as a swing that could supply the load with any power needed while the inverter has specific limits for the current and power passing through it, so it is recommended to use the latest version of ETAP that include solar panel representation.
Chapter six
Conclusion and future work

6.1 Conclusion

A hybrid power system which consists of diesel Generator, PV-arrays and wind turbines with energy storage and power electronic devices has been discussed in this report to achieve an efficient system configuration so that hybrid power sources could improve the life of people especially in rural areas where electricity from the main grid has not reached yet.

The hybrid wind solar electric power system containing the different power generation unit was modeled in ETAP software by modifying the basic IEEE 9-bus network with backup battery bank. The design included the overall control of the hybrid system. The simulation took into account the different modes of operation of the system transient and steady state. Also the impact of addition/rejection of hybrid system elements has been discussed. The results showed that the wind and the solar units have no negative impact on the stability of the system.

From the overall report, we can find out that hybrid model of solar and wind energy can fulfill the load demand (wind energy support the solar energy to fulfill load demand). So through this system we can supply the energy rural area where the sufficient energy cannot be produced or the cost of operation is very high.

6.2 Future work

Renewable sources of energy produces a large amount of energy and its available in Sudan in a wide range, in the future these wind solar hybrid systems or other hybrid systems that is all renewable or that contain non-renewable sources could be combined to be installed in Sudan for an isolated networks of remote areas or could be tied to the national grid when large amount of energy is produced, Red Sea, Nyala and North states are good examples for locations where renewable projects could be installed.
Bibliography

   http://www.aladdinsolar.com/pvsystems.html

   http://www.ehow.com/list_7477351_types-wind-energy-systems.html


   Available: http://thinktronix.blogspot.com/2012/05/robotics-using-atmega16-
   microcontroller.html

[17] "Relay," [online]
Appendix A: microprocessor control code

This program was produced by the
CodeWizardAVR V2.04.9a Evaluation
Automatic Program Generator
© Copyright 1998-2010 Pavel Haiduc, HP InfoTech s.r.l.
http://www.hpinfotech.com

Project :
Version :
Date   : 7/11/2013
Author : Freeware, for evaluation and non-commercial use only
Company :
Comments:

Chip type     : ATmega16
Program type  : Application
AVR Core Clock frequency: 4.000000 MHz
Memory model  : Small
External RAM size : 0
Data Stack size : 256

#include <mega16.h>
#include <delay.h>
#define ADC_VREF_TYPE 0x00

unsigned int read_adc(unsigned char adc_input)
{
    ADMUX=adc_input | (ADC_VREF_TYPE & 0xff);
delay_us(10);
ADCSRA|=0x40;
while ((ADCSRA & 0x10)==0);
ADCSRA|=0x10;
return ADCW;
}

int x; //load
int s; //solar
int w; //wind
int b; //battery
int d; //diesel

void main(void)
{
    PORTA=0x00;
DDRA=0x00;
PORTB=0x00;
DDRB=0x00;
PORTC=0x00;
DDRC=0xFF;
PORTD=0x00;
DDRD=0xFF;
TCCR0=0x00;
TCNT0=0x00;
OCR0=0x00;

TCCR1A=0x00;
TCCR1B=0x00;
TCNT1H=0x00;
TCNT1L=0x00;
ICR1H=0x00;
ICR1L=0x00;
OCR1AH=0x00;
OCR1AL=0x00;
OCR1BH=0x00;
OCR1BL=0x00;

ASSR=0x00;
TCCR2=0x00;
TCNT2=0x00;
OCR2=0x00;
MCUCR=0x00;
MCUCSR=0x00;
TIMSK=0x00;
ACSR=0x80;
SFIOR=0x00;
ADMUX=ADC_VREF_TYPE & 0xff;
ADCSRA=0x82;
while (1)
{
    //power inputs in watts:
    x=read_adc(0);
    w=read_adc(1);
    s=read_adc(2);
    b=read_adc(3);
    d=read_adc(4);
    //only the wind energy:
    if (w>=x)
    {
        PORTC.0=1;   //connect wind relay
        if ((w-x)>0)   //excess power
PORTD.2=1;   //charging the battery
else if (w<x) //not enough
PORTC.0=0;
}

//only the solar energy:
else if (s>=x)
{
PORTC.2=1;   //connect solar relay
if ((s-x)>0)  //excess power
PORTD.2=1;  //charging the battery
else if (s<x)    //not enough
PORTC.2=0;
}

//solar and wind individual are not enough, combine both:
else if (w+s>=x)
{
PORTC.0=1;
PORTC.2=1; //connect both relays
if (((w+s)-x)>0) //excess power
PORTD.2=1; //charging the battery
else if ((w+s)<x)//not enough
PORTC.0=0;
PORTC.2=0;
} //using the battery when both wind and solar are not available
else if (b>=x)
{
    PORTC.4=1; //connect battery relay
    PORTD.6=1; //discharging battery
}

//when even the battery is empty use the diesel generator without charging the battery
else if (d>=x)
{
    PORTC.6=1; //connect diesel relay
    PORTD.2=0; //do not charge the battery
    PORTD.6=0; //do not discharge from battery
    if (d<x)    //not enough
        PORTC.6=0;
}

//blackout:
else if (s<x && w<x && b<x && d<x)
{
    PORTC.0=0; //disable wind circuit breaker
    PORTC.2=0; //disable solar circuit breaker
    PORTC.4=0; //disable battery circuit breaker
PORTC.6=0; //disable diesel circuit breaker
PORTD.2=0; //battery is not charging
PORTD.6=0; //battery is not discharging
}
Appendix B: Atmega16 Microcontroller Pin description

<table>
<thead>
<tr>
<th>Pin Description</th>
<th>Pin Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>XCK/T0/PB0</td>
<td>1</td>
</tr>
<tr>
<td>T1/PB1</td>
<td>2</td>
</tr>
<tr>
<td>INT2/AIN0/PB2</td>
<td>3</td>
</tr>
<tr>
<td>OC0/AIN1/PB3</td>
<td>4</td>
</tr>
<tr>
<td>SS/PB4</td>
<td>5</td>
</tr>
<tr>
<td>MOSI/PB5</td>
<td>6</td>
</tr>
<tr>
<td>MISO/PB6</td>
<td>7</td>
</tr>
<tr>
<td>SCK/PB7</td>
<td>8</td>
</tr>
<tr>
<td>Reset</td>
<td>9</td>
</tr>
<tr>
<td>VCC</td>
<td>10</td>
</tr>
<tr>
<td>GND</td>
<td>11</td>
</tr>
<tr>
<td>XTAL2</td>
<td>12</td>
</tr>
<tr>
<td>XTAL1</td>
<td>13</td>
</tr>
<tr>
<td>RXD/PD0</td>
<td>14</td>
</tr>
<tr>
<td>TXD/PD1</td>
<td>15</td>
</tr>
<tr>
<td>INT0/PD2</td>
<td>16</td>
</tr>
<tr>
<td>INT1/PD3</td>
<td>17</td>
</tr>
<tr>
<td>OC1B/PD4</td>
<td>18</td>
</tr>
<tr>
<td>OC1A/PD5</td>
<td>19</td>
</tr>
<tr>
<td>ICP1/PD6</td>
<td>20</td>
</tr>
<tr>
<td>PA0/ADC0</td>
<td>21</td>
</tr>
<tr>
<td>PA1/ADC1</td>
<td>22</td>
</tr>
<tr>
<td>PA2/ADC2</td>
<td>23</td>
</tr>
<tr>
<td>PA3/ADC3</td>
<td>24</td>
</tr>
<tr>
<td>PA4/ADC4</td>
<td>25</td>
</tr>
<tr>
<td>PA5/ADC5</td>
<td>26</td>
</tr>
<tr>
<td>PA6/ADC6</td>
<td>27</td>
</tr>
<tr>
<td>PA7/ADC7</td>
<td>28</td>
</tr>
<tr>
<td>AREF</td>
<td>29</td>
</tr>
<tr>
<td>GND</td>
<td>30</td>
</tr>
<tr>
<td>AVCC</td>
<td>31</td>
</tr>
<tr>
<td>PC7/TOSC2</td>
<td>32</td>
</tr>
<tr>
<td>PC6/TOSC1</td>
<td>33</td>
</tr>
<tr>
<td>PC5/TDI</td>
<td>34</td>
</tr>
<tr>
<td>PC4/TDO</td>
<td>35</td>
</tr>
<tr>
<td>PC3/TMS</td>
<td>36</td>
</tr>
<tr>
<td>PC2/TCK</td>
<td>37</td>
</tr>
<tr>
<td>PC1/SDA</td>
<td>38</td>
</tr>
<tr>
<td>PC0/SCL</td>
<td>39</td>
</tr>
<tr>
<td>PD7/OC2</td>
<td>40</td>
</tr>
<tr>
<td>Pin No.</td>
<td>Pin name</td>
</tr>
<tr>
<td>--------</td>
<td>----------</td>
</tr>
<tr>
<td>1</td>
<td>(XCK/T0) PB0</td>
</tr>
<tr>
<td>2</td>
<td>(T1) PB1</td>
</tr>
<tr>
<td>3</td>
<td>(INT2/AIN0) PB2</td>
</tr>
<tr>
<td>4</td>
<td>(OC0/AIN1) PB3</td>
</tr>
<tr>
<td>5</td>
<td>(SS) PB4</td>
</tr>
<tr>
<td>6</td>
<td>(MOSI) PB5</td>
</tr>
<tr>
<td>7</td>
<td>(MISO) PB6</td>
</tr>
<tr>
<td>8</td>
<td>(SCK) PB7</td>
</tr>
<tr>
<td>9</td>
<td>RESET</td>
</tr>
<tr>
<td>10</td>
<td>Vcc</td>
</tr>
<tr>
<td>11</td>
<td>GND</td>
</tr>
<tr>
<td>12</td>
<td>XTAL2</td>
</tr>
<tr>
<td>13</td>
<td>XTAL1</td>
</tr>
<tr>
<td>14</td>
<td>(RXD) PD0</td>
</tr>
<tr>
<td>15</td>
<td>(TXD) PD1</td>
</tr>
<tr>
<td>16</td>
<td>(INT0) PD2</td>
</tr>
<tr>
<td>17</td>
<td>(INT1) PD3</td>
</tr>
<tr>
<td>18</td>
<td>(OC1B) PD4</td>
</tr>
<tr>
<td>19</td>
<td>(OC1A) PD5</td>
</tr>
<tr>
<td>20</td>
<td>(ICP) PD6</td>
</tr>
<tr>
<td>21</td>
<td>PD7 (OC2)</td>
</tr>
<tr>
<td>22</td>
<td>PC0 (SCL)</td>
</tr>
<tr>
<td>23</td>
<td>PC1 (SDA)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>24</td>
<td>PC2 (TCK)</td>
</tr>
<tr>
<td>25</td>
<td>PC3 (TMS)</td>
</tr>
<tr>
<td>26</td>
<td>PC4 (TDO)</td>
</tr>
<tr>
<td>27</td>
<td>PC5 (TDI)</td>
</tr>
<tr>
<td>28</td>
<td>PC6 (TOSC1)</td>
</tr>
<tr>
<td>29</td>
<td>PC7 (TOSC2)</td>
</tr>
<tr>
<td>30</td>
<td>AVcc</td>
</tr>
<tr>
<td>31</td>
<td>GND</td>
</tr>
<tr>
<td>32</td>
<td>AREF</td>
</tr>
<tr>
<td>33</td>
<td>PA7 (ADC7)</td>
</tr>
<tr>
<td>34</td>
<td>PA6 (ADC6)</td>
</tr>
<tr>
<td>35</td>
<td>PA5 (ADC5)</td>
</tr>
<tr>
<td>36</td>
<td>PA4 (ADC4)</td>
</tr>
<tr>
<td>37</td>
<td>PA3 (ADC3)</td>
</tr>
<tr>
<td>38</td>
<td>PA2 (ADC2)</td>
</tr>
<tr>
<td>39</td>
<td>PA1 (ADC1)</td>
</tr>
<tr>
<td>40</td>
<td>PA0 (ADC0)</td>
</tr>
</tbody>
</table>