Development of energy through wind simulation and design: a case study of Hebron Wind Farm in Palestine

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***Abstract*—Due to the increasing demand for energy in our everyday life, there is an increasing interest in the clean and renewable energy resources. this increasing interest motivates investors and stakeholders to increase the investment in this sector due to its long term cost effectiveness and due to its negligible pollution on the climate. Moreover, due to the growth of population and lack of enough resources specially in the outlying areas, engaging multiple energy resources will play a vital role in the urbanization sustainability and population distribution. Such that, on site energy generation will encourage people and facilities to leave the crowded large cities to other areas which in turn will increase the geographical space utilization. Therefore, solar and wind energy are considered the most useful sources of clean and renewable energy. In addition, simulation and parameters study for such systems has a great importance in the design and implementation processes. In this paper we will present a novel methodology that deeply analyze and simulate the design for windfarm to serve an important region in Palestine. And the results show the effectiveness of our system from both the technical side and from the financial side as well.**

Keywords*—*Wind Farm, Simulink, Matlab.

I. INTRODUCTION.

Nowadays, renewable energy plays a vital role in our everyday life due to different factors, such as, the increasing demand for energy, the limitation for sources of energy and due to the increasing environmental pollution. Therefore, there is an increasing demand to use the renewable energy sources. Wind is considered as the most promising source of renewable energy [1]. Wind turbine is directly affected by the natural environment such as, landform and wind conditions. Unlike other energy sources like, gas, steam and hydraulic power.

In order to achieve the optimum wind energy, the wind turbine regenerator should be running in variable speed variable frequency mode. Such that, maintaining the tip speed ratio to the value that maximizes aerodynamic efficiency, permits the variation in sympathy with wind speed [2].

Thereafter, complex technologies are currently used in modern wind turbines, such as, power electronics converters and control systems. Which makes the simulations tools such as Matlab/Simulink highly needed in order to evaluate the design performance of control systems [3][4].

Due to the importance of wind energy, in this paper we present a study to engage the wind energy with the existing energy sources in Palestine. The annual average wind velocity at different places in Palestine is 3 m/s which make the utilization of wind energy converters surely unfeasible in such places. In other places it is up to 5.5m/s (Al-Mazra'a Al-Sharqiyah /Ramallah is an example) and in our case about 6.94 m/s (Shaab al Butum/Hebron) which makes it feasible to be used to operate a wind turbine. In section II we present literature review, in section III we present the methodology, the system design is presented in section IV, section V contains results and discussion and section VI contains conclusion.

II. LITERATURE REVIEW

In literature, renewable energy attracted many researchers. For instance, modelling and simulation of wind energy got special interest by researchers due to its importance and since it has many parameters to be optimized by research. Therefore, different simulations approaches have be followed, such that some researchers followed existing modelling and simulation approaches where others created new modelling and simulation tools.

In [3], a new Matlab/Simulink toolbox was developed for wind turbine applications to simulate and optimize the design of wind turbine. In [1], the authors focused on the modelling and simulation of the DFIG generator. Such that, the authors presented a new method which combines the mechanical part and electrical part to model the wind turbine generation system. They used Matlab/ Simulink to establish the generator with voltage oriented control and the control system of pitching and generator. In [2], a prototype version of the control strategy of a 20-kW permanent management synchronous generator (PMSG) was proposed for maximum power tracking. as well the results produced by previous strategies was compared with the results obtained from this prototype.

In [5], the development of a generator and gearbox models in the matrix laboratory (MATLAB) environment was presented. As well coupling these models to different programs of the national renewable energy laboratory. These models were developed during the interfacing of the superior aerodynamic and mechanical models of Fast to the electrical generators models found in Simulink various libraries.

In [6], the results for simulation of a grid-connected wind driven doubly fed induction machine were presented with some real machine performance results. Such that, the operating conditions above and below the synchronous speed were considered.

In [4], the authors used Matlab/Simulink/SimPower to develop the model to simulate electrometric transient in power systems. And they presented the real-time simulation

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and modelling of a doubly-fed wind driven induction generator turbine in large power systems.

In [7], a hybrid energy system was proposed which combines both wind turbine generator and solar panel. Moreover, a control technique was proposed to track the operating point at which the PV system and the wind turbine produce the maximum power. The Matlab/Simulink was used to develop the simulation model.

In [8], two equivalent models for wind farms with fixed speed were proposed through aggregating wind turbines into an equivalent wind turbine. One of the models was developed for aggregated wind turbines with similar winds, and the other was for aggregated wind turbines under any incoming wind.

III. METHODOLOGY

The place of our research is located at an empty wide space (SHAAB AL BUTUM/south Hebron/Palestine). We choose this place because it has feasible wind speed because it located between two mountains which make a wind tunnel.

We performed our design over 1 Km² area and the optimum distribution of wind turbine was considered over this area. Moreover, Different wind measurements were carried for each day through a month (may-2015) as shown in Fig.1.

Moreover, we use excel program to calculate the frequency of each wind speed and also to calculate the probability of occurrence for each value as shown in Table.1. Then we used these calculations to draw the probability curve, Fig.2 shows the probability curve. And we used Excel program also to perform the data in order to find the Weibull value, such that we used the following equation:

$$F(v) = K * \frac{v^{(K-1)}}{C^{K}} * e^{-\left(\frac{v}{C}\right)^{K}}$$

Then we used Matlab to draw the curve, Fig.3 shows the Weibull distribution for the calculated data.

We had use the following value of scale and shape parameters (C & K)

C= 5m/sec

K=2

IV. SYSTEM DESIGN

It is so important to determine the appropriate size of the system components. The system shall not be oversized (expensive without increasing performance) or undersized (not capable to operate load).

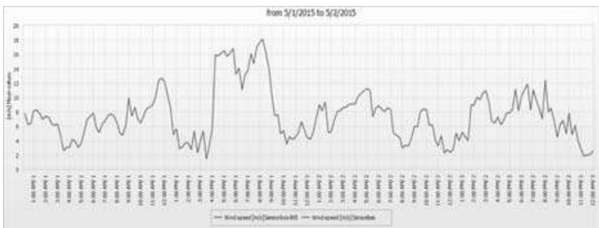

Fig.1.Average wind speed may-2015

Table.1. The frequency and the probability for each wind speed

Wind Speed	Frequency	Probability
0	17	2.28%
1	22	2.96%
2	73	9.81%
3	64	8.60%
4	75	10.08%
5	57	7.66%
6	79	10.62%
7	40	5.38%
8	82	11.02%
9	47	6.32%
10	48	6.45%
11	23	3.09%
12	32	4.30%
13	22	2.96%
14	20	2.69%
15	13	1.75%
16	12	1.61%
17	9	1.21%
18	6	0.81%
19	1	0.13%
20	2	0.27%

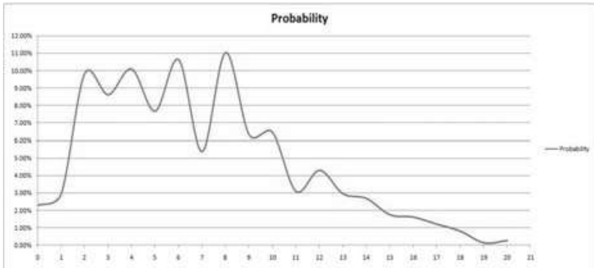

Fig.2. The probability curve

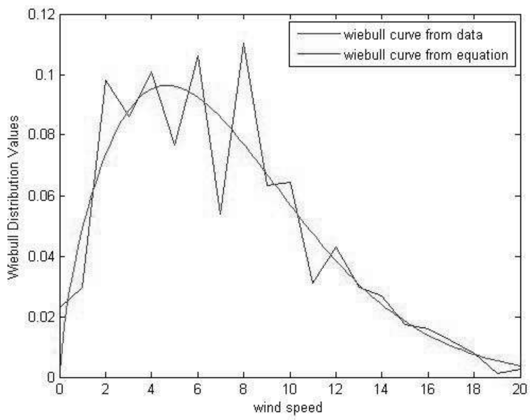

Fig.3. Weibull distribution/Shaab Al Butum

A. Load Study

The first step for design of any electric power system is load study; the behavior of consumers is the parameter that determines the load profile. In Palestinian case most of loads are lighting fixtures, radio/TV, and domestic appliances (washing machines, fans, refrigerators, and others).

The loads vary between day and night Fig.4 shows the average daily load curve here in Palestine.

B. *Wind Turbine Modeling and Sizing*

The power output of a wind turbine is determined by its power curve and the instantaneous wind speed at the sight of installing this wind turbine.

The most important parameters that must be known cut in speed, cut off speed, and rated power out.

In our case we chose a wind turbine rated at 10KW power out we take the other information we need from the data sheet of the wind turbine. such that, Table.2 shows the important parameters.

Table 2. Characteristics of wind turbine

Parameter Name	Parameter Value
Start up wind speed	2.5 m/s
Cut in wind speed	3.5 m/s
Cut off wind speed	25 m/s
Rotor blade diameter	9.8 m
Rated power output	10 KW

C. *Generator Modeling and sizing*

The most important thing that we must know is the type of the generator which is permanent magnet synchronous generator it's voltage 240 V at 150 rpm.

D. *Inverter Modeling and sizing*

The inverter is a critical component used in any PV or wind system where alternative current (AC) power output is needed. It converts direct current (DC) power output from the solar arrays or wind turbine into clean AC electricity for AC appliances.

Grid connected inverter or grid tie inverter is designed specifically for grid connected application that does not require battery backup system. Grid connected inverter or grid tie inverter converts DC power produced by wind turbine to AC power to supply to electrical appliances and sell excess power back to utility grid.

The size of the inverter is 10 KW and the input voltage range 230-400 V.

E. *Simple Economic Evaluation of the System*

1) *Cost of the wind turbine.*

Wind turbines are available in many different types and sizes, also wind turbine requires tower, control equipment, and installation.

The price of the wind turbine depends on its size:

- A residential-scale system (1-10 kW) generally costs between $2,400 and $3,000 per installed kilowatt.
- Commercial turbines (larger than 500 kW) cost in the range of $1,000 to $2500 per kilowatt, with the

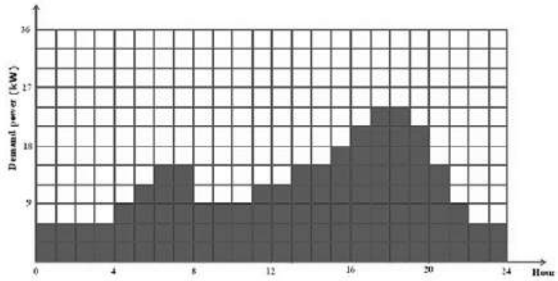

Fig.4. Typical daily load curve

lowest costs achieved when large multiple units are installed at one location.

In our work we used 10 turbines each sized 10KW then the cost of wind turbines is:

Cost=$2500*10=25000$

2) *Cost of the inverter*

The cost of the inverter also depends on the size, for the size 10KW the cost=7000$.

We will use 10 inverters so

Cost=10*7000$=70000$

This farm almost cost 100,000$, there are more complex calculation must be made to build a project like this such as simple payback period, present worth analysis, and life cycle cost.

V. RESULTS

A. *wind turbine*

As we told before, we had used the wind turbine 10Kw rated three blades 9.8m length of each one. Fig.5 shows how this wind turbine block is presented in Simulink:

The most important block in this part is the wind speed values over a month (may 2015) which was consists of 744 hours reading we took these values as array which was synchronized with time, these values are presented inside Matlab as time series object, then these values from work space were entered as input for wind turbine, in addition to that, generator p.u. speeds and pitch angle of rotor as inputs for these modules as 1 p.u. and 0 degree.

Inside the wind turbine subsystem, we implemented the following module in order to emulate the necessary equations as following:

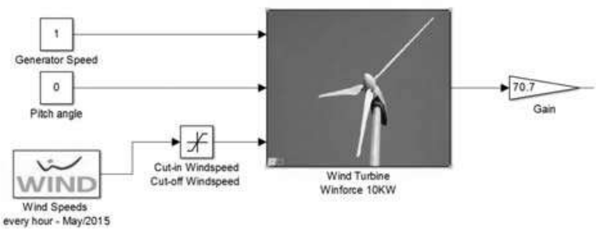

Fig.5. Wind turbine Simulink block.

The output power of the turbine is given by the following equation.

$$p_m = \frac{Cp(\lambda, \beta)\, \rho\, A\, V^3{}_w}{2}$$

Where

Pm – Mechanical output power of the turbine (W)

Cp – Performance coefficient of the turbine

ρ – Air density (kg/m3)

A – Turbine swept area (m2)

Vw – Wind speed (m/s)

λ – Tip speed ratio of the rotor blade tip speed to wind speed

β –Blade pitch angle (deg)

This equation was transferred to per unit values to be easily manipulated as mathematical module

$$Cp = C_1 \left(\frac{C_2}{\lambda i} - C_3\beta - C_4\right) e^{\left(\frac{-C_5}{\lambda}\right)} + C_6\,\lambda i$$

$$\frac{1}{\lambda i} = \frac{1}{\lambda + 0.08\,\beta} - \frac{0.035}{\beta^3 + 1}$$

Whereas the constant values are the following

C1 = 0.5176, C2 = 116, C3 = 0.4, C4 = 5, C5 = 21 and C6 = 0.0068

λ = 8.1

Fig.6 and Fig.7 show the subsystem that was implemented to solve these equations.

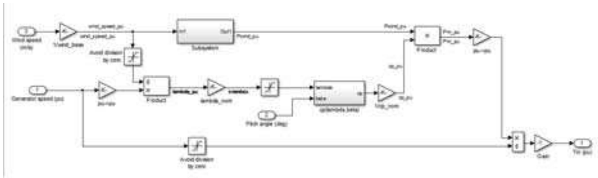

Fig.6. Subsystem solves the equation of the wind turbine

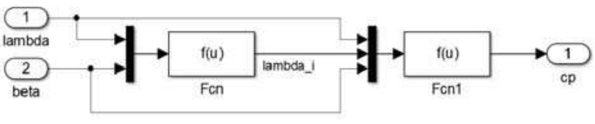

Fig.7. Subsystem represent the functions

$$Fcn \rightarrow \frac{1}{\frac{1}{(u[1] + 0.08u[2])} - \frac{0.035}{(u[2]^3 + 1)}}$$

$$Fcn1 \rightarrow C_1 \left(\frac{C_2}{\mathrm{u}[2]} - C_3\mathrm{u}[3] - C_4\right) e^{\left(\frac{-C_5}{u\,[2]}\right)} + C_6\,\mathrm{u}[1]$$

At the end of this module of wind turbine, the output was mechanical torque which is in p.u. value, and we had product it with (-1) in order to make it value negative, this is necessary when we made it as input to the next subsystem, generator side

The p.u. value of torque is multiplied q_i^{th} base to get the real value of output mechanical torque according to the following equations

rotor nominal speed (N) = 150rpm

$$\omega = \frac{2 * pi * 150}{60} = 15.7\ rad/sec$$

base torque =base power (VA)/base speed (rad/sec)

= 1.11x103 /15.7 = 70.7N.m

The value of the gain is 70.7 N.m.

B. Permanent Magnet Synchronous Generator

This part was implemented in order to transfer mechanical power which out from the turbine to electrical 3 phase signal

The Permanent Magnet Synchronous Machine block operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque (positive for motor mode, negative for generator mode).

There are 3 phase stator current which will be input to the pulse width modulation block which at final deal with it and with reference current value from the previous block, which convert the currents components q,d,0 to the 3 phase values a,b,c.

All of this is implanted as the following module.

1) Permanent Magnet Synchronous Generator

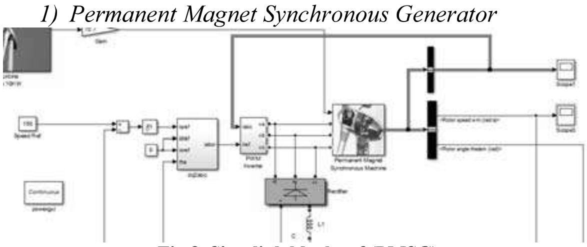

Fig.8. Simulink blocks of (PMSG).

2) PWM Subsystem

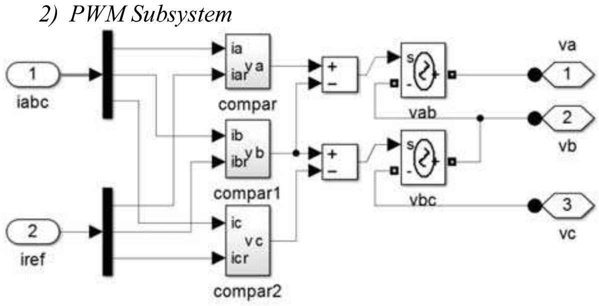

Fig.9.PWM Subsystem

3) qd2abc Subsystem

This module is converting the q,d components to a,b,c currents inside the generator according to sum equations inside it

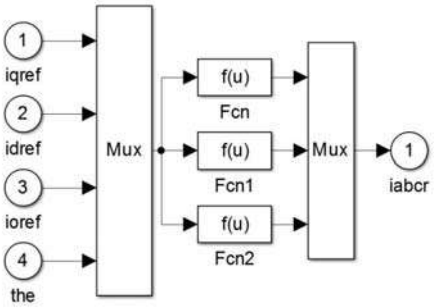

Fig.10. qd2abc Subsystem

Where as

$$Fcn \rightarrow u(1) * cos(u[4]) + u[2] * sin(u[4]) + u[3]$$

$$Fcn1 \rightarrow u(1) * cos\left(u[4] - \frac{2 * pi}{3}\right) + u(2) * sin\left(u[4] - \frac{2 * pi}{3}\right) + u[3]$$

$$Fcn2 \rightarrow u(1) * cos\left(u[4] + \frac{2 * pi}{3}\right) + u(2) * sin\left(u[4] + \frac{2 * pi}{3}\right) + u[3]$$

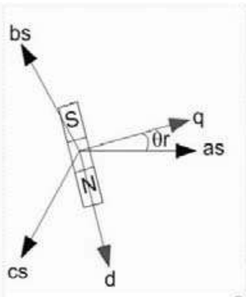

Fig.11. AC-DC-AC Convertor Module

Here is most important part of this work, since we got the output voltage signal from it. In simple way, it is a block to transfer the output signal which is not useful to DC signal which also be refined using LC circuit, series inductance and parallel capacitance.

This DC signal will be inserted to PWM IGBT 3phase inverter in order to transform it to 3 phase AC signal which is refined also using LC 3 phase filter subsystem, which at last get out the refined 3phase sinusoidal signal which represent the useful electricity which must feed the network.

It contains also a control feedback system using the output voltages and Vabc and some reference voltage Vref (=1p.u.) to make a signal input to the IGBT inverter as a switch to gate input.

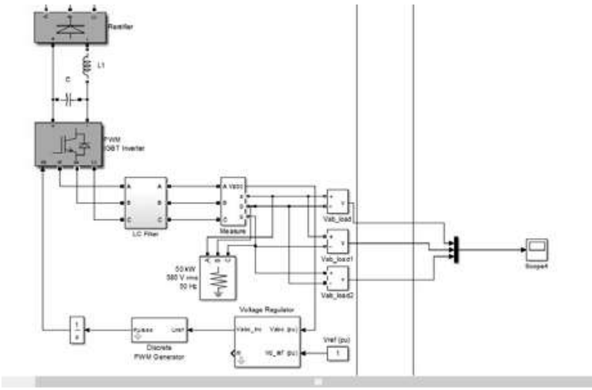

Fig.12. AC-DC-AC Convertor Module

The LC filter subsystem is implemented as the following:

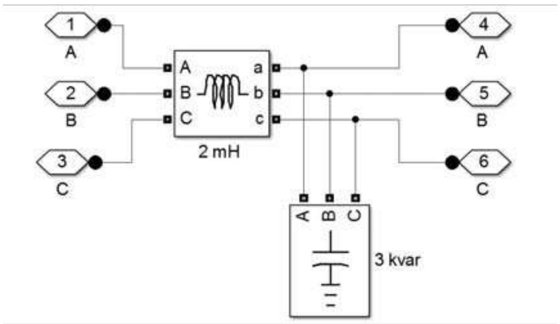

Fig 13. The LC filter subsystem

The module of voltage regulator subsystem is as the following:

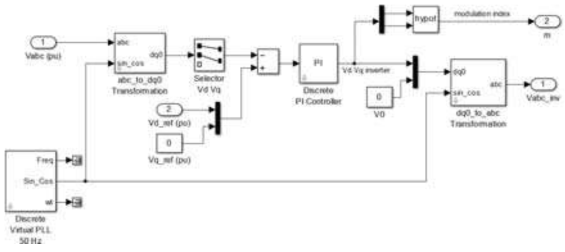

Fig.14. Voltage regulator subsystem

The subsystem of the PWM generator as the following:

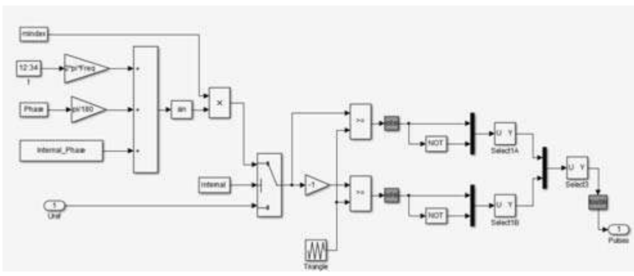

Fig.15. The subsystem of the PWM generator

C. The Final Measured 3Phase Voltage

The output signal was entered to 3 voltmeters in order to catch the 3 phase output signal which at last shown in a scope likes the following:

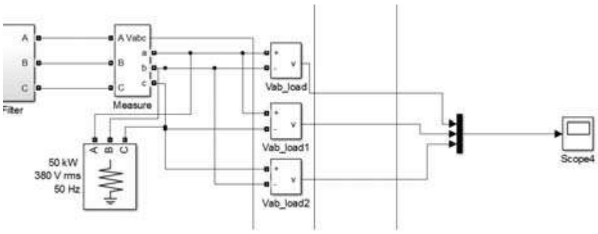

Fig.16. The Final Measured 3Phase Voltage

The output signal as the following (which is the wanted signal):

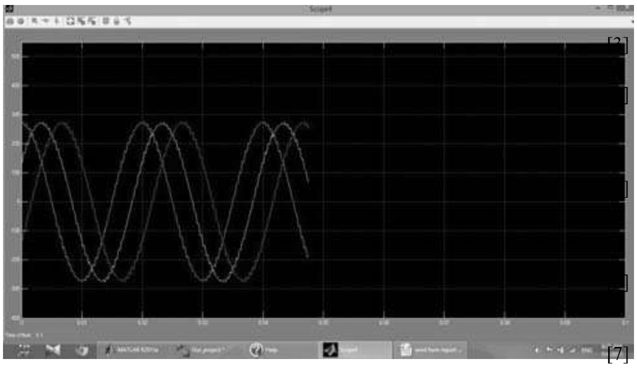

Fig.17. The output signal

VI. CONCUSION AND FUTURE WORK

Wind energy is a clean and promising energy and electricity nowadays is vital. In this work we presented a model that shows the possibility of generating energy for the faraway regions using wind. The results were promising and the cost is not large. This is just the beginning of the work; the work can be continued by designing a hybrid model that combines more than one resource of clean energy especially solar energy. This can generate more and maintain the continuance of electricity during the whole year.

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