A microcontroller for two parallel inverters to manage voltage and frequency in microgrid (An Experimental study)

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ABSTRACT

Microgrids are receiving tremendous attention due to increasing need to integrate distributed generations (DG) and to provide reliable power to critical loads. Proper power management in microgrid is required to regulate the system voltage and frequency, maintain power quality, and manage DGs. A microgrid system has been studied. A microcontroller method for two parallel inverters which represent two DG in microgrid is proposed and described in details. The proposed technique has been applied to adjust the frequency and voltages of the two inverters to suit the grid requirements in various operating mods in order to manage the system and improve its efficiency.

Key words: Distributed generation, Islanding, microgrid, power quality, renewable energy.

INTRODUCTION

Over the past few decades, energy has played an increasingly important role in the technological and economic development. The global electrical energy demand is seen to be increasing in recent years and it is expected to double in the next 20 years[1]. Fossil fuels that have been used as a source of energy till date are rapidly depleting requiring us to look towards more alternative sources of energy. Wind and Solar PV are two of the major alternative sources of energy being utilized in many parts of the world[2]. According to American Wind Energy Association (AWEA) as of September 2012, the total installed wind power capacity was at 51,630 MW in the U.S. The U.S. government has a vision to generate 20% of electricity using wind energy by 2030[3-4]. Solar PV is also a large source of renewable energy and the U.S. now has over 6,400 MW of installed solar electric capacity, which is enough to power more than 1 million average American households[4]. However on the other hand, U.S. relies on an aging electrical grid and pipeline distribution systems, some of which originated in the 1880s. The U.S. grid was graded a low score by the American Council of Civil Engineers[5]. Integration of renewable energy and DGs will support better utilization of the existing systems, reduce consumption of fossil based fuels, reduce transmission and distribution losses, and improve voltage quality. However, higher penetration of DGs creates technical and non-technical issues which include power quality, power surety, reliability, power management, overall system efficiency, interconnection of grid and regulations. Ongoing generation, transmission and distribution permitting issues, weather related events, and limited maintenance have contributed to an increasing number of failures and power interruptions. They are some of the driving forces behind the microgrid concept[6-9]. Transmission constraints requiring supplies closer to loads, lower cost of solar PV installations, energy storage and natural gas and military demand for more energy surety and security are several other driving factors.

MICRO GRID

The traditional electrical grid as shown in Figure (1) consists of power stations, transformers, transmission lines and distribution substations. Today's electrical grid suffers from a number of problems, including one-way flow of electricity, dpendency on high capacity fossil-fuel generators, increasing carbon emissions, getting a large amount of power in one place, using a long transmission lines to deliver power, not economic, has low reliability against sudden faults, centralized, bulk generation, limited automation, limited situational awareness and consumers lack data to manage energy usage.

Microgrid as shown in Figure (2) is a group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. There are number of components such as CHP which means combined heat and power system which used in recovery and use of waste heat of power generation.

A virtual power plant is a link-up of small, distributed power stations, like wind farms, photovoltaic systems, fuel cells, small hydropower plants and biogas units, but also of loads that can be switched off, in order to form an integrated network. Central power plant injects power more than 30 % of the whole power that injected to the grid. Storage elements store power especially for plants such as wind and solar cell planets. Microturbines are a relatively new distributed generation technology being used for stationary energy generation applications. They are a type of combustion turbine that produces both heat and electricity on a relatively small scale.

Advantages of microgrid include two way flow of electricity and information, expanding deployment of renewable and distributed generators, better monitoring using sensor networks and communications. Consequently, better control and resource management in real-time. A microgrid provides a solution to manage DGs and renewable energy[10-11], it has ability to maximize the overall system efficiency, power quality and power surety to critical loads. Microgrid can operate in parallel to the grid or as an island. The most compelling feature of a microgrid is the ability to separate and isolate itself from the utility's distribution system unintentionally during events (i.e., faults, voltage collapses, black-outs). It may also intentionally disconnect during grid maintenance and also when the quality of power from the grid falls below certain standards. Microgrid can be reconnected to the utility grid without any interruption once the utility is recovered. The autonomous controller is one of the control methods in microgrid in which, voltage and frequency stability are achieved by drooping the voltage and frequency according to active and reactive power requirements[7]. In this traditional droop control method, voltage and frequency vary a lot to achieve the stability in island mode.

Some of the key microgrid control scheme concerns are: (i) maintaining stability, (ii) regulating voltage and frequency, (iii) proper active and reactive load sharing, and (iv) easier and faster islanding and reconnection.

This study introduces a new control using microcontroller to control two parallel inverters for voltage, frequency and power management in microgrid, this control in island mode of operation. The proposed method addresses the concerns related to microgrid control mentioned previously.

A microcontroller for two parallel inverters to manage voltage and frequency in microgrid (An Experiment)
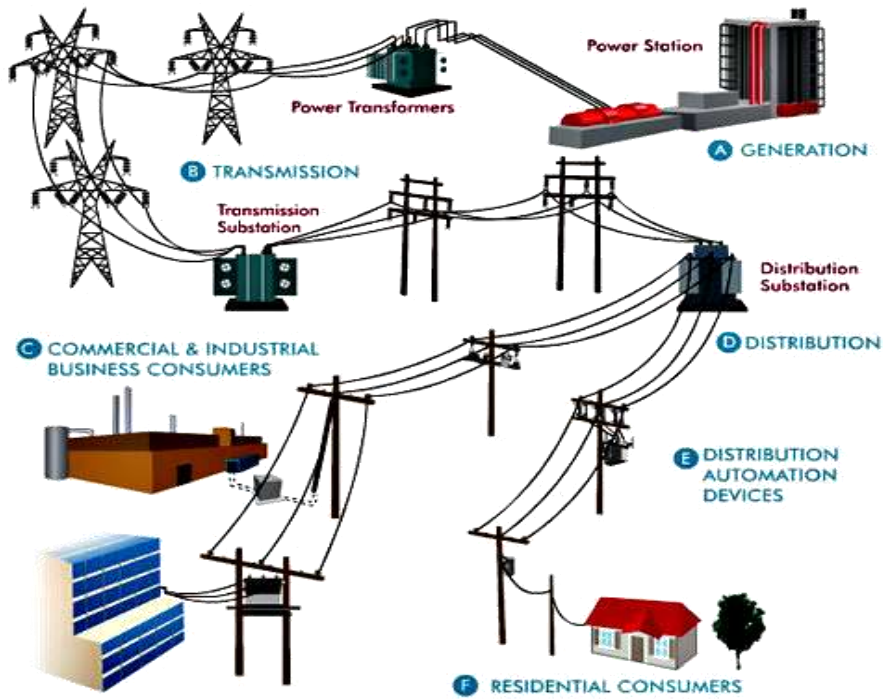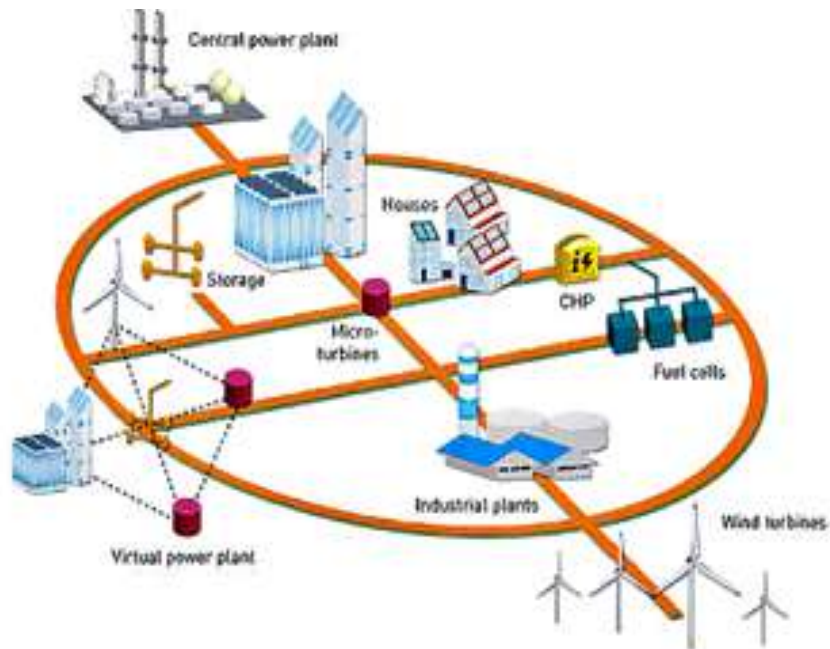

Fig.1 Traditional grid

Fig.2. Microgrid

The two inverters feed from two renewable energy sources (DG) and the objective of the work is to control the inverters output voltage and frequency to coincide with the grid.

The proposed control schame compoesd of inverter circuit , microcontroller (MCU), analouge to digital converter (ADC), contactors,batteries and trnasformers as in Figure (3).
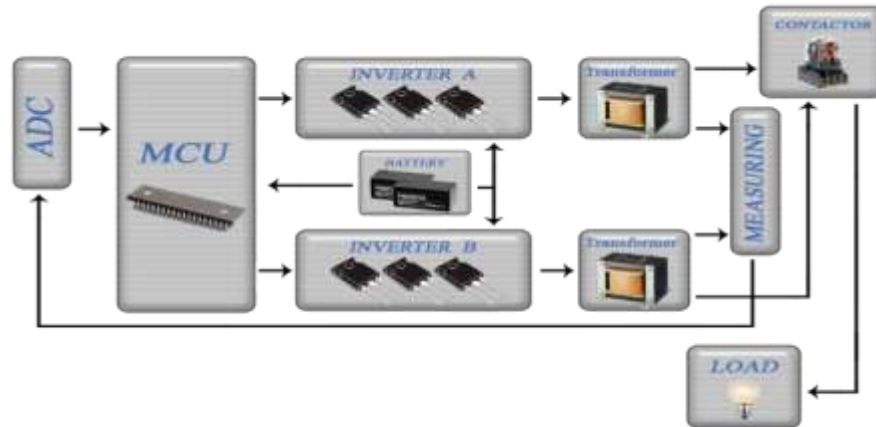

Fig. (3). The control scheme

The Experimental Circuit:
In this part, the practical side of the experiment is described. Its entire components and importance of each one.
The output power which represents the two distributed generator (DG) depends on 3elements:
- Battery storage
- Switches
- Transformers

The maximum current that can be taken from the battery during a defined time (Ah) determines the battery storage. In the present study, a battery with (12V, 7Ah) was used.
The max current = 1.5 of normal current
$I_{MAX} = 1.5 * 7 = 10.5A$
$P = 12 * 10.5 = 126$ watt
The current pass from battery to the load so that the switches and transformers must be able sustain the value of current drawn, so that we used transistors with ability to support power up to 1 kilowatt, also transformer currents must be within suitable limits.

A.Inverter
To get alternating output wave form a positive half cycle and negative half cycle are needed. The output wave form will be as shown in Figure (4).The popular (common) ways to get this wave form is from half bridge inverter or full wave bridge inverter. For simplicity a half bridge inverter was used.

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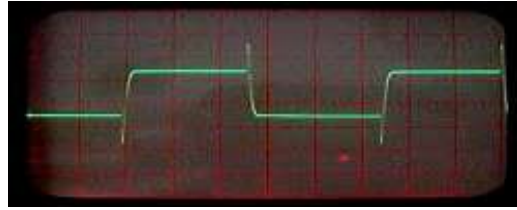

Fig.4. The output wave form from the invertor.

The inverter block digram and inverter circuit are as shown in Figure (5a,b).

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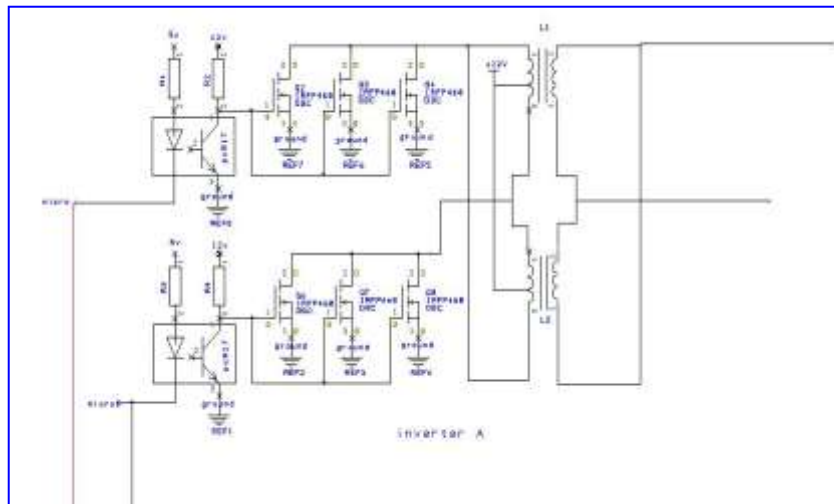**Fig.(5a). Inverter block diagram**

Fig. (5b).The inverter circuit

S_1 is on and S_2 is off at the positive half cycle, there is a voltage applied on the above windings only. At the negative half cycle S_1 is off and S_2 is on then the second below half winding has a voltage applied on it i.e. energized so the output voltage or current is inverted.

Switches

Mosfet switch Transistor type is used, the switch only pass sufficient current in primary winding so 6 switches connected in parallel instead are preferred:

$$I_{total} = I_1 + I_2 + I_3 + I_4 + I_5 + I_{6(1)}$$

All switches must be pulsed on together and pulsed off together.
Drive circuit
    The Drive circuit shown in Fgure (6) has two main functions:
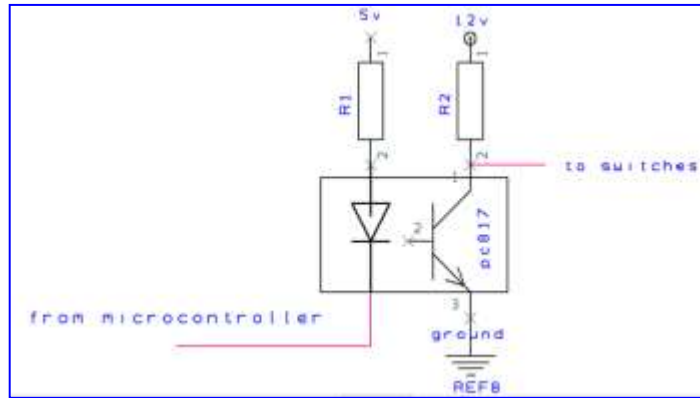- Drive function
- Isolation function

Fig. 6. Drive circuit

Drive function
        As microcontroller pulses can't supply sufficient voltage or currents to operate power transistors due to its limited current. So optocoupler chip is used as   mediator to achieve this mission. When photo diode is on it turns the photo transistor to be on by its photo effect, when photo transistor is on then the 6 switches gates connected to zero volt and don't operate, when photo diode off the photo transistor off and the 6 switches gates are under 12 volts DC. A resistance is needed between microcontroller and optocoupler. Load needs to be forward as in intern structure of microcontroller chip. Connection in Figure (7a) will not makes the current sufficient to light the photo diode, but the connection in Figure (7b) makes the current sufficient to light the photo diode.
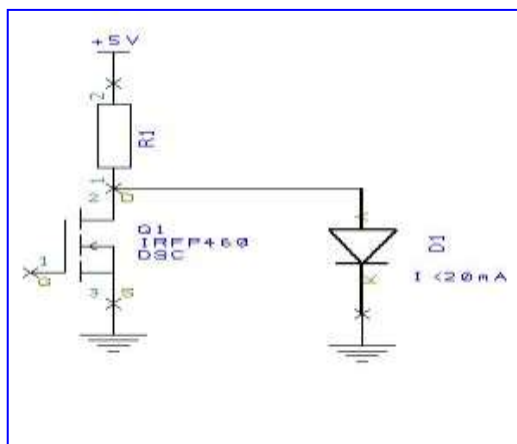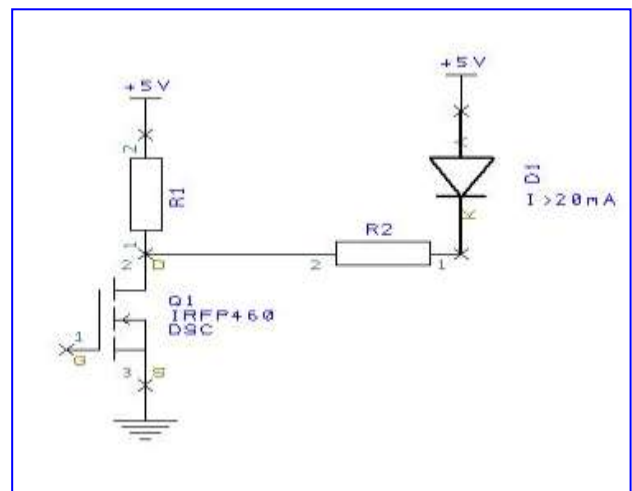

Fig.7a

Fig.7b

Fig. 7. Connection of drive circuit with the micro controller chip.

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Isolation function
This part function is to isolate power circuit from control circuit. If there is an error the only affected part is optocoupler chip which protect control circuit, it is very cheap and available.

Transformers
The main function of transformers is to step up voltages to 220 volt. For each inverter two step-up centre tap transformers (9-0-9) are used and connected in parallel to save output voltage at 220 with doubling the power instead of one transformer, each transformer has power of 60 watt, so the total power for each inverter is 120 watt.

B.The measurements devices (sensors)
In any feedback control system the sensors is an essential element, here sensors are LV and LA which measure voltage and current during all time. These high reading values of voltages and currents must be scaled before entering the control circuit which deals only with lower values.

C.Analogue to digital converter (ADC)
The output of the measuring devices is analogue values but microcontroller ship deals only with digital numbers so , an important step to convert these measurements into digits , this could be performed by using the ADC as in Figure (8).
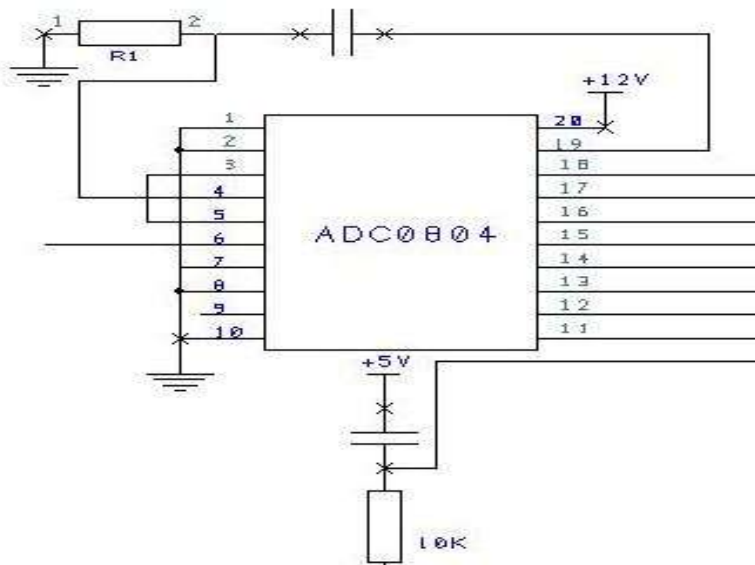

Fig.8. ADC configuration.

Switching frequency (f) and number samples of ADC depend on resistance (R) and capacitance (C) connected with it as in equation 2:

$$f = \frac{1}{1.1\,RC} \qquad \text{.......................(2)}$$

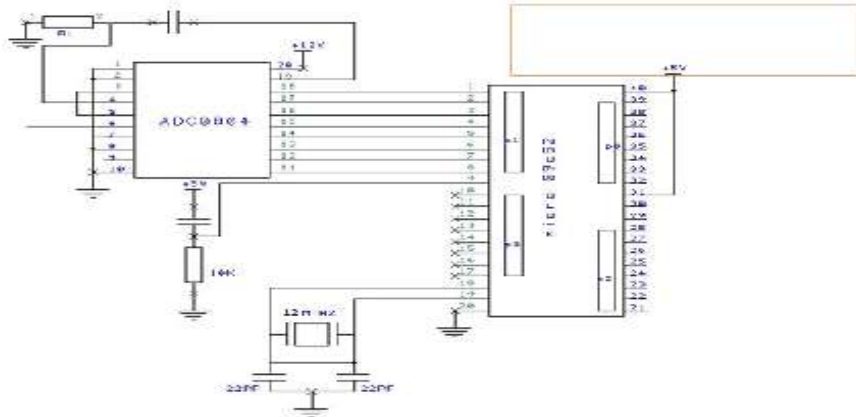ADC connected microcontroller as shown in Figure (9).

Fig. 9 Connection of ADC to microcontroller.

D. Microcontroller chip

The most important component in control circuit is the microcontroller chip; it gives commands to operate all projects and also perform all control operations according to the software burned on it, microcontroller has 40 pins. These pins divided into 4 ports, these ports are responsible about inputs or outputs of microcontroller chip , pins from 31to pin 40 connect to +5 volt supply voltage and pins 29,30 are not connected , pin 9 is connected as a reset pin, pin 20 is grounded ,pins 18,19 are connected to a quartz crystal oscillator and capacitors as shown in Figures (9). The speed of microcontroller (machine cycle) depends on oscillator frequency connected to it, for example 50 HZ frequency depends firstly on delay time in software program and secondly on crystal oscillator so, choosing crystal oscillator of 12 MHZ provides more simplicity in calculations of software as shown in equation 3:

Machine cycle =12/crystal oscillator frequency...(3)
$$= 12/12MHZ = 1\mu HZ$$

Also, all port 3 connected as input port with ADC, also

- Pin 0 in port2 (pin 21) to optocoupler of S_1 of inverter A (AG_1).
- Pin 3 in port 2 (pin 24) to optocoupler of S_2 of inverter B (BG_2).
- Pin2 in port2 (pin 23) to optocoupler of S_1 of inverter B (BG_1).
- Pin1 in port2 (pin 22) to optocoupler of S_2 of inverter A (AG_2).

These output signals of microcontroller give pulses to switches,another pins such as pins14,15 give output signals forfans operation. Pin 13 is connected to another optocoupler for contactor operation when needed.

E. The Contactor

Contactor used to connect or disconnect second inverter when load increasing or decreasing above the maximum power of first inverter.

Contactor coil energized from a small relay connected in series with the coil of contactor acting as a switch and this relay energized by drive circuit from 12 volt DC and the drive take its commands from pin 13 in microcontroller. When contactor coil circuit closed the contactor connect the second inverter in parallel. Contactor circuit is shown in fig.10.

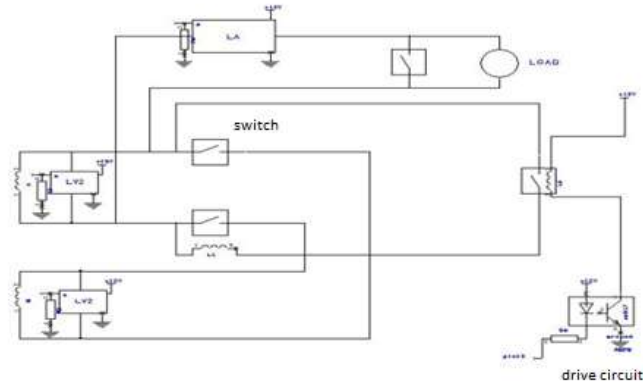# A microcontroller for two parallel inverters to manage voltage and frequency in microgrid (An Experiment)

Fig. 10 Contactor connection

CONTROL OPERATION

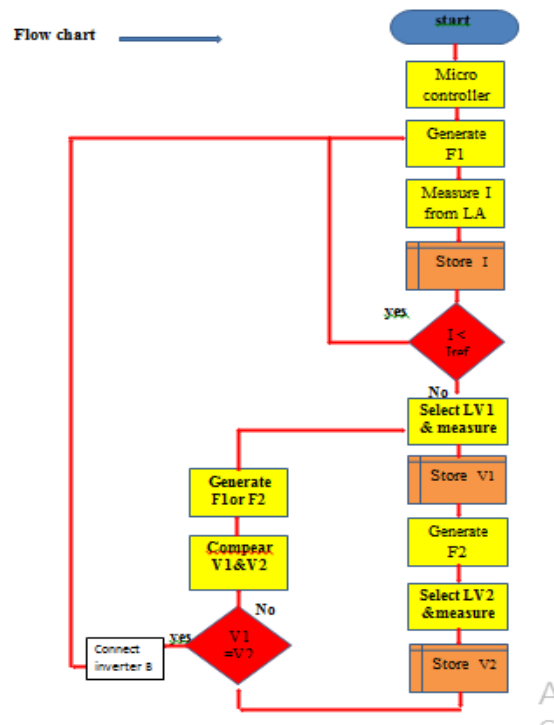The experiment control operation is sequenced as shown in flow chart (Fig.11).

Fig.11 flowchart shows the control sequence.

When microcontroller starting the processor, it will execute the software program. Firstly give pulses to the drive circuit to perform inverter connection mentioned previously.Adjusting delay time in software according to machine cycle that equal (1µsec) the result is generating frequency of inverter A (50HZ). During each half of each cycle microcontrollergenerate PWM

with high frequency to control the voltage levels, control permit measuring the load current by selecting LA and store this value to comparing with the reference current that equal to the maximum current drawn from inverter A, if this value less than maximum value the inverter A continue to generate the same frequency, if this value change to be more than reference current, in this case microcontroller select LV1 to measure V1 and storing this value. Microcontroller gives control command to generate pulses to inverter B with frequency F2, and then select LV2 to measure V2 of inverter B and store it. If V1 equal V2 connect the two inverter A,B. if V1 don't equal V2 microcontroller compare between them and the largest value must be decrease to equal the lower value.

EXPERIMENTAL RESULTS

Figure (12) represents the practical experiment circuit; the lambs in in the circuit represent the ac loads. Figure (13) shows the inverters circuit on Mattlab Simulink. Figure (14) shows the inverter output on Mattlab. Figures (15,16) show the inverters outputs on oscilloscope in laboratory, as shown its output is ac which could feed any ac loads. Figure (17) shows the transformer output. Figures (18 and 19) show the two parallel inverters output in case of no load and loading case, it is clear that the two inverter voltages have the same reading to assure that they act with the same voltage for different loading cases.

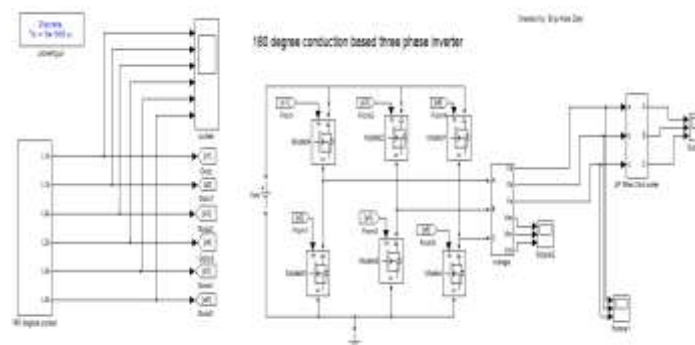**Fig. 12. The practical experimental circuit**

Fig.13. Matlab Simulink circuit for inverter

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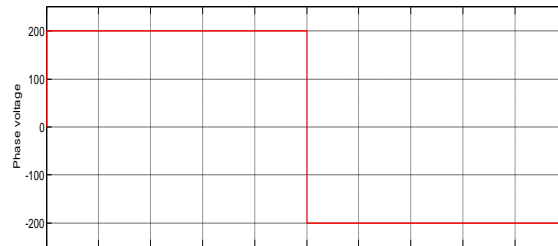

Fig.14 Matlab output for inverter

Fig. 15 Output of inverter A on osciliscope.

Fig. 16 Output of inverter B on osciliscope.

Fig.17 Output of the transformer on oscilloscope.

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Fig.18. Output voltage of the two inverters by voltammeter at no load.

Fig.19. Output voltage of the two inverters on voltmeter at loading.

CONCLUSION

In this study, a new control method is proposed and introduced to manage microgrids in various operating modes. The proposed method was applied to a microgrid under construction. It regulates the distributed generators output to suit the voltage and frequency of the microgrid. This method is more tightly than the traditional droop control technique and could be applied during islanding and reconnection process.

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شبكة كهربيه ذكيه صغيره لاثنان من دوائر العاكس يعملا بالتوازى للتحكم فى جهد وتردد شبكة كهربائية صغيرة (دراسة تجريبية)

سامية غريب على
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أصبحت الشبكات الذكيه الصغيرة تجد اهتماما اكبر بسبب ازدياد المنابع الكهربية الصغيرة المنتشرة عبر هذه الشبكات والاحتياج لطاقه   ذو موثوقيه اكبر للاحمال الحرجه .ولأمداد طاقه كهربيه لائقه لهذه الشبكات كان لابد من التحكم فى جهد وتردد المنظومة ولأجل الحفاظ على جودة القدرة الكهربية وادارة المنابع المنتشرة عبر الشبكة.

فى هذا البحث تم دراسه شبكه كهربيه ذكيه صغيره وهى عباره عن اثنان من دوائر العاكس يعملا بالتوازى ويمثلان اثنان من المنابع المنتشره عبر الشبكه دراسة وافيه وكانت الطريقة المقترحهة هى التحكم فى خرج دوائر العواكس من جهد وتردد لتناسب جهد وتردد الشبكة فى احوال التشغيل المختلفة من اجل اداره المنظومه وتحسين كفائتها .