Sudan University of Sciences and Technology

College of Engineering

School of Electrical and Nuclear Engineering

Study of Micro Grid System

A project submitted in partial fulfillment for the requirement of the degree of B.Tech.(Honor) in electrical engineering

Prepared by:

1. Ahmed Adam Ahmed Bakheet
2. Ismael Ahmed Adam
3. Nabil Ahmed khamees
4. Nasraldin Ali Mohamed Adam

Supervised by:

Professor :KhameesArbeesh

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صدق الله العظيم

سورة النور ـ الآية٣٥

الإهـــــداء

جمعا من الرائعين ... جمعتنا بيهم دروب هذه الحياة الفناهم والفونا عرفناهم وعرفونا فتعلمنا منهم ان الحاضر هو اثبات لذواتنا والغد هو تمرة نياتنا ساروا معنا خطوة بخطوة دون كلل او ملل بالرغم من مشقة الرحلة منحونا صبرا لا يعرف الياس وعزما لا يعرف المستحيل فصاروا أرقاما في حياتنا ونقوشا في ذاكرتنا وكانوا وكنا ...

أولاًالي من ضمنا فؤادنا الحنون جامعة السودان ونخص بالتحية قسم الهدسة الكهربائية ...

ثم دكاترتي اساتذتي امي ابي اخواني زملائي كنتم أولئك الرائع فلكم منا الود في زمن يصعب فيه اهداء الود ويندر فيه الوفاء...

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Last but not least, we owe the success of this project to our dear families who gave everything from motivation throughout this time period, and supported us during our ups and downs.

Abstract

The electric power system has evolved through large, central power plants interconnected via grids of transmission lines and distribution networks that feed power to customers. The system is beginning to change – rapidly in some areas – with the rise of distributed energy resources (DER) such as oil-fueled generators, combined heat and power plants, electricity storage, and solar photovoltaic (PV) on rooftops and in larger arrays connected to the distribution system. In many settings DER already have an impact on the operation of the electric power grid. Through a combination of technological improvements, policy incentives, and consumer choices in technology and service, the role of DER is likely to become more important in the future. Many governments as a way of handling energy independence promote such a modern electricity network.

The idea of the project is to evaluate the effect of adding PV generation on the distribution system and its influence on transmission line, how it can decrease the losses and increase the efficiency of the power generation by using new

technology called distributed generation. For the simulations, we used a specialized simulation tool; ETAP, which is one of the best available tools for simulating power systems and renewable energy resources.

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Chapter One
Introduction

1.1Introduction:

In the last few years, the cost of electric power generation in Sudan has risen dramatically because of increase in fuel cost. In order to increase the generation, the simple method is to use PV system because of availability of the sun in Sudan.So the use of a PV is adopted of this solution.Here we used renewable energy to decrease the cost of generation.

These problems; Due to poor economic conditions scarcity of fuel, and difficulty of obtaining it, the state should turn to renewable energy.

For this reason, the Sudanese government adopted comprehensive national strategy for the energy sector, which aims to increase the reliance on domestic and renewable energy sources [2].

Sudan has many renewable energy resources and future potential in this sector, especially in terms of solar and wind energy. Sudan is located within the Sunbelt; that is, the solar radiation intensity is 5-7 kWh per meter square, and wind speed in certain regions is between 7-9 m/s. These figures are promising for exploiting renewable energy for electricity generation in Sudan.

In line with investment requirements and in order to open the door for the private sector to effectively participate in the implementation of renewable energy projects, the Renewable Energy and Energy Efficiency Law was enacted as a permanent law under no. This law provides the legal, regulatory, and legislative framework for investments in renewable energy.

With all that in mine, we started to think about the design and implementation of a power grid for a small city using both conventional and renewable sources.

The second part of the project will study all possible solutions for the construction of solar cells in the city, and how they will affect the transmission lines. For each possible solution, we will have a full data set for these effects. Furthermore, improvements will occur such as decreasing the cost of power generation as well as iteffects on the power factor of the generator.

The organization of this documentation is as follows. In Chapter two, a literature review will be presented, to discuss the history of power systems, their types, and a brief introduction about the simulation used in the project. Overall system review will be discussed in chapter three, followed with a detailed description of the final design included in the project in chapter four, in addition to the best design. The final chapter, Chapter five, will offer a conclusion and what can be done with the system to enhance it in future work.

1.2 Over view:

Our project will cover some areas in AL Fashir, Sudan, and we will study the effect of bringing renewable energy sources closer to customers, in addition to how the conventional energy that we take from the grid will affect the voltage drop and the frequency of the power.

Economic benefits of our project(this project will participate to the national budget with 1.5$ million annual profits). Which is high source of income to the national GDP(Gross Domestic Product).

The capacity of AL Fashir solar station is shown below:

1. Total capacity 5.27 MWp
2. Total number of panels 16220, 325Wp each
3. No charge controller

4. No batteries

1.3 Problem Statements:

to reduce the cost of generation we should establish a PV system near the customer.

to provide clean energyand decrease the carbon dioxide emission.

micro grid system is more reliable.

1.4 Project Layout:

Chapter one include introduction and over view problem statements project layout, chapter two system components, chapter three system design, chapter four simulation and results, chapter five conclusion.

Chapter Two
System Components

2.1 System components:

Power system is a mixture of electrical components made up of the electrical network, what we call a grid. We use the grid to generate and transmit the energy from power stations to the consumer; either industrial or residential.

The electric power system can be divided into three major parts:

1)Generation

2)Transmission

3)Distribution

4)The main components of the electrical system are illustrated in the Figure (2.1)

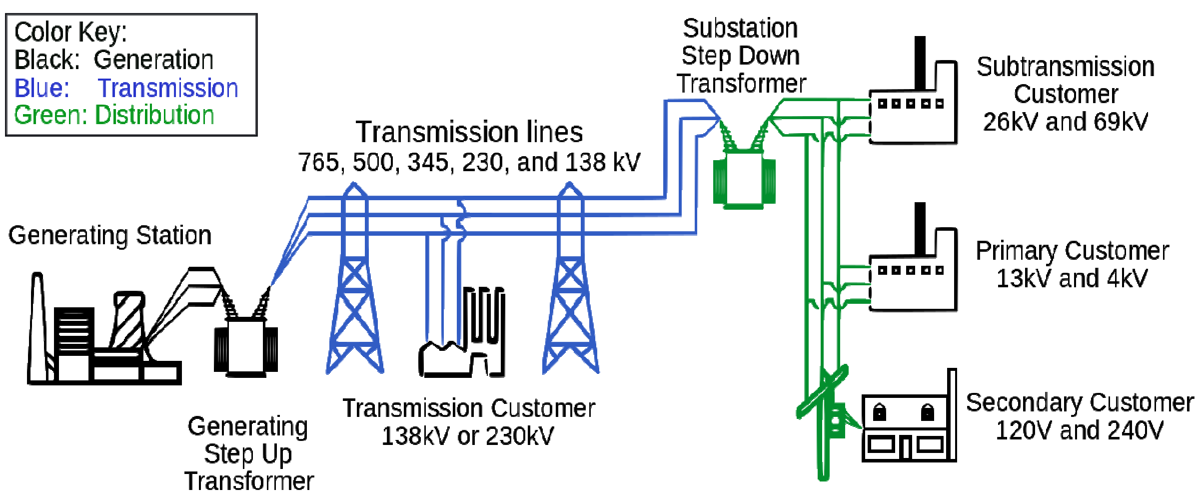


Figure 2-1: Real Power system connection.

2.1.1 Power Plant Generation

A power generating station is an industrial location that is used for the generation and distribution of electric power in mass scale, usually in the order of several hundred Mega Watts. These are generally located at the sub-urban regions or several kilometers away from the cities or the load centers. This is because it requires huge land and water demand, along with several operating constraints such as the waste disposal. For this reason, a power generating station has to, not only take care of efficient generation, but also the fact that the power is transmitted efficiently over the entire distance. Moreover, that is why the transformer switchyard, which regulates transmission voltage, also becomes an integral part of the power plant.

At the center of it, however, nearly all power generation stations have an AC generator or an alternator. This rotating machine is equipped to convert energy from the mechanical domain (rotating turbine) into electrical domain by creating relative motion between a magnetic field and the conductors. The energy source harnessed to turn the generator shaft varies widely, and is manly dependent on the type of fuel used.

As mentioned above there are four types of generation:

a) Thermal power generation
b) Nuclear power generation
c) Hydro power generation
d) Renewable energy

2.1.2Transmission:

Electrical power is generated at different stations in various locations. These generating stations are not necessarily placed at the load center. During the

construction of the generating station there is a number of factors to be considered from the economical point of view. Not all of these are factors that may be easily available at the load center. Hence, generating stations are not normally situated very near to the load center. The Load center is the place where maximum power is consumed. So, there must be some means by which the generated power must be transmitted to the load center. In summary,electrical transmission system is a means of transmitting power from generating stations to different load centers.
There are two systems by which electrical energy can be transmitted:

(1) High voltage DC electrical transmission system.
(2) High voltage AC electrical transmission system.

2.1.3Distribution

Distribution is the system of lines that connect the individual customer to the electric power system. In this system, we have the highest losses but shorter distance and lower power per line involved in distribution. This allows the design emphasis to shift from the maximum efficiency to accessibility, safety, and continuity of service.

2.2ETAP

Electrical Transient Analyzer Program (ETAP) is an electrical network modeling and simulation software tool used by power systems engineers to create an "electrical digital twin" and analyze electrical power system dynamics, transients and protection.
ETAP was developed for utilization on MS-DOS operating system and intended for commercial and nuclear power system analysis [5] and system operations. OTI has been developing ETAP for 30 years by providing the comprehensive and widely used enterprise solutions for generation, transmission, distribution, industrial, transportation, and low-voltage power systems.

OTI has generated numerous innovations and patents throughout the years,including the first digital twin drivenpredictive simulation and automationplatform; the first Intel-based energymanagement system based on the MSDOS platform in the 1990s; the firstcomprehensive advanced user interfaceand situational awareness system fortransmission, distribution, and generationoperators; the first advanced intelligentload shedding system in the mid-2000s;and the adoption of big data technologyand no-SQL database technologies.

[*citation needed*]Today, OTI provides electrical design tooperation on a single platform, openautomation, network management, andoptimization solutions worldwide. Power system simulation requires anelectrical digital twin consisting of apower system network model thatincludes system connectivity, topology,electrical device characteristicshistorical system response and real-timeoperations data in order to make offlineor online decisions. ETAP powerengineering software utilizes an electricaldigital twin in order for electricalengineers and operators to performfollowing studies in offline or onlinemode:

- Load flow or power flow study.
- Short circuit or fault analysis.
- Protective device coordination,discrimination or selectivity
- Transient or dynamic stability.
- Substation design and analysis.
- Harmonic or power quality analysis.
- Reliability.
- Optimal power flow.
- Power system stabilizer tuning.
- Optimal capacitor placement.

- Motor starting and accelerationanalysis.
- Voltage stability analysis.

ETAP software applications include:

- Power system design for ANSI and IECnetworks.
- Electric supply substation simulation.
- Monitoring and feeder analysis.
- Simulation of distributed photovoltaic power.
- Study of a DC network.
- Open-phase fault analysis.
- Diesel power plant analysis.
- Combined cycle power plantanalysis.
- AC/DC hybrid system simulation.
- Wind turbine design and analysis.
- Harmonics in railway powersystems.
- Rural distribution system analysis.
- Reliability assessment of renewableenergy systems.
- Wind and PV penetration studies.

2.3 Renewable energy:

Renewable energy (RE) resources have some special features and attributes that differ from conventional energy resources. However, they put some constraints on their application or usage. Such limitations include site specificity, small size of power output, and current marginal feasibility. On the other hand, environmental benefits of these sources favor them over conventional resources.

The concept of renewability is based upon the scale of human events and if the source can be replaced during that period. For instance, wood is a renewable biomass energy source as long as adequate conditions are kept for reserves to be replenished. Rates of exploitation / deforestation in a number of areas are so high that biomass may be considered as a nonrenewable source in those circumstances.

2.3.1 PV:

A solar cell or photovoltaic cell (PV) is a device that converts light directly into electricity by the photovoltaic effect. Sometimes the term solar cell is reserved for devices intended specifically to capture energy from sunlight, while the term photovoltaic cell is used when the light source is unspecified. Assemblies of cells are used to make solar panels, solar modules, or photovoltaic arrays. Photovoltaic is the field of technology and research related to the application of solar cells in producing electricity for practical use. The energy generated this way is an example of solar energy (also called solar power).

2.3.2 Solar energy:

Solar energy is the energy provided by the sun. This energy is in the form of solar radiation, which makes the production of solarelectricity, light, heat water and many more things possible.

The photovoltaic panels convert the solar radiation into electricity using semiconductor cells.

The panels that we used in this project from q _cell solar company; and the data sheet of the panels in the following below:

2.3.3Solar batteries:

Solar batteries are usually lead-acid deep cycle batteries. This kind of batteries are tolerant to the way of charging and discharging going on in a solar system and they have a long life time compared to regular car batteries.

Deep cycle batteries can discharge 80% of their rated capacity. In PV deep cycle batteries are favored so that during no sunlight periods the battery is able to supply the load demand.

2.3.4Charge controller:

As the name implies, controls the amount of charge that the battery would receive. When the battery has reached its charging limit, the charge controller will withhold further charging of the battery, sometimes known as voltage regulating.

The absence of this would lead to overcharging of batteries, consequently damaging batteries and even causing fires.

The charge controller that we used in this project it is MPPT from Nenoblecompany.

2.3.5 Inverters:

Inverters are power electronics circuitries that convert power from the (DC) sources of PV to alternating current (AC) power synchronized with the national grid in amplitude and frequency. There are 3 possible connections between the PV modules and the inverters; central, string and micro.

The inverters that we used in this project from q _cell solar company.

Figure 3-3: (a) Central, (b) 3 Phase String, and (c) Micro Inverters.

2.3.6 Circuit Breakers(CBs):

Photovoltaic arrays always produce output voltage when exposed to sunlight, so it must be possible to disconnect the system for maintenance or testing. CB’s are designed according to the maximum voltage and current that exist in the system.

A reachable CB must be connected to each inverter in the system, to make it easy to disconnect the inverter in case of maintenance or when faults occurs.

CB’s ratings vary according to their location in the system, molded case Circuit Breaker (MCCB) and Residual Current Circuit Breaker (RCCB) and Residual current device (RCd).

circuit breakers are connected directly after each inverter.

Figure 3-4shows an example for the connection.

Figure 3-4: (a)The Connection of CB`s With Inverter, (b) The Connection Between RCCB and MCB].

Chapter Three

System Design

3.1 load:

In this section we present a major part in this project, which will cover the load of the geographical area, All the values used in the project come from the Sudanese electrical power company.

3.2 Requirements:

The system has the following requirements and design specification:

Energy Demand	5 MW
PV array modules connected in series	1812
PV array modules connected in parallel	12
Reference irradiation	1000
Reference temperature	25

Table3.1: design Requirements

3.3 PV Module:

In this section, we present the PV module we used for our system, which is developed using the ETAP software.

The PV system consists of PV array model, DC link capacitor, DC-DC converter, three phase inverter, AC filter and transformer connected to the utility grid, as shown in Figure (3.3). In this section, the function of each component will be discussed. Moreover, the function of additional circuits, which are used to control some components in the model, will also discussed. Figure(3.3) shows a real PV connected to a grid

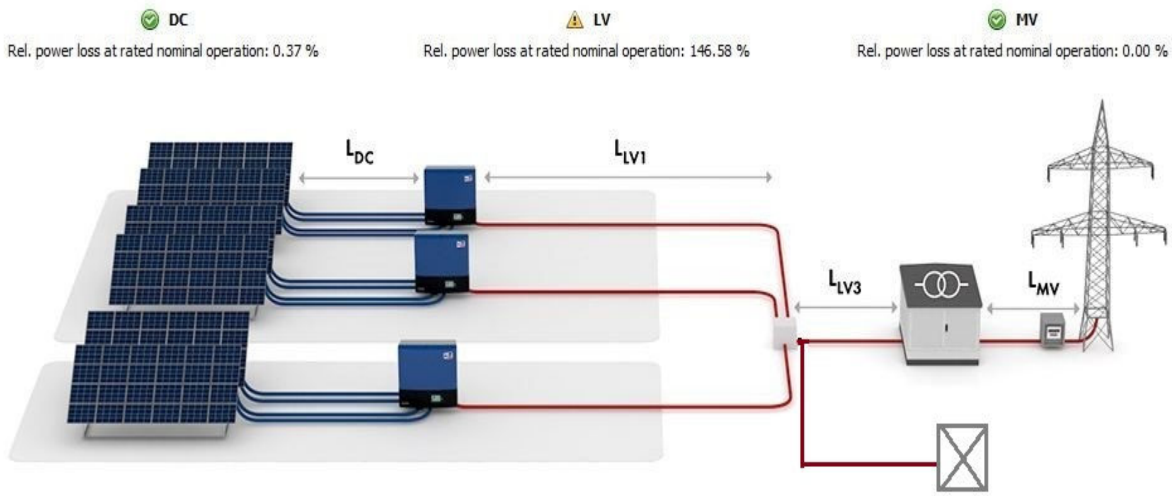


Figure 3-3: Real PV panels connected to grid

3.4PV Array:

Photovoltaic cell is a semiconductor device that converts the energy of irradiation directly into electricity by the photovoltaic effect when exposed to radiant energy such as sunlight.

Input temperature and irradiation have an effect on short circuit current and open circuit voltage. As the irradiation increased, the short circuit current increased. While the temperature is increased, the open circuit voltage is decreased. The total number of cells per models connected in series determines the total voltage of the module per array. Also, the total number of cells per models connected in parallel determines the total current of the module per array.

Standard Test Conditions (STC) are conditions that are used to test the module in laboratory with irradiance intensity of 1000 W/mm^2, AM1.5 solar reference spectrum and cell per module temperature of 25 ± 2 °CC.

3.5 Calculation:

Achieving the required PV system design must pass through several calculation, the main part of the calculations are shown below:

3.5.1PV System size:

In order to cover the annual electric energy demand of 5MWh/year, it is important to size the PV arrays according as in equation (3.1) and (3.2) below:

$$E.avg=\frac{E.total}{12months} \quad \ldots\ldots(3.1)$$

$$PV\ size = \frac{E.avg}{derate\ factor\ x\ sunpeak\ x\ 30days} \quad \ldots\ldots(3.2)$$

E .total The total energy consumption per year (KWh/year)

E .avg Average monthly consumption (KWh/month)

PV size The solar PV system size (KWp)

PV system size is the quantity that represent how much power needed to cover all the geographical area consumption.

Derate factor is a quantity that represents the power losses in the system such as PV module, inverter and transformer losses, mismatch losses, dc wiring losses, ac wiring losses, shading losses, and age losses, as well as the temperature.

The total size of PV system must be 5 x 1.25=6.25 MWh here we add a safety factor between (1.2 -1.3) because the losses decrease our total load that can be generated.

3.5.2The number of panels:

To calculate the total power can be generated we should divide the total power that we want to generate by the sun irradiation, thus in Sudan this value between(6-7) hour.Sothe total power can be generated is equal to:

Power can be generated =PV system size / PSH

PSH = peak sun hour (6-7) hour

So the number of panels can be calculated by divide the power can be delivered from the PV system by the capacity of one cell the

Number of panel = 5.000000 / 230 =21740

3.5.2Inverter determination:

To guarantee the synchronization with national companies, a string inverter is the most commonly used type for home and commercial solar power system, compared to the central inverter or micro inverters because they allow a high design flexibility, with high efficiency, availability, of several sizes and it is low cost.

To specify the range of inverters it is depend on system size, the size of inverter will be evaluated using the equations below:

PV size = N xP.nom = 27174x 230 = 6.25 MW …………….(3.3)

Number of inverters = PV size / inverter rating ………………..…(3.4)

Where :

PV size total output power (MWp)

N the number of modules

P.nom nominal power of the module(Wp)

So to guarantee that the total number of inverters is enough to serve all PV modules; it must ensure that the total power of inverters is equal to the PV modules

3.6Simulation:

We make a simulation of the system to verify andcompare between the result of manual solution and the result of the simulation by using a program called (ETAP).

3.6.1 Single line Diagram:

A single line diagram shows the main part of the system and show how the system can work, also the single line diagram it can show us the load flow and the voltage regulation of the system, figure below show the single line diagram of a PV system connected to grid

3.6.2Did the Design meet Requirements and Constrains?

Hybrid PV system design that is proposed for this design has indeed meet all the requirements and constrains, all available rooftop area was exploited with an output yielded more than what is needed to cover all the energy consumption for the facilities. Chapter 4 will test design under simulation to further verify results.

Chapter Four

Simulation and Results

4 Simulation and Results:

In this chapter, after the detailed system design was introduced in the previous chapter, the design of the city will be discussed; also more than one case will be displayed, and will demonstrate the advantages and disadvantages of each design.

4.1 Introduction to ETAP:

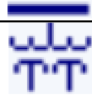
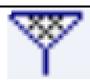
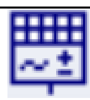
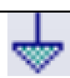
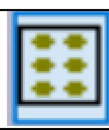
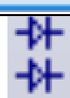
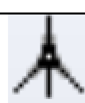
Symbol	Name
	Bus
	3W XFMR
	Reactor
	Power grid
	PV module with inverter
	Static load
	Instrumentation
	HVdc
	Wind turbine

Table4.1 ETAP symbol

In addition, there are some useful information that should be known:

1) The value of the real power in output graph is in MW and it single-phase power.
2) The value of the voltage in output graph is in kV, also its peak voltage.
3) The value of the current in output graph is in kA.
4) The value of angle of power factor is in degree.
5) The value of the reactive power in output graph is in MVAR and it is single-phase power.

4.2 Rating values and measurements:

Below is a list of the items used in our simulation, and the ratings information for each item:

- Transmission line

  Voltage = 33 kV, base power = 40 MVA, frequency = 50 Hz.

- Transformer

  We use 2 transformer in our design both for step down voltage near to generator side , oThe step down transformer rating value: delta-wye, 33/11 kV,base power = 40 MVA

Measuring devices were added (multimeters) in the first feeder to get some readings, so a multimeter will be seen at first at the generator side and its measures real power, reactive power, peak voltage, rms voltage, and power factor angle.

The second multimeter was installed at the first point of the feeder before the transformer and a third one after the transformer before the transmission line, so loses on the first transformer can be calculated.

In addition, another multimeter was added after the transmission line so that the loses in transmission line can be calculated as well. At last the final multimeter was installed at the receiver end of the feeder line after the transformer but before the feeder bus so the power flow from the conventional source can be measured. Furthermore, a multi meters placed near the PV side; the output of the PV parameters that are measured are real, reactive power, current and voltage. The measurement system is illustrated in Figure (4.1).

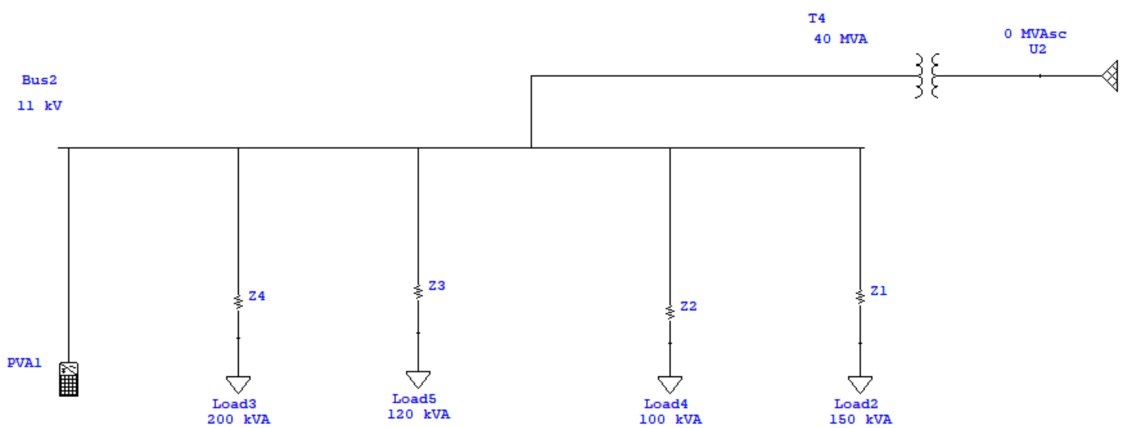


Figure 4-1: Measurement of system

The following scenarios will be simulated in ETAP to evaluate the best design for this system, such that we have the least amount of losses in the system.

a) Normally operating grid

b) Grid with PV

4.3Case 1: Normally Operating Grid:

The first step of this project starts from here. The design and implementation of power grid for a town using conventional sources, adding transmission line and transformer was simulated in ETAP. As shown in figure(4.2) below:

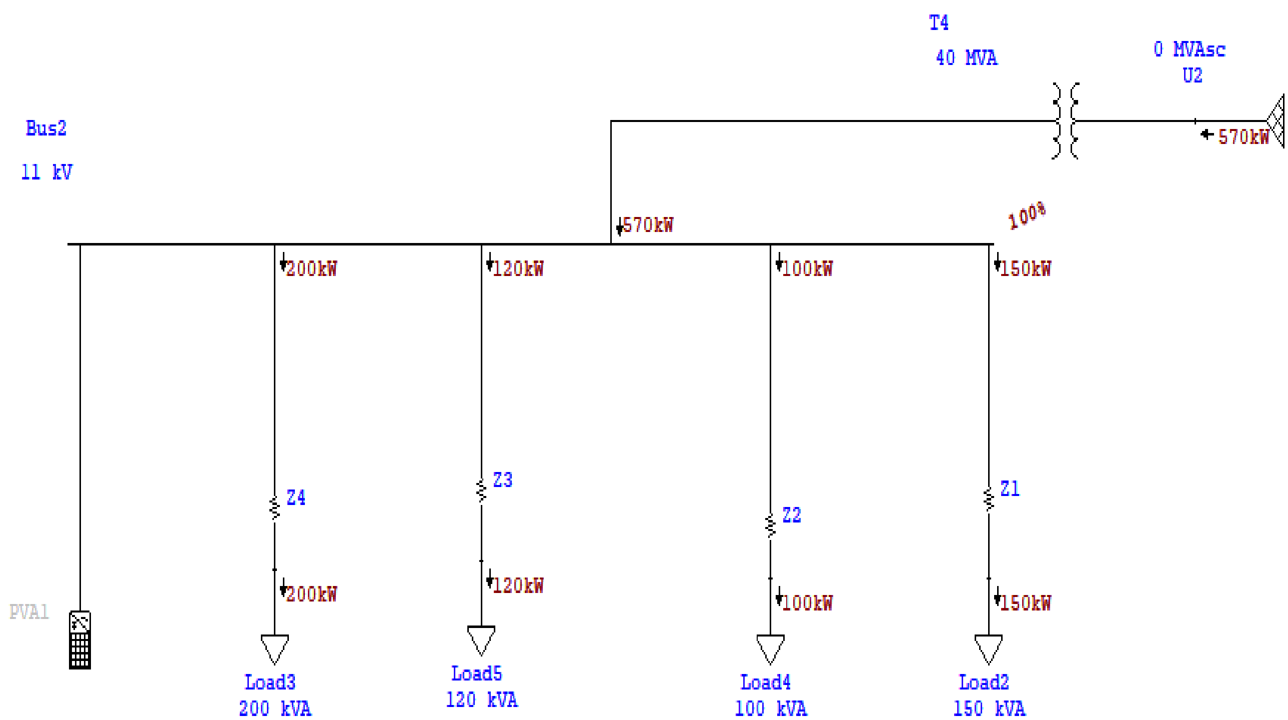


Figure 4-2: Simulated power grid

Signal name	Measurement
Real power	38 MW
Current	1.15 KA
Voltage Rms	33 KV
Power Factor	0.95

Table 4-2: Generator output values for case 1

4.4 Case 2: Grid with PV

In this case, the second part of the project is continued by integrating the power grid of the city with renewable energy; specifically photovoltaic (PV) model. In the first case, we add a PV model in the feeder.

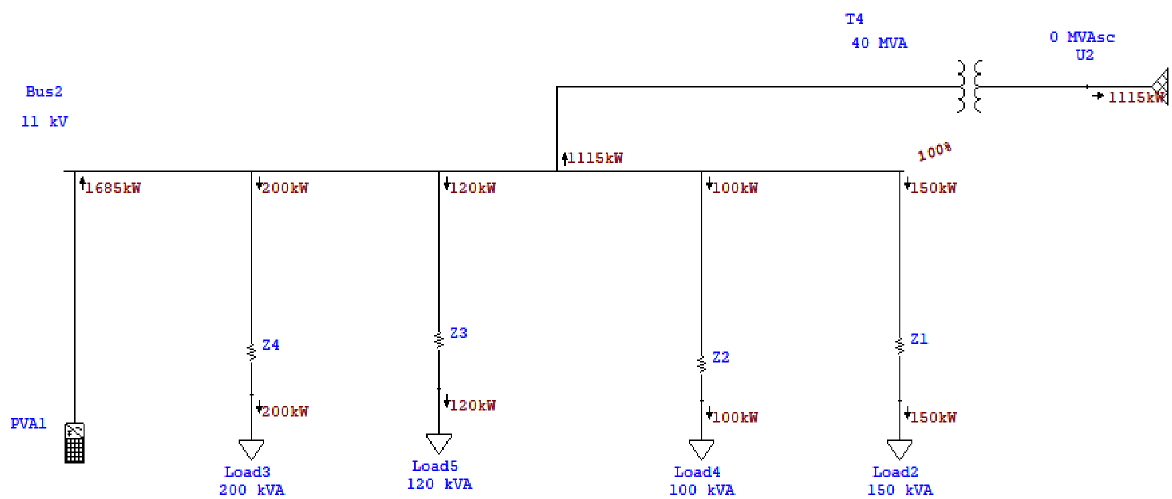


Figure 4-3: Simulated power grid with PV

a) Real power (P) in (MW)

Type	Power from PV	Power generator	Power at load
Grid	0	570 KW	570 KW
Grid with PV	1685 KW	1115 KW	570 KW

Table 4-3: Real power measured values in KW

b)Current (I) in (KA)

Type	Power From PV	PowerFrom generator	At the load
Grid	0	0.001 KA	0.0299 KA
Grid with PV	0.0884 KA	0.019 KA	0.1183 KA

Table 4-4: current values measured in kA

c)Reactive power in (MVAR)

Type	power From PV	power From generator	At the load
Grid	0	0.13 KVAR	0
Grid with PV	0	-0.36 KVAR	0.05 KVAR

Table 4-5: Reactive power measured values in KVAR.

4.5 Discussion:

In case one, the system operates without PV. The real power is 570KW, the current is 0.001KA and the reactive power is 0.13KVR.

In case two, the system operates with PV. The real power is 1115KW, the current is 0.019KA and the reactive power is -0.36KVAR.

Chapter Five

Conclusion

5.1 Conclusion:

In conclusion, we have successfully achieved a power grid that derives energy from conventional and renewable sources, efficient in terms of reliability and energy consumption through the correct choice of the final design. In addition, a major feature we have added is the way that we distributed the PV models in each feeder, which is an effective idea that gave us best values.

The goals we have put were completely and effectively met. As a result of the data that was shown in the final design at chapter four, the power generation losses of the grid decreases. On the other hand the power factor increases at the generator side. Furthermore, other objectives in our project are to decrease the power losses in the transmission line and transformer by adding a renewable energy.

5.2 **Recommendation**s

Traditional energy grid designs marginalize the value of information and energy The authors support .but a truly dynamic power grid requires both ,storage ,within the electric grid system defining energy storage as a distinct asset class supported with effective regulatory and financial policies for development and based smart grid system in which storage is placed in -deployment within a storage through realization This would enhance load and market operations .a central role Energy storage .of the full range and value of services from storage technologies technologies provide significant opportunities to further enhance the efficiency ergy services specific en-Its ability to provide application .and operation of the grid across different components of the grid make it uniquely suited to respond quickly energy storage as a ,Therefore .and effectively to signals throughout the smart grid enhancing distinct asset class will increase the value of storage investments while storage requires policy ,To further this goal .the operation of the smart grid policies will increase (D&RD)development and demonstration ,Research .support investment tax credits will accelerate ;operational experience and reduce costs and continued market deregulation will augment ;nt in storage projectsinvestme and provide more accurate prices for ,enhance competition ,revenue streams storage services

A majority of the Republic of Su**dan**population does not have access to electric power service. Although that Su**d**anhas good sources in the field of energy in general and electricity particularity. The share of renewable energy in energy mix does not exist in the Republic of Su**d**a**n**. In this paper we review the Potentials, the strategies of conventional electricity generation and the main problems in Sudan energy in the late five years. This paper documents the potentials of renewable energy (solar) as one of the most important alternatives for solutions most of the power problems in Sudan. The barriers and challenges facing the implementation of renewable energy investment projects in **Sudan** has been clarified

On that basis, and because of the political and financial problems we propose to use the renewable energy as the best solution method inSudan

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