KURDISTAN ENGINEERING UNION

MODELING AND INTELLIGENT CONTROL OF A STANDALONE PV - WIND - DIESEL - BATTERY HYBRID SYSTEM

BY

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***Abstract-* This paper presents a study of the modelling and intelligent control of a stand-alone hybrid energy system based on solar-wind-diesel with battery. In this study as the proposed system operate in a standalone mode the power quality is expected to decrease by the fluctuations from each of the voltage and frequency with varying loads and each of the two renewable sources which have depended on the wind speed, and solar radiation and temperature. This can be solved, by controlling the Pulse Width Modulation (PWM) of Voltage Source Converter (VSC) as modelled with Battery Energy Storage System (BESS).**

Consequently, it is of great interest the operation and intelligent control of the aforementioned systems for certain normal, and abnormal operating conditions. Furthermore, the other aim of this work is to design this control by soft computing techniques such as fuzzy logic and PI controller have been adopted in Matlab/Simulink to simulate the outcomes, and choosing a suitable controller with proposed modelling hybrid system, as more as robustness; By compare the dynamic performances of PI and the fuzzy controllers through the study of the voltage and frequency control of the micro-grid under disturbances, moreover, to express and verify a much more capable, precise and robustness between these two types of controllers to quickly repair and stabilize the micro-grid during events such as the islanding.

***Index Terms* - Renewable energy, solar photovoltaic system, wind turbine, diesel engine, hybrid stand-alone power system, frequency regulation, voltage control, fuzzy logic controller.**

I. INTRODUCTION

Electricity supply in remote areas without having the main source of grid electricity has been mostly provided by stand-alone diesel generators. This solution is relatively inefficient and expensive and pollutes environment due to the greenhouse emission. Some level of penetration of hybrid systems containing panel solar photovoltaic-wind turbine-diesel generator can be considered for more efficient and clean electrical power generation. Analyzing the hybrid system implies the development of simulation models of hybrid system operating standalone in a rural/remote area. The demand for energy grows by the day. The rapidly increasing energy increasing uptake, along with limited resources of fossil fuel and the continued increase price of fuels .provides a more reasonable sense for an alternative energy source in the form of renewable energy [1]. The classical power systems such as large power generation plants are situated at a convenient geographical location to receive a maximum of the electrical power, which is then transformed into large consumption centers over the long distance transmission line. The system control centers detect and determine the power system continuously to guarantee the quality of the power, rated voltage, and frequency. Though, at this stage the complete power system is under challenge, that is, a large number of generation units, including both nonrenewable and renewable sources such as wind turbines, wave generators, solar photovoltaic (PV) generators, are being developed, and installed as a micro-grid. Those are then defined as two or more DGs or storage assets configured in a network and capable of operating either in parallel with, or independent from, a larger electric grid, while providing continuous power to one or more end users. A common use of renewable energy sources in distribution networks and a high inventive level will replace the aged ones in the near future and thus replacing the old ones.

Renewable resources are a natural resource, which basically gain from the natural environment the surrounding atmosphere. Over the last few decades or so, natural resources have become something popular to use. This is particularly the case with developed countries. It's worth mentioning that the new energy source has both cost effective and more environmentally friendly use. As well as being less reliant on importing energy from other countries. Moreover, it also provides a good source of employment for the local population.

A common application of renewable energies is electricity generation. Renewable energy facilities generally require less maintenance than traditional generators, so has minimal impact on the environment. Among all the renewable energy resources, the solar and wind energies have the greatest potential as a power generating energy source, because of their many advantages like low or zero emission of pollutant gasses, low cost, inexhaustible sources and easy availability of these energy sources. But these systems have some disadvantages also like dependency on weather conditions. The difficulty to generate the quantities of electricity is one of the major disadvantages that are as large as those produced by traditional fossil-fuel generators. So it's necessary to reduce using the amount of energy or simply find an alternate source of energy. Using different power sources, is the best solution to balance our energy problems [1].

In this paper, a hybrid micro-grid is proposed, modeled and studied in Matlab/Simulink. Since the controlling of voltage and frequency in micro-grids is one of the most important cases; therefore, control schemes are designed in order to it, within changes of loads and whether [2]. The voltage source converter (VSC) works as a bi-directional switch, by trigger fed signals can be monitored its direction and changing output current's. The fuzzy logic control (FLC) and PI control scheme are used in the control action. The PI controllers among the converters were designed and tuned to investigate the stabilization to restore the voltage and frequency of the micro-grid by Discrete PID controller blocks during uncertainties existed in the load and generation powers. Then, three FLC-based controllers were designed and implemented in place of the PI controllers located in the control schemes of the inverter and storages. Results are achieved during the off-grid mode (islanding) and show that the FLCs are more robust to steady the voltage and frequency of the micro-grid, and better than of the tune PI controllers [2].

This paper is organized as follows: Section II deals with modeling of the hybrid standalone micro-grid system and explains the principle of the intelligent control and how it is effective to improve power quality (regulating voltage and frequency). It also explains the structure of the FLC. In Section III, the results are presented, obtained with Matlab/Simulink by changing the loading conditions, wind speed, and as well as the temperature and solar radiation in the hybrid micro-grid. The discussion of the outcomes is given in Section IV. Lastly, Section V conclusions the work.

II-MODELING OF HYBRID STANDALONE MICROGRID SYSTEM

Integration of renewable energy generation with battery storage and diesel generator backup systems is becoming a cost-effective solution for resolving less usable renewable energy during the year. However, if storage runs out, there is no way of importing energy. Therefore, a combination of PV and wind energy sources with the battery energy storage system (BESS) is a suitable alternative supporting energy source for this type of generation systems, where are fed the several of three phase resistive with inductive (RL) circuits which represents as a variable loads by opening and closing of the circuit breakers, thus it due to fluctuations in power energy. And distributed generators can help of these fluctuations in power supply since generation units will be close to the loads. However, introducing diesel generators will require an upgradation in the existing protection schemes, but it is not enough to the regulation of power because of the renewable sources depend on the weather [3].So the hybrid system needs to a controller to make a balance at each of any fluctuations that caused by each of the loads varying and the weather to keep of power quality by regulating of voltage and frequency. In this model, we have benefited by the charge and discharge of batteries, can be controlling both of active and reactive power for solve this problem. After designing a simulation of the hybrid power system by using sim power system toolbox and Fuzzy logic Toolbox in Matlab/Simulink software, which was obtained the results of simulation as shown in Fig.1.The performance of the proposed system which contains solar PV/wind turbine/diesel generator/battery was then tested under different operating conditions, as illustrated in characteristics of each of the solar panels and the wind turbine as shown in Figs. 3, and Fig.5. (a) and (b). The results were gained completely where the proposed system run at [0 to 6] was second that is the simulation time.

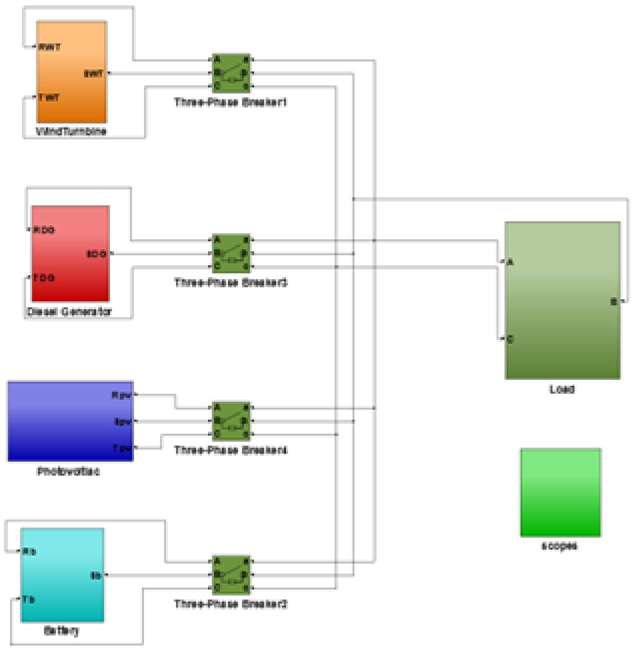

Fig. 1. Standalone Micro Grid Hybrid system modeled in Simulink/MATLAB

A. Modelling of Wind Turbine

Wind turbine generator is the other renewable source used widely in the places that have the wind at all reason, which is flexible to capture kinetic wind energy and convert to mechanical energy into electrical energy in a variables wind speeds as illustrated in Fig.3., for this reason, it be used Synchronous Generator [4] as shown in Fig.2.

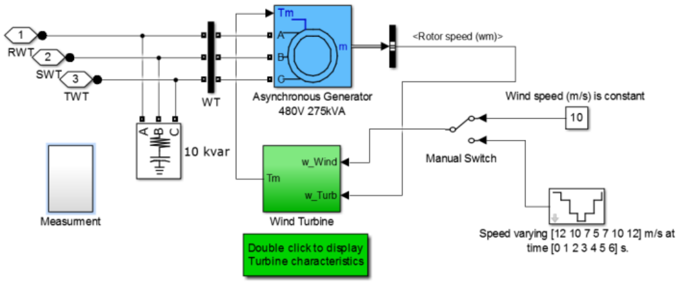

Fig. 2. Wind Turbine Synchronous Generator System Model in Simulink/MATLAB [5]

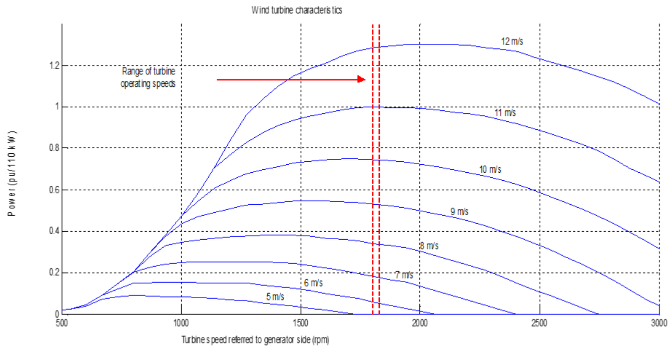

Fig.3. Profile of wind power with respect to the wind speed [5]

B. Modelling of Photovoltaic

Photovoltaic is a combination of more than one solar panel array of several solar cells, connected in series and parallel with large voltage and current output of one solar cell, which it can be simplified to a diode in parallel with a current source. The current generation is directly proportional to the sun radiation falling on the cell [6] and [7] as shown in Fig.4.

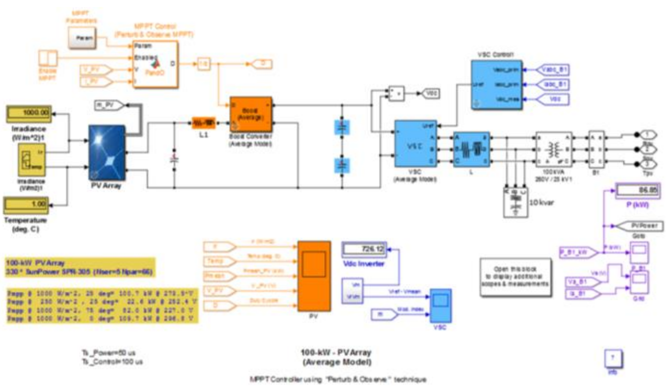

Fig. 4. Photovoltaic System Model in Simulink/MATLAB [5]

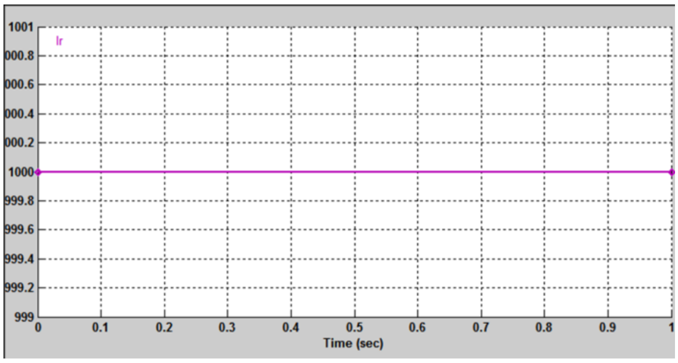

Fig.5. (a) Profile of Irrigation (kw/m^2) in the PV panel system [5]

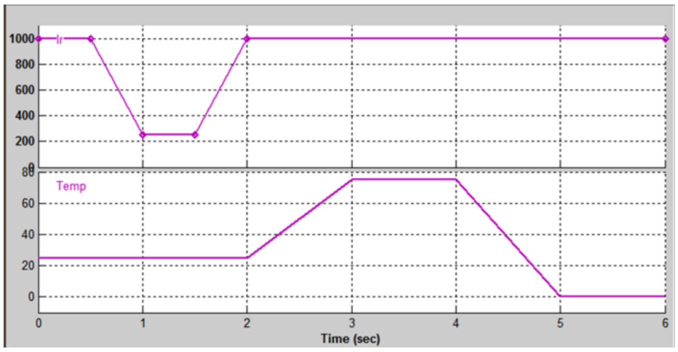

Fig. 5(b) Profile of Irrigation (kw/m^2), and Temperature (C^o) in the PV panel system [5]

C. Modelling of Diesel Generator

Diesel generator is the set of an electric generator with a diesel engine to generate electrical power by controlling the field current of the excite in the electric generator and speed governor in diesel engine can be regulation voltage and frequency of the generator [5], respectively as shown in Fig.6.

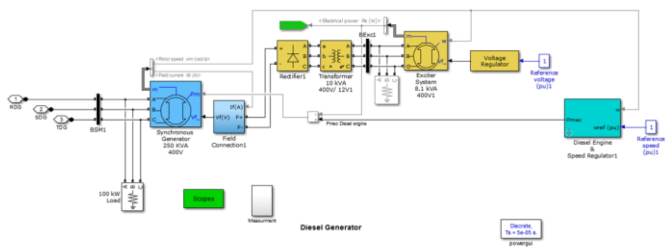

Fig.6. Diesel Generator system Model in Simulink/MATLAB [5]

D. Modelling of (BESS)

Because of the battery output voltage depends on current and state of charge, which is a non-linear function of the current and time, is represented as a non-linear voltage source that changes with the amplitude of the current and the actual charge of the battery. Then the output of voltage is zero when a flow of current is zero [6]. Fig.7 illustrate a model of battery.

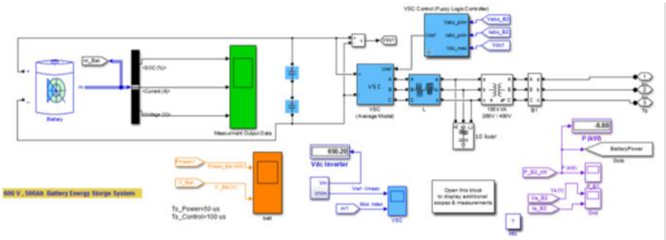

Fig.7.Battery Energy Storage system Model in Simulink/MATLAB [5]

E. *Control system*

In this study the battery system used for voltage and frequency regulator that is due to active and reactive power load compensate according to variation of the load demand. By using two loop controls, and modulation index the control of the terminal voltage and control of system's frequency was investigated. In the existing work, a trail has been made to control the terminal voltage and frequency (VF) of a standalone hybrid system that is driven by several renewable and nonrenewable energy sources by using the (BESS) with (VSC) is working for autonomous system. Average-model based (VSC) worked as a voltage and frequency controller is injected and absorbed both active and reactive powers, because of proportionality between power with frequency and reactive power with the voltage. The hypothesis were if any change occurred on active and reactive power will be changed each of voltage and frequency in system and so controls were investigated on system's frequency and terminal voltage. [8]. This paper deals with the application of a bi-directional power electronic device with a small stand-alone hybrid micro-grid system. Power managing method is proposed to conversion system which has its capability to support the load demand and remained the voltage and frequency near to steady state. (VSC) is used to lead active and reactive power flow between (BESS) with the capacitor that connected in parallel with a battery in DC side, and loads by the current regulator, as shown in Fig.7. In another hand by each of the Id and Iq frames, as shown in Fig.8.

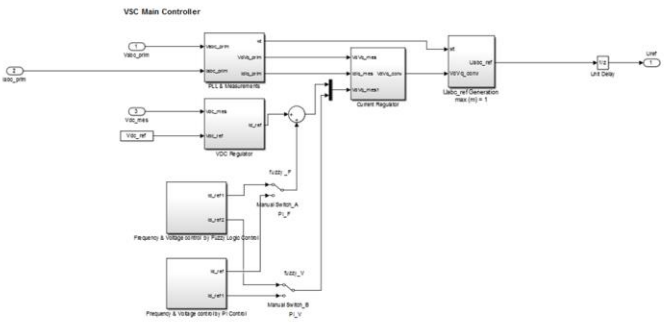

Fig.8. SVC (PI and Fuzzy Logic) Controller of BESS System Model in Simulink/MATLAB

Sudden changes in active power drawn by a load could cause system frequency fluctuation in AC grids.
These changes represent unbalanced situations between load and generation. In view of the above, it is important to design control loops for power and frequency control to mitigate quality issues, in this paper, a new modified id and iq frame as a control signal, which are proposed for effective control and system stabilization, thus a pulse width modulation (PWM) which is fed a VSC, which is working as adjusting voltage and frequency in three-

phase local load bus system. Harmonics are normally caused by power electronics devices and non-linear appliances. Appropriate filters and PWM switching converter can be used to mitigate harmonics distortion [4].

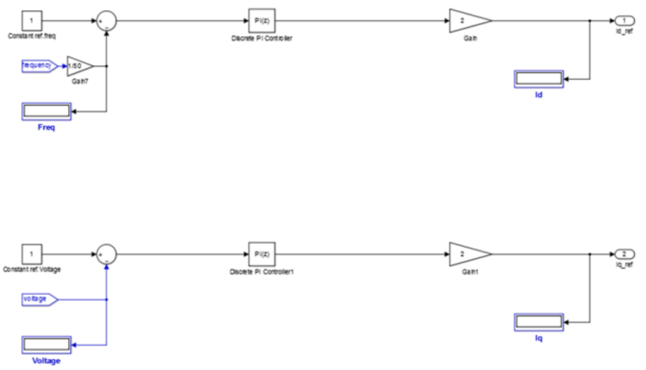

Fig.9. Id and Iq -PI Controller of VSC in Battery System Model in Simulink/MATLAB

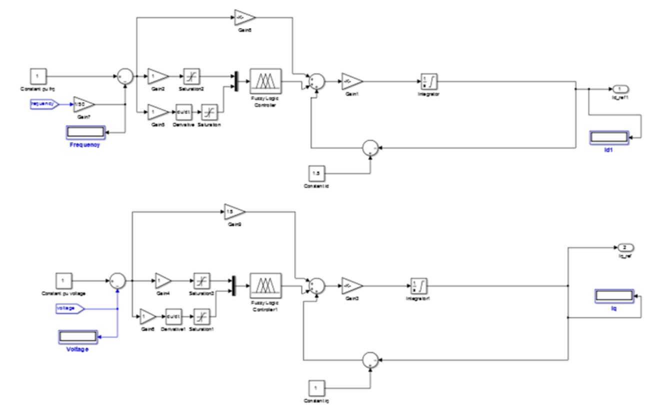

Fig.10. Id and Iq -Fuzzy Logic Controller of VSC in Battery System Model in Simulink/MATLAB

E.1. Intelligent control

To regulate a quality of generation of electricity in any power system must control the system output, so that the voltage and frequency is maintained. Consequently, the control system is necessary for power systems, particularly at standalone hybrid system.
In this study, it was used one of the types of intelligent control to control frequency and voltage of the micro-grid power system. One of the intelligent control method is fuzzy logic control which is used widely as a controller in the recent years. Lately, fuzzy logic is also used in science and manufacturing sectors, one of them is power system control [9].

E.2. Fuzzy logic controller

Fuzzy logic set up of rules used in a non-linear systems to provides a basis for a systematic way for the application of suspiciously and unbounded models. Fuzzy control is based on a logical system called fuzzy logic, and it is extremely closer to human thinking than classical logical systems [9].
Fuzzy control algorithm is used to appreciate the fuzzification and defuzzification operation in MATLAB/Fuzzy toolbox. The variable and Membership functions (MFs) of fuzzy toolbox is created.Fig.9.show PI controller system, and Fig.10.shows fuzzy control system. By implementing this technology can control the two important parameters in this work, which were voltage and frequency, the error from voltage and from frequency is given to the fuzzy controller and the output of fuzzy is given to the controller of the plant. Variables of the fuzzy logic controller includes the input variable error (e), d/dt of error Δe and the output m. (e) is taken as the deviation of reference and signals frequency, and voltage of the load. Δe is taken as the change rate of change of e. m is taken as change each of id for frequency control and iq for voltage control. The design of fuzzy controller involves formation of Membership function and rule base Input to the fuzzy controller are voltage error and frequency error. And the output from the fuzzy controller are Id and Iq which are caused by chancing of the

real and reactive power respectively, from battery system to micro-grid networks system In MATLAB /Fuzzy Toolbox the controller is simulated which having two inputs [10]. The input and output variable are shown in Fig.11. For the each of input variable voltage and frequency which consist of 'error(e)' and 'rate of error change (Δe)' signals and each of output of voltage and frequency 'm' signals, with choosing a suitable range of them.

All Membership functions are in 'trimf' types, which each of them created in seven (MFs), namely positive large (+L), positive medium (+M), positive small (+S), negative large (-L), negative medium (-M), negative small (-S), zero (0), as presented in Table I [10], as illustrated in Fig.11. , Fig.12, and Fig.13. These (MFs) are regulated by relationship (If e is ---- Δe is ----- Then m is ----) as a rule by Rule Editor in (FIS Editor) as shown in Fig.12, the rule base proposed by Mamdani method for the simulation of the Fuzzy controller, as shown in Fig.14, whosesoever, Forty-nine fuzzy rules are used, in the fuzzy Logic control. The chosen of this code number is somewhat heuristic. We find that good control performance is done with only a few rules for all [12].

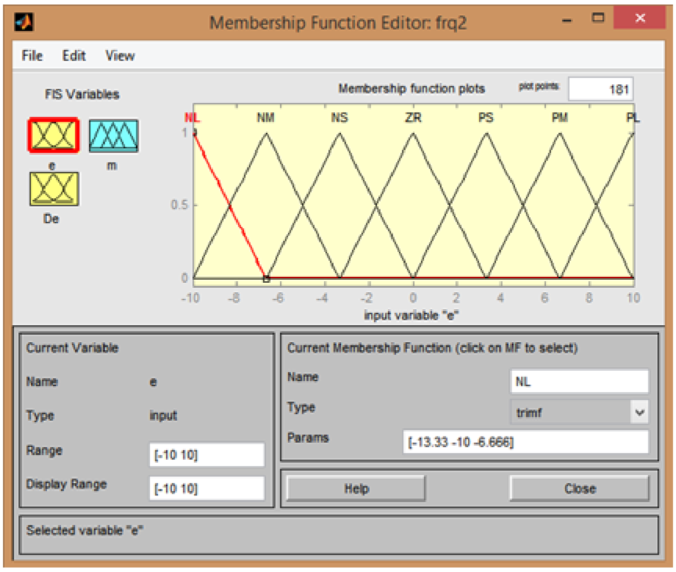

Fig.11. Membership Function for input and output of fuzzy logic system

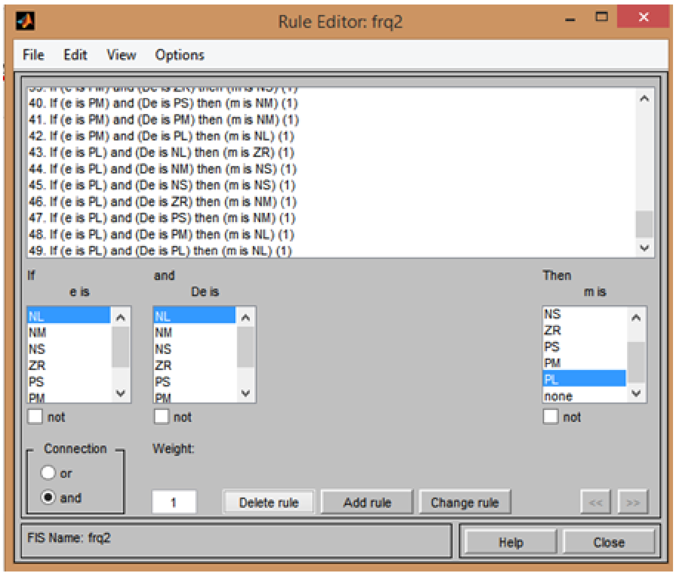

Fig.12. Rules of Fuzzy logic system

Table I
FUZZY RULES

Δe / e	-L	-M	-S	0	+S	+M	+L
-L	+L	+L	+M	+M	+S	+S	0
-M	+L	+M	+M	+M	+S	+S	0
-S	+M	+M	+S	+S	0	-S	-S
0	+M	+S	+S	0	-S	-S	-M
+S	+S	+S	0	-S	-S	-M	-M
+M	+S	0	-S	-S	-M	-M	-L
+L	0	-S	-S	-M	-M	-L	-L

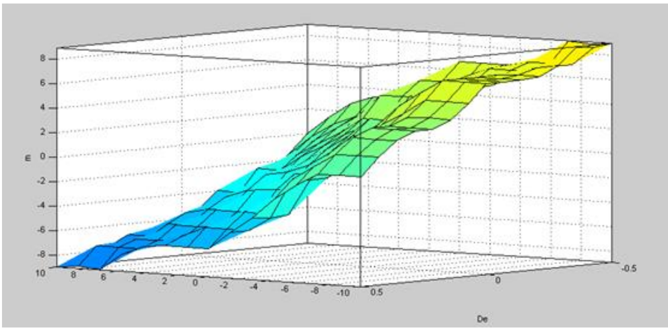

Fig.13. Surface of Rules

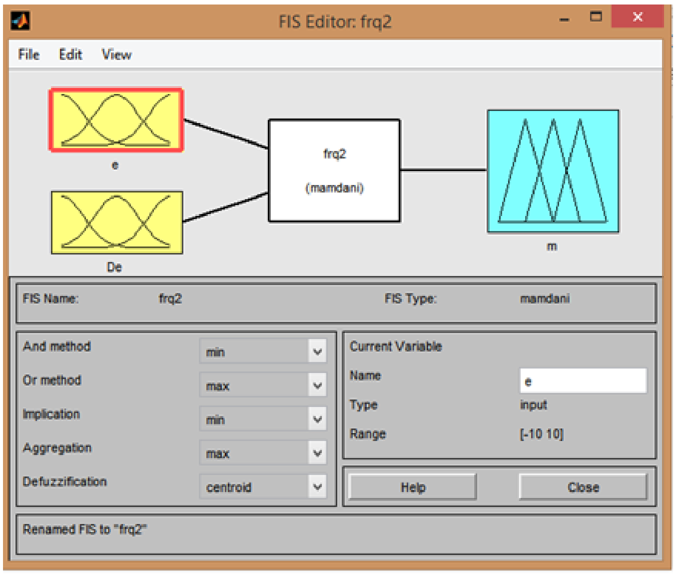

Fig.14. Fuzzy Logic Interface (FIS)

Table II
LOAD PROFILE WITH TIME INTERVAL

From Time (Sec)	To time (Sec)	Increasing of power load (KW)	Decreasin g of Power load (KW)	Power load (KW)
0	**1**	**95**	**-**	**95**
1	**2**	**5**	**-**	**100**
2	**2.5**	**5**	**-**	**105**
2.5	**3**	**10**	**-**	**115**
3	**3.5**	**-**	**5**	**110**
3.5	**4**	**-**	**10**	**100**
4	**6**	**-**	**5**	**95**

III.SIMULATION STUDIES

The comparison between the dynamic performances of PI and fuzzy controller on frequency and voltage control is tested in a model system as shown fig. 1. A system consists of 4 sources 1 load bus, to taking more cases in my work. The change applied is three phase load as a Time Interval bellow, when the loads change, as presented in the Table I, as an optimal scenario, with normal/abnormal operating conditions, and taking those cases:

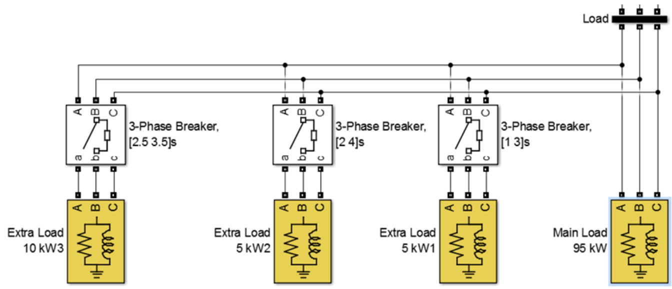

Fig.15. Load Profile modeled in Simulink/MATLAB

a) *Case study one:*

Compare the dynamic performances of PI and fuzzy controller on frequency and voltage control when the load changes (as shown in the load profile as an optimal scenario) when the wind, temperature and solar irradiation are constant.

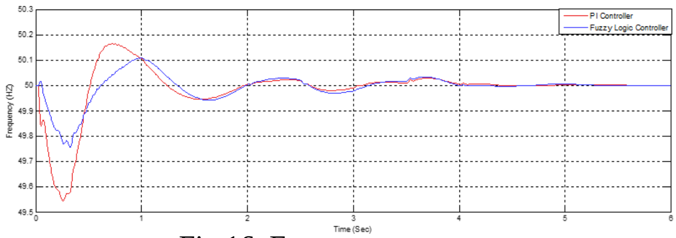

Fig.16. Frequency response

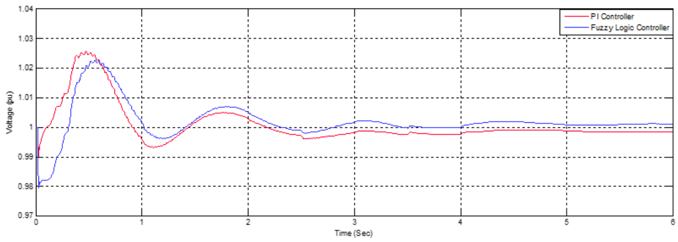

Fig.17. Voltage response

b) *Case study two:*

Compare the dynamic performances of PI and fuzzy controller on frequency and voltage control when the load changes (as shown in the load profile as an optimal scenario) only wind speed changes and temperature and solar irradiation constant.

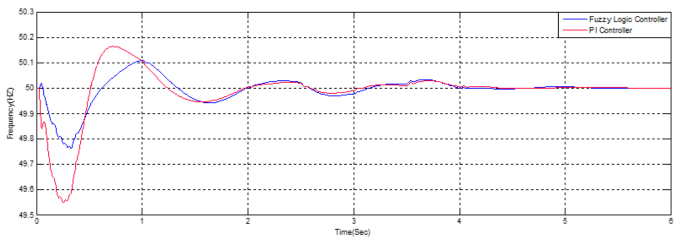

Fig.18. Frequency response

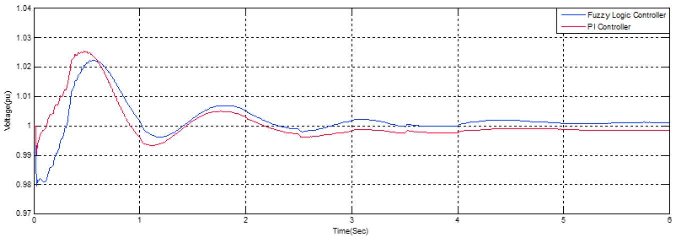

Fig.19. Voltage response

c) Case study three:

Compare the dynamic performances of PI and fuzzy controller on frequency and voltage control when the load changes (as shown in the load profile as an optimal scenario) only temperature and solar irradiation change and wind speed constant.

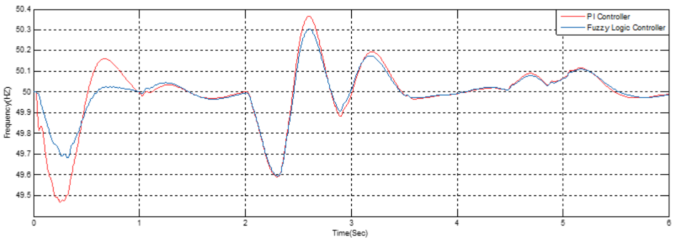

Fig.20. Frequency response

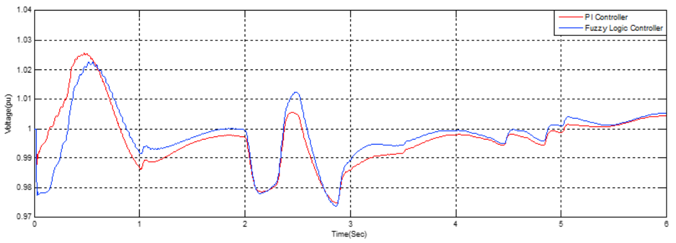

Fig.21. Voltage response

d) Case study four:

Compare the dynamic performances of PI and fuzzy controller on frequency and voltage control when the load changes (as shown in the load profile as an optimal scenario) and all the system variables (wind speed, temperature, solar radiation change randomly.

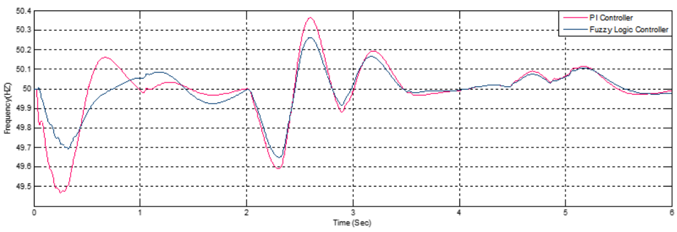

Fig.22. Frequency response

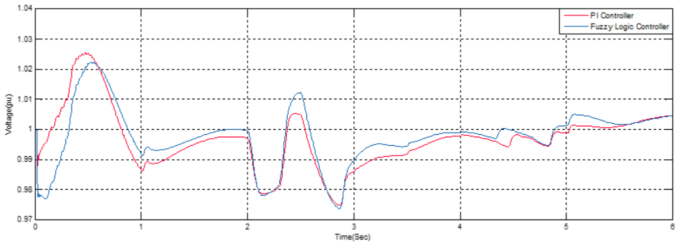

Fig.23. Voltage response

IV. DISCUSSION OF RESULTS

The suggested developed control strategies for hybrid generating system that is made of PV-Wind-Diesel-Battery is that simulated using Matlab/SIMULINK in different situation. For the desire of capturing the response of the control system. In this state each one of the irradiance and temperature are constant at all simulation time as shown in Fig.5 (a), where only load was variable, as presented in Table II. which are 1000W/m2 and 25C^{o}, otherwise wind speed is constant by 10m/s the PV irradiance is predicted to decreases from 1000 to 250 W/m2 at (0.5 -1) s, and increase from 250 to 1000 W/m2 at (1.5-2) s, also the PV temperature is assumed to increase from 25 to 75 C^{o} at (2-3) s, and decrease from 75 to 0 at (4-5) s, as shown in Fig.5 (b), it is due to changing power flow from the PV system moreover, the frequency and voltage changes on the load, too.

Furthermore, assumed that the radiance and temperature are constant at all simulation time, only wind speed is changing according to turbine characteristic, as shown in Fig.3. Choose assumption range, [12 10 7 5 7 10 12] m/s at times [0 1 2 3 4 5 6] receptivity, it is due to changes of power flow from the wind system moreover, the frequency and voltage changed on the load too. Except the variation of the load as presented in Table II. In general, the distortion of signals from two Annoying things, one of them is changing from the load, and another one being each the wind and solar sources.

Moreover, the proposed system operated under the above conditions that illustrated from figures 16 to 23, the compare dynamic response of the fuzzy logic controller to the Proportional-integral(PI) controller of the proposed system, by screening the responses each of them with the fluctuations that occur on the overall of the system as the impact on the voltage and frequency, can be admitted to the presentation of fuzzy logic controller has advanced dynamic response of the hybrid system, and has minimum overshoots, as well as being faster than (PI) controller at overall cases [13].

V. CONCLUSION

This paper investigated the three important work in one project by using MATLAB Simulink. First, the work shows a connection four different generation system that consist of PV/Wind/Diesel/Battery and operated together to support the load. Secondly, applied dq0-axis theory in a voltage source converter controller to controlling each of the frequency and voltage of standalone hybrid micro-grid system by supporting of a charging and discharging of the storage system with a capacitor in DC side. Finally, a comparison between the performance of PI and Fuzzy logic on voltage and frequency controller. The comparison examined hybrid power system, when occurred change on the three phases RL load and taking four cases, first, when the wind, solar irradiation, and temperature are constant. A second situation is only wind speed changes, while temperature and solar irradiation are constant, and the third situation, both temperature and solar irradiation change however wind speed is constant and final situation, wind speed, temperature, and solar radiation all change according to its characteristics, and show that the Fuzzy controllers are more robust and able to alleviate the frequency and voltage of the Micro-Grid as compared to the PI controllers. This work proposes a version method to using a fuzzy logic for voltage and frequency controller in a standalone hybrid power system, and so this method has been evaluated in simulation form in this study.

The ability of maintained to a certain level, without transgression on the balance of the terminal voltage and output power, as demonstrated in the obtained results.

The study of qualified comparative a dynamic response between the proposed controller and the conventional PI controller, with the fluctuations that has an effect on the voltage and frequency of the proposed hybrid power system. As a result, under different operating conditions, where recognized fuzzy logic controller was more effective than on the stability of the systems' frequency and voltage terminal in a standalone hybrid power system compared to the PI controller. [13].

Appendix

1. Generators:

Table 3 generators data

Parameters	G1	G2	G3	G4
Gen. types	PV	WT	DG	BESS
Capacity	100KW	110KW	250KVA	50KWh

2. Terminal Voltage overall system: 400v.
3. Systems frequency: 50HZ.

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