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Maximum Power of PV Cells Using Fuzzy Control

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Abstract: Since 2006, power generation sector faced several obstacles with limited output of Gaza Power Plant and fixed imports from Israel and Egypt. The demand keeps increasing annually while the supply is either fixed or decreased. Thus, there is a need for alternative power sources for emergency cases as hospitals and medical centers. The shortage in electric power, forced hospitals and medical centers to run their own generation units when fuel is available; creating more pollution and noise. This paper proposes replacing diesel generator by solar photovoltaic (PV) cells as a backup system, and a battery-bank as a storage system. Such system is expected to: satisfy the load demands, minimize the costs, maximize the utilization of renewable sources, optimize the operation of battery-bank which is used as backup unit, and reduce the environment pollution emissions. This paper proposes a methodology to maximize power of a PV grid connected system by optimizing the performance of the inverter. A fuzzy logic controller is proposed to control a DC/AC inverter that forces the photovoltaic array to deliver its maximal power for any value of solar insolation rapidly. Results shows improvement in the system performance using fuzzy logic control and the PV is capable of feeding the load with the required energy and charges the battery with its demands.

Keywords: Maximum power, fuzzy logic, solar energy, photovoltaic cells.

1. Introduction

Energy is an essential commodity to the whole world in terms of economic, social and environmental implications. Access to reliable, affordable and sustainable energy is a formula for prosperity and growth. A challenging issue facing developing countries is access to modern energy if they are to achieve economic growth; moreover, investment in modern energy is indispensable for prosper and sustainable future economy [1].

Renewable energy sources are found to be promising energy sources toward building a sustainable and environmentally friendly economy in the next decade. Solar and wind energy are two of the most promising renewable power generation technologies. The growth of PV and wind power generation systems has exceeded the most optimistic estimation. However, geographic and seasonal climatic conditions affect the solar-wind energy output. Therefore, a backup power system is needed to improve the energy supply reliability.

Gaza Strip is a small but one of the most densely populated area in the world. About 1.8 million people live in 360 square kilometers. Gaza Strip has come to be known as a fast growing area in the Middle East in terms of population. In 2002, it had a manageable population of 1.2 million, and reached 1.7 million in 2012. Gaza Strip’s population is expected to grow at a rate of 4.2% annually and reach a total of 2.13 million in 2020 [2].

The energy infrastructure of Palestine is quite small, insufficient and poorly managed. Gaza Strip is supplied with 211 MW of electricity from three main sources [3]:

1. Israel Electricity Corporation (IEC) provides 120 MW to all of the Gaza Strip.
2. Gaza Power Plant (GPP') provides 70 MW to the northern and central area of the Gaza Strip; and
3. Egypt provides 21 MW to Rafah area.

The demand for electricity is growing at a rate of 7% per year without any well designed plan to meet the demand. The average consumption of power in 2013 was about 360 MW, whereas the average peak demand of power was about 400 MW. This deficit leads to extensive load shedding. Other problems in the Gaza Strip electric power sector include high system losses, delays in completion of new plants, low plant efficiencies, erratic power supply, electricity theft, blackouts, and shortages of funds for power plant maintenance [3].

Ones can say that our society in Gaza Strip suffers from electricity shut down since 2006. Small units diesel generators can provide temporary solution, but they are inefficient because of their output compared with their running cost and are unreliable due to the fact that fuel is not available at all times. Since Palestine is considered one of the sunny countries and percepts good solar radiations over the year, solar energy was excellently utilized in water heating, but lacks clear feasibility to be utilized for electricity because

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of the high cost of photovoltaic system per watt [4]. The solar system efficiency is in the range between 7% to 15%. This efficiency can be increased using various methodologies ranging from better tracking of the sun to better use of batteries.

Previous studies show different use of technologies and achieve varying performance. Ricalde, et. al. [5] proposed a smart grid integrating wind, photovoltaic and batteries into an AC bus. The solar and wind characterization taken from a meteorological station during 2010 was presented showing the vast wind and solar energy potential in the region. The second part was to scale the microgrid installing 20 kW in two Wind Turbines and 7 kW in Photovoltaic modules. It dealt with microgrids, which mean small scale energy generation systems mainly from renewable energy. Although this study maintained the microgrid energy balance, it did not minimize the total cost.

Muoka, et.al. [6] developed models using Matlab/Simulink for an integrated PV power plant consisting of PV array, SEPIC (single ended primary inductance converter) converter, bidirectional dc-dc converter, dc-ac converter, and battery energy storage system. Also, the integration of energy storage to PV system via bidirectional dc-dc converter was invaluable in the mitigation of the problems of intermittency and variability of a PV power generator. This study did not address improving the performance of the PV system; it only presented a model and simulation result.

AlBarqouni [7] implemented of an experimental solar model for lighting of an apartment taking into account the IEEE Recommendations. The researcher re-designed and re-evaluated lighting in Gaza Strip and optimized batteries usage but did not improve the system performance.

EL-Moghany [8] presented fuzzy logic controllers that were fabricated on modern FPGA card (Spartan-3AN) to increase the energy generation efficiency of solar cells. Maximum Power Point Tracking in Solar Array Systems was used in his study. The results showed that the proposed sun tracking solar array system and MPPT were feasible methods of maximizing the energy received from solar cells. This study used fuzzy control for tracking the sun and did not consider regulatimg the current.

In this paper we are interested in solar power system which offers the best solution for the situation in Gaza. This paper proposes a solution to maximize power using fuzzy logic for a PV stand-alone system. The work in this paper involves optimizing the performance of the inverter. A fuzzy logic controller is proposed to control a DC/AC inverter that forces the photovoltaic array to deliver its maximal power for any value of solar insolation rapidly.

The remaining sections of this paper are organized as follows: Section 2 presents the building blocks of the proposed solar power system. Section 3 handles fuzzy control. Section 4 focuses on the design of the fuzzy logic controller and presents simulation results. The final section concludes this paper.

2. Solar Power System

The main building blocks of the proposed solar power system are PV panels, Controller, DC-AC inverter, and also diesel generator, as shown in Figure 1.

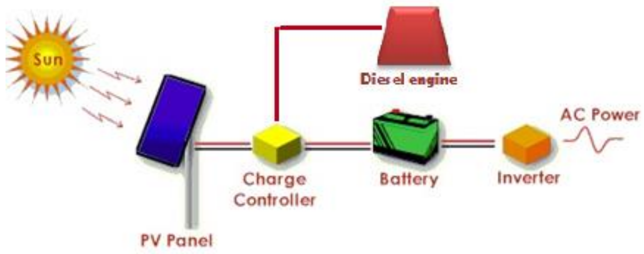

Figure 1: Typical PV power system

2.1 Solar PV

The word 'photovoltaic' consists of the two words, photo and Volta. Photo stands for light is the unit of the electrical voltage. In other words, photovoltaic means the direct conversion of sunlight to electricity. The common abbreviation for photovoltaic is PV [5]. Solar PV modules collect the sun's energy and convert it into direct current (DC) electricity.

2.2 Battery-bank

Batteries in PV system are needed when sunlight is unavailable. So the longest period without sunlight is an important factor in sizing batteries and considering cost effect. Battery-bank can be connected to the grid with a photovoltaic inverter. Photovoltaic generators can be combined with a diesel generator to create a hybrid system; thus, reducing energy costs and increasing system availability; however, operating complex systems needs a complex energy management system [9].

2.3 DC/DC converter

To connect a photovoltaic to an external system, it is necessary to boost its voltage or to increase its number. Therefore, a boost converter is used. A boost converter is a class of switching-mode power supply containing at least two semiconductor switches and at least one energy storage element. In addition, a capacitor is often added to the converter output to reduce the ripple of its output voltage [10].

Basic DC-DC converters are classified such as: buck converter (Step-down converter), boost converter (Step-up converter) which is used in the research, buck-boost converter (Step-down/step-up converter).

Equation (1) describes the relation between the input voltage, V_{in}, and the output voltage, V_{out}, of a boost converter as a function of the duty cycle, D [11]:

$$\frac{Vout}{Vin} = \frac{1}{1-D} \quad (1)$$

2.4 Inverter

An AC averaged switched model inverter is implemented to convert the direct current (DC) into alternating current (AC), at a switching frequency (f_s) greater than the AC line frequency (50Hz - 60Hz) and feeds it into an existing electrical grid. Equation (2) describes the relation between the input voltage, V_{in}, and the output voltage, V_{out}, of the inverter as a function of the duty cycle, D [10]:

$$V_O = V_{in}(2D-1) \quad (2)$$

According to the above problem, the purpose of the present work is to develop a fuzzy controller to control a DC/AC inverter that forces the photovoltaic array to deliver its maximal power for any value of solar insolation rapidly and precisely without the need to the exact mathematical model of the system. Figure 2 shows the input and output of the DC/AC inverter. PV arrays supply I_{PV} and V_{PV} in a DC form and the inverter converts them into AC form. A fuzzy control is designed to optimize power management based on a hierarchical controller implemented for a stand-alone solar power system to obtain maximum power supply out of the inverter.

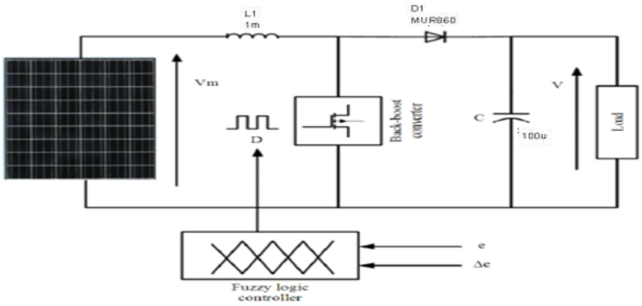

Figure 2: The block diagram of proposed PV control system[12].

3. Fuzzy Logic Controller

The basic parts of every fuzzy controller are displayed in Figure 3. The fuzzy logic controller (FLC) is composed of a fuzzification interface, knowledge base, inference engine, and defuzzification interface.

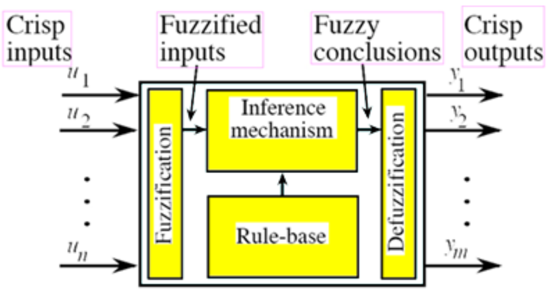

Figure 3: Basic parts of a Fuzzy Controller

3.1 Fuzzification

The input of a common controller is a specific numeric value, but the knowledge base for fuzzy control is expressed with language. The system must turn numeric values into language and corresponding domains to allow the fuzzy interface engine to interface. This transformation is called fuzzification [13].

3.2 Knowledge Base

Knowledge base is the inference basis for fuzzy control. It defines all relevant language control rules and parameters. The knowledge base (including the database and rules base) is the core of a fuzzy control system.

3.3 Fuzzy Interface Engine

The fuzzy inference engine performs the actual decision-making process and is considered the most important part of fuzzy control.

3.4 Defuzzification

Defuzzification transforms the fuzzy inference engine's output values into equivalent assured values, making the assured value comply with the input signals of the controlled system. This process gives output control signals to the controlled system.

4. Simulation Results And Discussion

In this paper, the proposed Fuzzy controller that is shown in Figure 4 has two inputs, i.e. error and change in error with membership functions. Each input has seven linguistic variables.

There are two widely used approaches in FLC implementation: Mamdani and Sugeno. In this paper, Mamdani approach is used to implement FLC for the solar power system. As shown in pervious section that FLC contains three basic parts: Fuzzification, Base rule, and Defuzzification. Now we will apply these steps to reach the result.

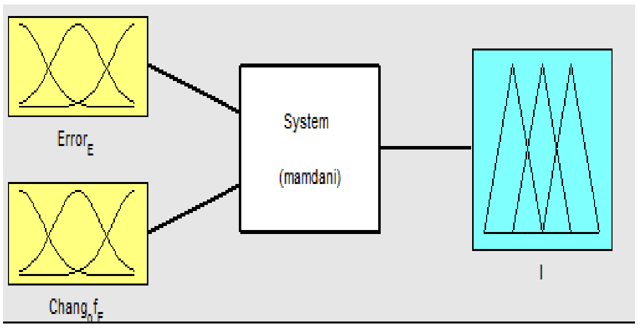

Figure 4: The block diagram of FLC for system

FLC has two inputs which are: error and the change in error, and one output feeding to the charge controller. Input of the FLC will be current and the voltage constant (Figure 5). A relation of error and change of error for current can be explained as an example if the error is positive (desired current – reference current) and the change error (error – last error) is negative which means that the response to going increase; hence, the FLC will go forward in this direction. Using the same criteria at the error is negative and CE is bigger negative; hence, the response is going in decrease.

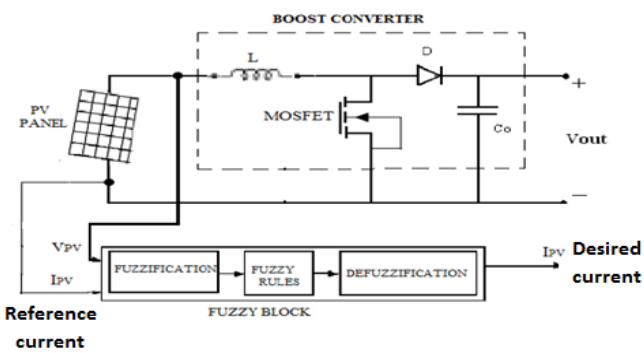

Figure 5: FLC controller

Figure 6 illustrates the fuzzy set of the Error input which contains 7 Triangular memberships.

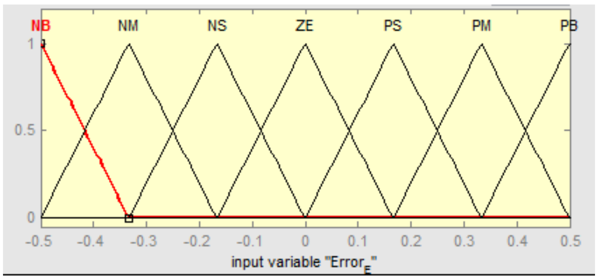

Figure 6: Input Membership function for given error

Figure 7 illustrates the fuzzy set of the Change of Error input which contains 7 Triangular memberships

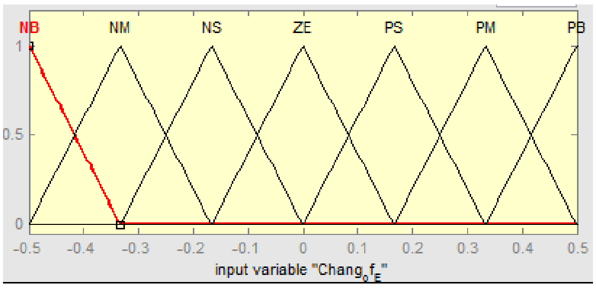

Figure 7: Input Membership function for change *in error*

Figure 8 illustrates the fuzzy set of the output which contains 7 Triangular memberships.

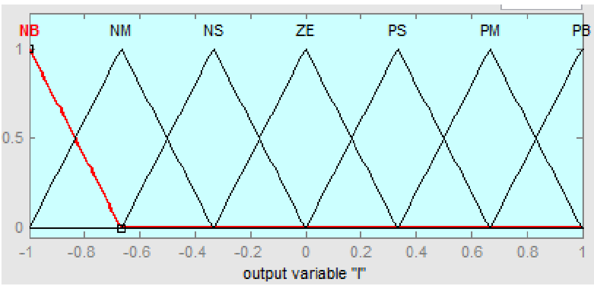

Figure 8: Output Membership Function

The knowledge base defining the rules for the desired relationship between the input and output variables in terms of the membership functions illustrated in Table (1). The control rules are evaluated by an inference mechanism, and represented as a set of:

IF Error is ....and Change of Error is ....
THEN the output will ….

Figure 9 shows an example of a rule: IF Error is NS and Change of Error is ZE THEN the output is NS.

Figure 9: General Rule Base

Table 1: Fuzzy table

	Chang of Error						
Error	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The linguistic variables used are: (NB) Negative Big, (NM) Negative Medium, (NS) Negative Small, (ZE) Zero, (PS) Positive Small, (PM) Positive Medium, and (PB) Positive Big. Table 1 shows the fuzzy rules table. Consider that the actual current is high compared with reference current, so the error obtained is negative. If the change in error is also negative then the fuzzy controller is made to operate in negative region. Now the duty cycle of the converter is reduced to minimize the error so that the battery tends to charge as per the standards.

Figure 10 shows the surface of the base rules using in FLC which is the representation for the inputs and output values of the controller in three dimensions.

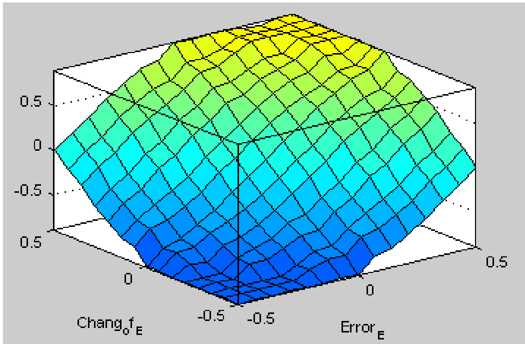

Figure 10: Surface shape (E, ΔE and output I)

According to that error and change in error, the fuzzy controller is made to select the appropriate duty cycle of the converter. So this intelligent controller will make the battery to charge immediately with the standard charging current.
Figures 11 and 12 show the error and change of error respectively the difference between them is so little and the percentage of error is about 0.013 which give high performance of the FLC output.

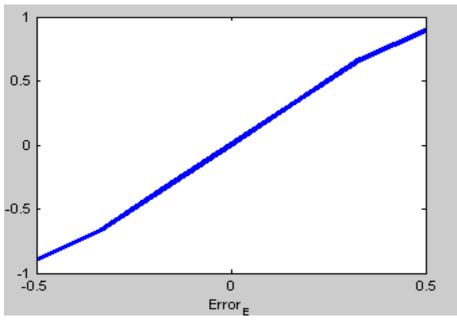

Figure 11: Input – error

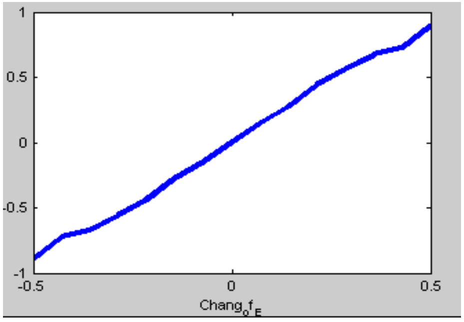

Figure 12: Input - change in error

Similarly, since the energy system cannot respond directly to the fuzzy controls, the fuzzy control sets generated by the fuzzy algorithm have to be changed back by using the method of defuzzification. Subsequently, the approximate center of gravity (COG) method as shown in equation (3) is used for the defuzzification.

$$\mathbf{COG} = \frac{\int_a^b \mu_A(x)\,x\,dx}{\int_a^b \mu_A(x)\,dx} \qquad (3)$$

Figure 13 shown the output of the FLC after apply equation (3)

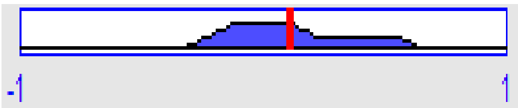

Figure 13: Output of the FlC (I)

Simulation has been done on a simplified model of a grid connected photovoltaic array via a dc link line commutated inverter. The input of FLC controller is PV current and constant voltage, the output is the desired current which gives the maximum power that can be generated under given conditions.

In this part we will apply the controller to the case study which is solar power system in UCAS. Table 2 shows the values of current before applying fuzzy control and after implementing fuzzy controller.

Figure 14 illustrates the deference between the values before applying fuzzy controller (reference value of I) and after applying FLC (desired value of I). We can see that the desired value on the proposed system increases by decreasing the error which make the power increase as P=I*V, and V is constant.

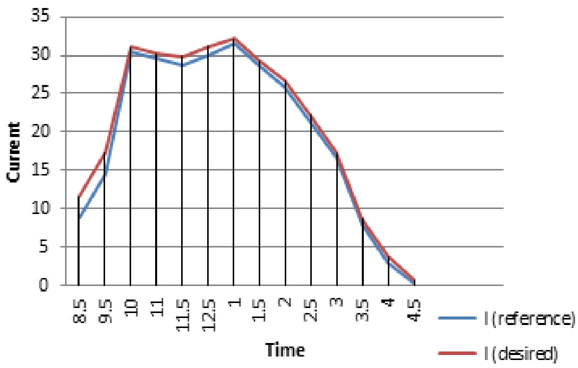

Figure 14: Values of reference and desired current

For example at first row in (Table 2):

$$\mathbf{P_{Before}} = \mathbf{I * V} = \mathbf{8.8 * 12} = \mathbf{105.6W}$$

$$\mathbf{P_{After}} = \mathbf{I * V} = \mathbf{11.7 * 12} = \mathbf{140.4W}$$

This result conclude that when we apply FLC to the proposed solar power system we get more power depending on the output current which is controlled by the rules of FLC applied on the system.

Table 2: Values of PV current

Time	I (reference)	I (desired)
8:30 AM	8.8	11.7
9:30 AM	14.5	17.3
10:00 AM	30.4	31
11:00 AM	29.6	30.2
11:30 AM	28.8	29.8
12:30 PM	30.1	31.2
13:00 PM	31.5	32.1
13:30 PM	28.6	29.3
14:00 PM	25.9	26.7
14:30 PM	21.3	22.2
15:00 PM	16.8	17.3
15:30 PM	8	8.7
16:00 PM	3.1	3.8
16:30 PM	0.4	0.8

In this section, we generate the error and change in error signals as inputs for the FLC as shown in Figure 15.

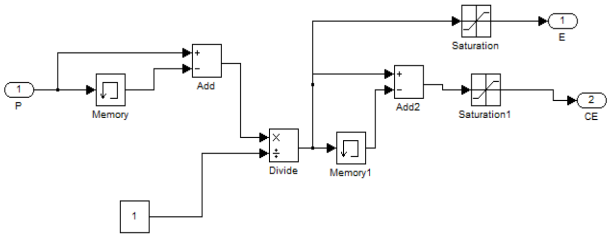

Figure 15: Generating the Error and Change in Error

After generating the error and change in error as shown, we converted to one subsystem block with input and outputs (E, CE) which collected in multiplexer to inter in FLC as shown in Figure 16.

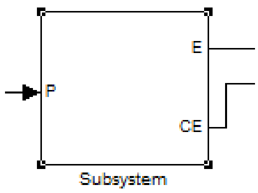

Figure 16: Error and change of error model subsystem

Now, the simulated system using the FLC and Simulink is shown in figure 17.

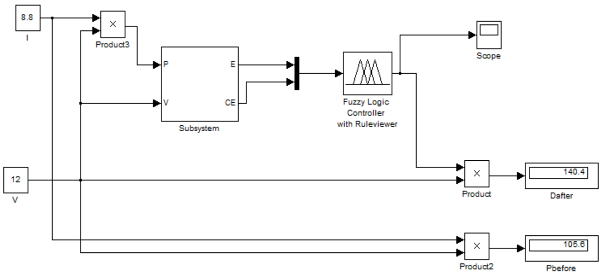

Figure 17: Output of the solar system using FLC

5. Conclusion

Gaza Strip faces electrical power crises with an increased growing demands and limited non growing supplies. Power generation by expansion of the local power generation plant is not feasible due to the political situation. Solar power is a good feasible option; however, it is inefficient and costly. This paper offered a design of fuzzy logic controller to maximizing the power at the output of the PV array. The performance of the inverter is improved by rearranging the duty cycle. The results showed that the proposed system improved the system's efficiency by 20% in average calculation.

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Dr. Elaydi is a member of IEEE, SIAM, Tau Alpha Pi, AMS, Palestine Engineering Association, and Palestine Mathematic Society. He served as editor board member, member of technical council, member of scientific committees for several local, regional and international journals and conferences.

Ahmed Alhaddad received his B.S. and M.S. degrees from the Islamic University of Gaza, Gaza, Palestine in 2007 and 2014 respectively. He has published paper in national conversance due the study of M.S program. His research interest in control systems, fuzzy logic control and power systems. He is currently working as head engineer at Ministry of Telecommunication & Information Technology, Gaza, Palestine. Mr. Alhaddad is a member of Palestine Engineering Association.