Compensation of Power Quality using Solar-Powered Distributed Generation Interfaced by Fuzzy Logic Controlled Inverter to the Main Grid

Omar A. AlKawak

Abstract**: *This paper presents a distribution static compensation (DSTATCOM) schematic for grid interconnected DG implementing solar energy to be interfaced by an inverter that uses advanced controller, which will mainly compensate power quality issues, providing active power to the grid when needed such as peak times and cutoffs, also to eliminate current harmonics at the distribution stage, in addition to compensating current unbalance at the neutral line in grids that uses three phase four wire system, the inverter involved can effectively be utilized to perform such tasks with the ability of fuzzy logic as a controller to deal with rough and sudden data, particularly when the models or the procedures are too complex to be dealt with by other controllers, which made it very suitable for this application to control the voltage of the renewable energy resources (RES) ,the Schematic is simulated using MATLAB/SIMULINK to verify the proposed outcome of this method and the results shows a fast dynamic response and high accuracy tracking the voltage of (RES) and maintained regulation to several loads variation.***

Keywords: distributed generation, solar-powered renewable energy, 4-legged inverter, fuzzy logic controller.

I. INTRODUCTION

In the long-term of energy productions it shows that renewable energy resources (RES) will play an important role in the world energy supply, with the ability to increase gradually in the second half of the century. Iraq is mostly dependent on expensive Extraction of fossil fuel energy resources like (coal, gas and oil) [1]. and will ultimately lead to increase of the production of renewed sources (solar energy) use according to its geographical location in order to achieve two important goals ,restrain global climate change effects by decreasing the emission of carbon dioxide and to increase the safety of energy supply by decreasing the proportion of the use of fossil fuel of energy (increasing the production of renewed sources of energy), and the environmental protection interests can also be better proved effectual [2]. For sustainable and pollution free of energy advancement in Iraq, the geographical location support the widespread use of most of these renewable energy resources, which is continually reestablished and never run out [1].

Distribution level integrated renewable energy resources are categorized as distributed generations, the point of connection level may pose a threat to the power system and cause several problems that needs to be sorted otherwise issues like stability, power quality and voltage unbalance might be found [3][4]. the solution is that distributed generators systems need to be controlled with strict and technically approved methods to make sure the whole power system would have efficiently safe operation and reliable to maintain voltage balance between both system's at the point of common coupling(PCC) [5]. although digital techniques may be applied using power electronics and advanced control technology to ensure and enhance power quality of the DG at the (PCC) [6][7].

equipment's such as drives with nonlinear loads uses several power electronics devices pose a threat by injecting harmonic currents at the PCC which would decrease the overall system efficiency[8][9].

Nonlinear loads can be categorized into two types of harmonic sources, current-source type and voltage-source type [10]. Characteristics of both parallel active filters and series active filters might be used in compensation [11]. Series active filter is better suited for compensating harmonic voltage source type at PCC such as a diode rectifier with smoothing DC capacitor in this case. parallel active filters might become a problem and increase harmonic current which may cause overcurrent of the load at the PCC when the load is a harmonic voltage source [10]. Unfortunately current and voltage harmonics at PCC increases losses in the lines and may lead to power quality reduction and switching errors in electronics based equipment's[8].

Three phase nonlinear loads produce sequenced positive (7th, 13th, etc.), negative (5th, 11th, etc.) voltage and current harmonics in loads such as thyristors (SCR's), uninterruptable power supplies (UPS), and large motor drives. voltage and current Harmonic produced by single phase (phase to neutral) producing tripled (third order) harmonics (3rd, 9th, 15th, 21st, etc.) in power supplies used in personal computers [12]. these harmonics adds up and don't cancel each other like sequenced positive and negative harmonics which may lead to phase current as high as (1.73) times its actual

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value passing through the neutral line, Special considerations and designs needed to suppress such harmonics (third harmonic). Otherwise equipment's like cables, transformers can suffer effects like overheat and efficiency reduction as a result [13][14].

Harmonic mitigation using passive filters is normally used because of their design simplicity and overall low cost. Despite the fact that passive filters have several disadvantages such as tuning, resonance risks and large size, which may increase harmonics in the power network [8]. that's why new method where developed using advanced electrical and electronics devices to perform adjustable solutions by suppressing harmonics and eventually power quality compensation with the help of DG, such equipment's known as active power filters (APF) [15]. which is usually used at the distribution level to regulate load unbalance and harmonic current compensation which is costly effective [16]. in this project the solar power is to be fed to the grid using inverter with advanced control techniques to perform (APF) functionality features and solar power DG conversion to the grid an addition to the compensation of load reactive power and load neutral current [17][13].

The inverter involved can effectively be utilized to perform such tasks with the ability of fuzzy logic as a controller to deal with rough and sudden data particularly when the models or the procedures are too complex to be dealt with by other controllers [18] . This made it very suitable for this project to control the voltage of the renewable energy resources (RES) which is solar energy.

II. SCHEMATIC DESCRIPTION

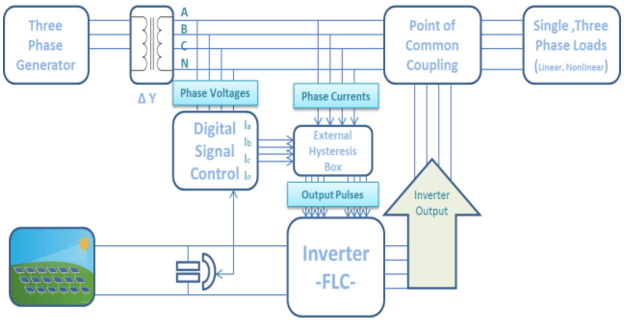

Fig. 1. proposed Schematic of Solar energy based distributed generating system.

This paper used RES (solar energy) as DG to generate electricity using a free source of energy (the sun) locally and feed into the local electricity grid on bright cloudy days as well as in direct sunlight. simulated solar farm is shown in (fig2) ,Solar panels produce direct current (DC) electricity, which will need a conversion equipment [19]***. to convert DC link stored power to alternating current (AC), which is the form transmitted by the electricity grid. To maximize their efficiency, maximum power point trackers of solar power may also incorporated, as separate units. to achieve peak power point, These devices keep each solar array string close to its maximum value*** [20].

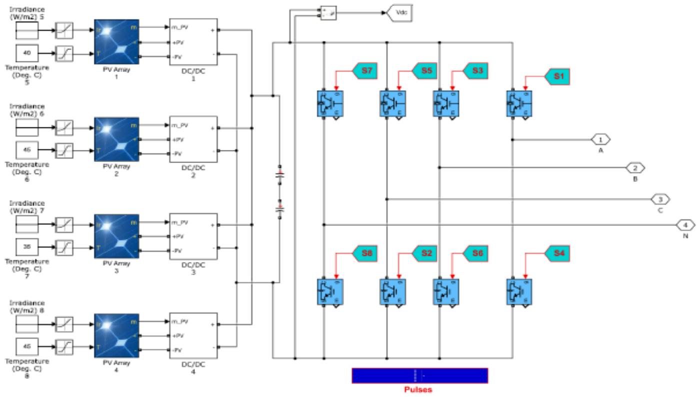

Fig. 2. Simulink Diagram Of Solar-Powered Dg With Inverter.

This conversion is done by the proposed inverter using appropriate control strategy, it is possible to handle voltage regulation issues and delivers the generated power to the grid. Proposed system interconnections involving solar-powered DG with the grid interfacing inverter shown in (fig 1), in this application the DG is interfaced to the grid through the voltage source current controlled inverter using four-wire with a forth leg as neutral line.

III. CONTROL STRATEGY

Using three phase current-voltage measurements to acquire grid currents, voltages at the PCC, and the DG output voltage (VDC) .all of these readings goes to the control, line voltage used to get the right waveforms and phase of the grid currents with the help of phase locked loop (PLL), in order to be used as a reference.

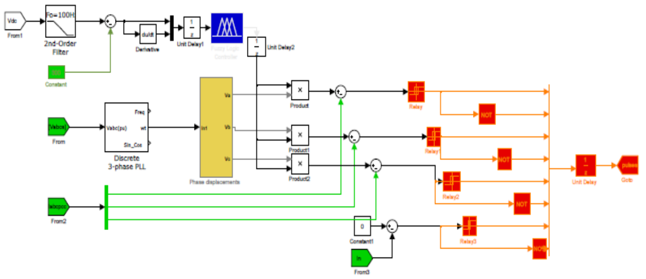

Fig. 3. Simulink diagram of inverter control Strategy.

if there is an error signal between the DG voltage and the reference voltage, a current with a magnitude of IM is passed to the controller (flc) and then a phase displace by (0,120,240) is to be added, three phase currents serving as a reference can be expressed by:

<u>Phase displacements</u>

$$a = \sin\theta \quad (1)$$

$$b = \sin(\theta - \frac{2\pi}{3}) \quad (2)$$

$$c = \sin(\theta + \frac{2\pi}{3}) \quad (3)$$

<u>Currents references</u>

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$$Ia^* = Im\sin\theta \quad (3)$$

$$Ib^* = Im\sin(\theta - \tfrac{2\pi}{3}) \quad (4)$$

$$Ic^* = Im\sin(\theta + \tfrac{2\pi}{3}) \quad (5)$$

IV. FUZZY LOGIC CONTROLLER (FLC)

fuzzy logic controller has several advantages including the ability to respond to sudden changes in the error value (ε) and rise and fall changes in the error by taking the derivative of the error value (Δε) ,that's why fuzzy logic controller is proposed as a controller as shown in Fig 4 below :

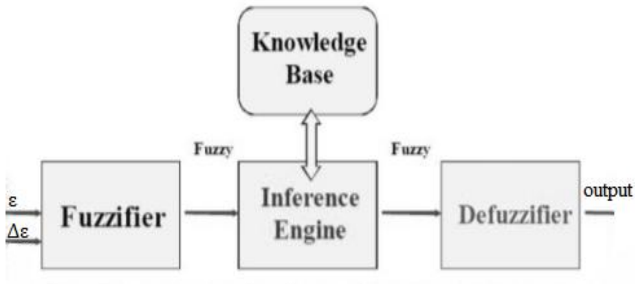

Fig.4. Elements of FLC.

Using the rule base (IF-THEN) for two inputs, the error signal value **(ε)** and its rate (derivative Δε) as in (if ε is…. AND Δε is…. THEN output is….). The output signal can be determined in the inference engine. The structure of the rule base is done by tail and error method.

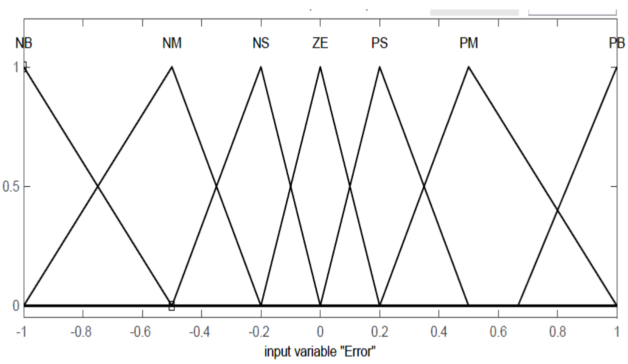

Fig.5. Membership functions of error input Ɛ.

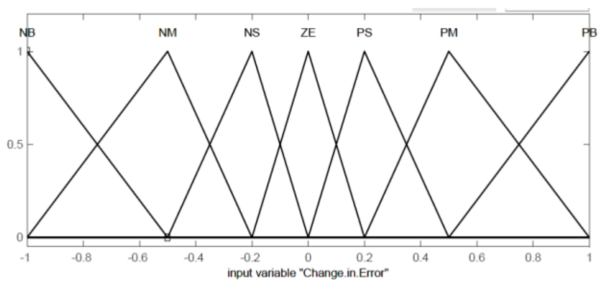

Fig.6. Membership functions of change in error input ΔƐ.

TABLE- I .RULE BASE

Δε \ ε	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PM	NS	ZE	PS	PM	PM	PB	PB

Using (PB, PM, PS, Z, NB, NM, NS,) subsets as fuzzy variables for the inputs ε and Δε. both inputs membership functions are shown in fig.5&6. Fuzzy rule base control is illustrated in the table 1.

V. SWITCHING CONTROL

Switches status control depends on the error value, it changes when the current exceeds a certain positive or negative values in order to keep it around the reference , weather the controller was linear or nonlinear based thanks to the hysteresis box shown in (fig 3), hysteresis techniques is used for faster response and better tracking reliability to load variations .one drawback of the hysteresis box is the large harmonics created by it ,which effects the switching frequencies because of the frequency rapid change [7] [21].

VI. SIMULATION RESULTS

A simulation study using MATLAB/Simulink was performed to the proposed method and strategies like compensating power quality issues, providing active power to the grid when needed, also eliminating current harmonics at the distribution stage, in addition to compensating current unbalance at the neutral line in grids that uses three phase four wire system, and has proven that the controller can efficiently achieve such goals, it also shows strong and stable response for sudden and unexpected DG conditions changes in power generation. (Fig. 7) involves grid voltages and currents, unstable load currents and DG inverter currents. (Fig. 8) involves real and imaginary powers (P, Q) respectively, (PQ Grid) for the main grid, (P,Q Load) the load and for the DG inverter (P,Q DG Inv). Positive amplitudes shows that the grid and DG powers are being delivered to the point of connection at PCC and absorbed to the connected loads.

From t=0-0.61s, the DG inverter has not being connected yet, that's why unbalanced waveforms of load currents are shown in (fig.7-b) same as (fig7-c)

From t=0.61-0.71s the DG is now connected at normal radiations and PV temperature conditions through the inverter and solar power is being delivered to the grid, that's why unbalanced grid currents waveforms started to change to a balanced sinusoidal waveforms as shown in (fig 7-b)

also (fig.8-a) shows that after 0.61s power is being fed back to the main grid from the DG, since the load demand is lower ,then the generated power combining both grid and DG outputs is much higher ,grid received power is recognized by the negative amplitude sign (-ve) from t=0.71-0.81s DG conditions are changed at higher radiations meaning higher generated power (fig.8-c) ,still the DG inverter managed efficiently to maintain steady and stable grid currents for the same load demand as before(fig.7-b).

From 0.81-0.91s DG conditions are changed again with higher temperature meaning lower generated power (fig8-c), as we know each PV panel has a temperature coefficient for every degree above its manufacturing temperature, which means for every degree above, maximum power falls, still the DG inverter managed efficiently to maintain steady and stable grid currents for the same load demand as before.

From t=0.91-1s normal conditions are changed back again (fig.7-b), temperature falls to normal manufacturing degree which increases the power back to its normal values as in t=0.61-0.71s (fig8-a) noticing all the changes made and their effects shows that the proposed controller (FLC) has fast responds with high accuracy to all the variations parameters.

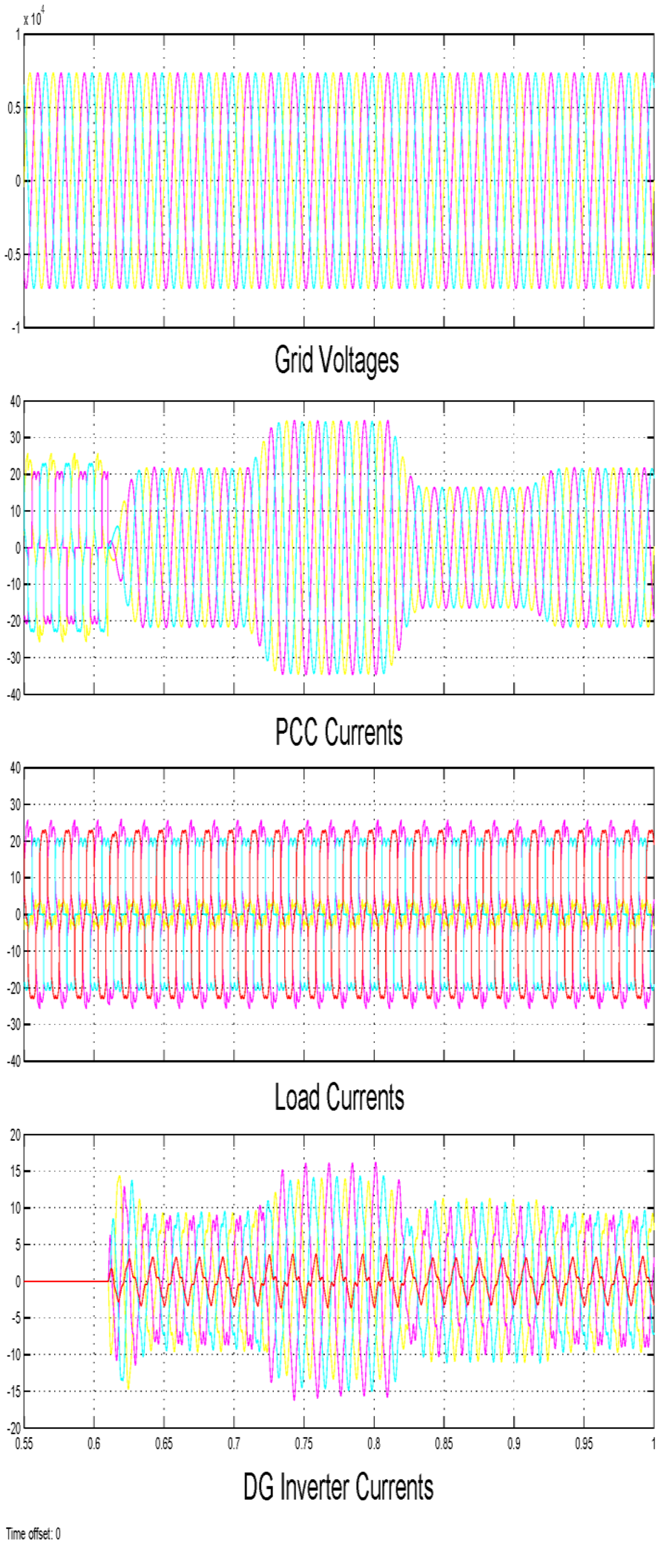

Fig.7. I-V simulation results: (a) main grid voltages, (b) PCC currents, (c) load currents, (d) DG inverter currents.

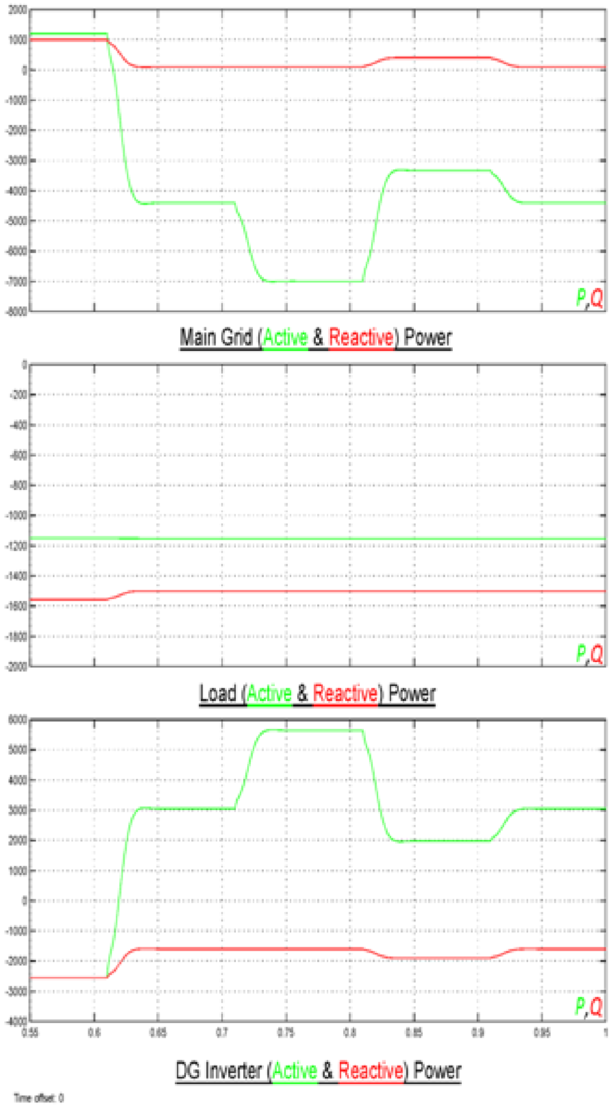

Fig.8. P-Q simulation results: (a) PQ grid, (b) PQ load, (c) PQ inverter .

VII. CONCLUSION

Simulation results showed that the proposed inverter compensates power quality issues very efficiently hence the waveforms changes before and after its being connected, supporting the main grid with active power by interconnecting it to a solar-powered DG at PCC, also different generation conditions were investigated at DG level, still fuzzy logic controlled inverter demonstrates a strategy with high accuracy, solid and dependable procedures to follow DC link voltage changes, this method eliminates the need to use several power quality shaping equipment's at the PCC, which makes this method very handy by implementing RES (solar-powered) DG to perform such tasks in addition to the main grid support.

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