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Using Parallel Diesel Generator and Fuel Cell as an Islanded Microgrid

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ABSTRACT

By improving technology for extracting higher produced power from Renewable Energy Resources (RES), and reducing CO2 emission, a new concept called Microgrid has been introduced in the electrical systems. The microgrid is an integration of loads and RES which can work independently and interconnected to the grid. In this paper, a microgrid with two different sources Diesel Generator and Fuel Cell is presented. Conventional droop control is responsible to deliver power to the load. The detailed design and simulated systems for Diesel Generator and Fuel Cell are given and extracting the droop controller is shown. The effectiveness of the presented system is validated in the MATLAB/Simulink environment.

***Keywords*—** Diesel Generator, Fuel Cell, Islanded Microgrid, Droop Controller

I. INTRODUCTION

The concept of a microgrid is defined as a cluster of sources that most of them are renewable energies such as wind, solar, fuel cell and nonrenewable resources such as Combined Heat and Power (CHP) systems, and diesel generator and different types of loads like domestic or commercial. Microgrids are a new concept in the electrical modern system [1-2]. A new concept will have lots of issues that should be solved. Several aspects such as cost, environment, optimization, interconnecting new facilities, different topologies, power quality and so on. The mentioned issues have been considered in recent research in recent decades. But, other factors such as forecasting or numerical issues based on economic models need to be considered soon [3-7].

The microgrid for delivering power sufficiently to the load should be controlled. Therefore, two different modes of operation have been introduced for them interconnected and islanding. The islanding condition is expressed as a time when the sources of microgrid should provide the load without the upstream grid. Several control strategies for a microgrid in islanding mode has been categorized such as

- ***Communication-Based Control Techniques***

In communication-based control systems, the perfect voltage regulation will be achievable. Furthermore, they can deliver the output voltage and frequency in desire ranges without secondary control. Nevertheless, they need communication lines and it can add more communication lines and add more cost. Several communication-based control techniques are used nowadays:

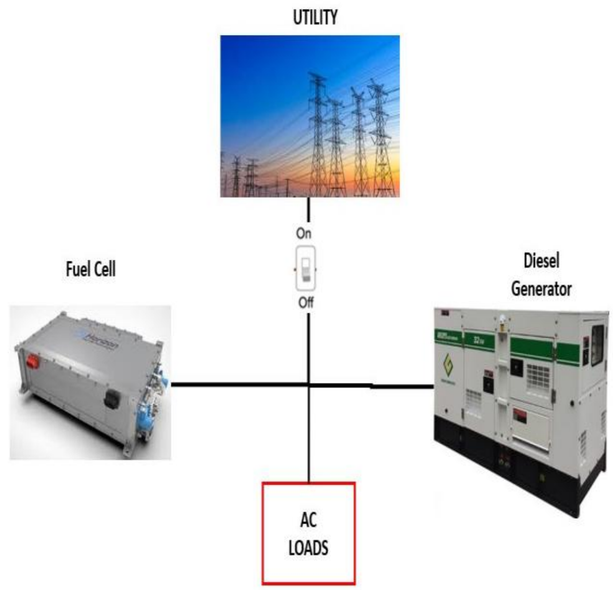

Figure (1): A view of defined microgrid

Concentrated/Central Control

The Phase Locked-Loop (PLL) unit ensures the consistency of output frequency and voltage. In the case of parallel DGs this method will control currents among DGs, and control currents of DGs with adding adequate error. In fact, DGs track average current to achieve equal currents.

Master/Slave Control

In this control strategy, the initial starting unit works as a master inverter and other inverters work as the slave units. The slave units track the current reference which is provided by the master inverter.

Distributed Control

The principle of this control system is based on the instantaneous average current. Every individual parallel unit has a special controller and no central controller any longer is needed

- ***Droop Characteristic-Based Techniques***

The droop control strategy is using as a prominent controller for microgrid because of simplicity and they don't need communication [8-11]. Figure (1) shows a microgrid

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including diesel generator, Direct Methanol Fuel Cells (DMFC) and load. In this work, a droop controller has been applied to inverters of two resources to deliver desire power from the sources to the load. The simulation result of the designed microgrid is done in MATLAB/SIMULINK environment to verify the effectiveness of the simulation.

II. DIRECT METHANOL FUEL CELLS

Fuel cells are the new generation of renewable energy resources that are used these days as a part of microgrids. Different types of fuel cells are as follows:

- Polymer electrolyte membrane fuel cells
- Direct methanol fuel cells
- Alkaline fuel cells
- Phosphoric acid fuel cells
- Molten carbonate fuel cells
- Solid oxide fuel cells
- Reversible fuel cells [12]

Among all the above types, the Direct Methanol Fuel Cells (DMFC) type has been considered and simulated based on the given equations. DMFC has several advantages such as low price and ability to match with distribution systems, and a high level of energy density turn them as a reliable and attractive source for microgrids. The other point which is worthy to mention is they don't need any external source to connect for providing long term power. In remote areas, there is a need for a source that has refuel capability.

$$E_{max} = \frac{RT}{2F} \ln \frac{P_{H2\ an}}{P_{H2\ cat}} \quad (1)$$

$$I_{max} = \frac{2\ F_{nH2}}{A} \quad (2)$$

The electrical model has been introduced by authors in [13]. The below figure shows the equivalent electrical circuit for DCMF. The below equation is calculated based on the equivalent circuit of MDFC for cell voltage. While Faraday's law gives the current equation.

DMFC can present this capability. However, some drawbacks such as quick degradation should be solved. The presented model of DMFC in this paper is included of two Gibbs reactors for anode and cathode ports and they will be separated by a splitter. Nernst equation can describe the maximum voltage of cell and Faraday's law for current density as above equations [12-13].

III. DIESEL GENERATOR

Today, regarding greenhouse gas policies, diesel generators are connected to wind power plants to generate electric power in remote areas of the world. The hybrid diesel-wind energy system is being used by the Canadian government in Quebec State as a trusted solution to provide power for areas that are far from networks in the north of the state.

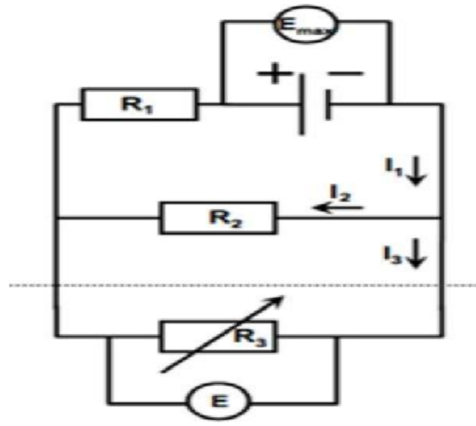

Figure (2): An equivalent electrical circuit for DMFC [12]

A diesel power plant has been designed to feed an isolated and stable load which is stable in a variety of load. While it can be unstable when connected in parallel with a continuously fluctuating such as wind generator or a synchronous generator for displaying diesel. The synchronous generator is usually used for simulating diesel generator and surveying its performance [13].

As with many electromechanical systems, electrical power generation system, a diesel generator set can be divided into three main parts: 1. a Permanent Mover consisting of a motor and a speed governor 2. Synchronous generator. 3. Automatic voltage regulator. Governor can create a stable operating speed for the variable condition of loads, and it stabilizes the produced voltage.

$$T'_{doi}\frac{dE'_{qi}}{dt} = -E'_{qi} - \left(X_{di} - X'_{di}\right) I_{di} + E_{fdi} \quad (3)$$

$$T'_{doi}\frac{dE'_{di}}{dt} = -E'_{di} - \left(X_{qi} - X'_{qi}\right) I_{qi} \quad (4)$$

$$\frac{d\delta_i}{dt} = \omega_i - \omega_S \quad (5)$$

$$\frac{2H_i}{\omega_S} . \frac{d\omega_i}{dt} = T_{Mi} - E'_{qi} I_{qi} - E'_{di} I_{di} - \left(X_{qi} - X'_{qi}\right) I_{di} I_{qi} - D_i \left(\omega_i - \omega_S\right) \quad (6)$$

- ***Synchronous generator***

The SG is modeled in a d- q frame (11- 14) are equations that define the dynamics model of the

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synchronous generator, (15- 16) are the equations which represent the dynamics of the exciter [13-15].

$$T_{Ei}\frac{dE_{fd,i}}{dt} = -\left(K_{Ei} + S_{Ei}\left(E_{fd,i}\right)\right)E_{fd,i} + V_{R,i} \tag{7}$$

$$T_{Fi}\frac{dR_{F,i}}{dt} = -R_{F,i} + \frac{K_{F,i}}{T_{F,i}}E_{fd,i} \tag{8}$$

The (17) represents the dynamics of the turbine governor.

$$T_{Ai}\frac{dV_{R,i}}{dt} = -V_{R,i} + K_{Ai}R_{F,i} - \frac{K_{Ai}K_{F,i}}{T_{F,i}}E_{fd,i} + K_{Ai}\left(V_{Ref,i} - V_i\right) \tag{9}$$

Below figures is shown also simulation of Diesel, Governor and Excitation system model [10-11].

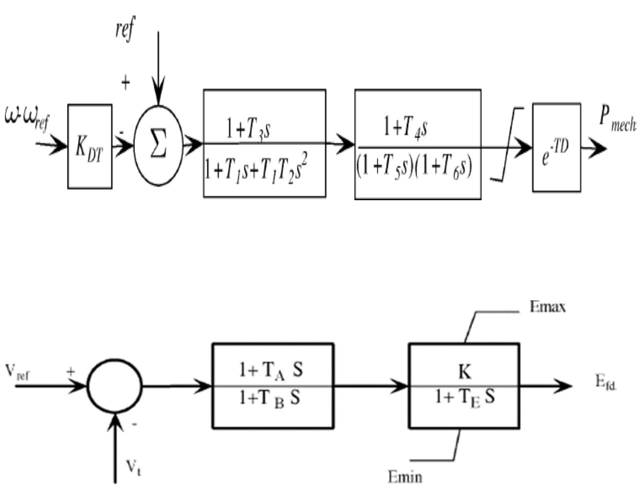

Figure: Diesel engine and governor model

III. DROOP CONTROL

The droop control concept has been achieved by below equations where the inverter voltage is $E\angle\delta$. This voltage tries to deliver the produced power to the grid with the $V_o\angle 0^o$ voltage by $Z_o\angle\theta$ impedance.

The real both active power P and reactive power Q obtained by the utility $V_o\angle 0^o$ created by [4] as

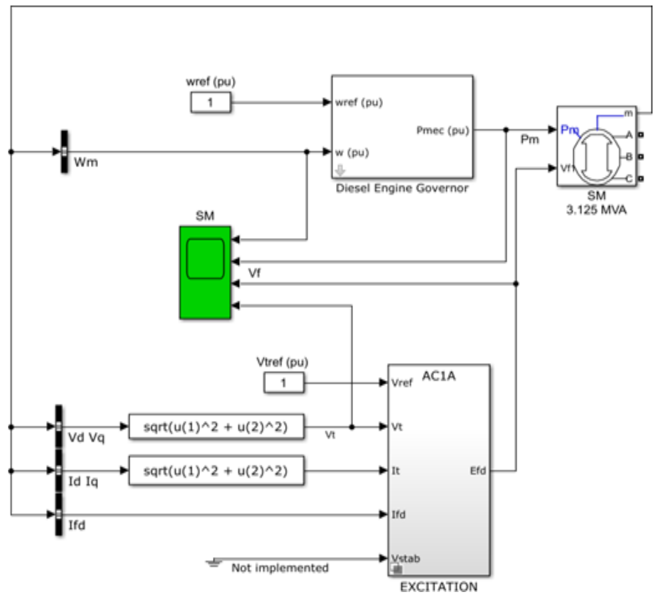

Figure (3): Diesel Generator model in Simulink

$$P = \left(\frac{EV_0}{Z_0}\cos\delta - \frac{V_0^{\ 2}}{Z_0}\right)\cos\theta + \frac{EV_0}{Z_0}\sin\delta\sin\theta \tag{10}$$

$$Q = \left(\frac{EV_0}{Z_0}\cos\delta - \frac{V_0^{\ 2}}{Z_0}\right)\sin\theta - \frac{EV_0}{Z_0}\sin\delta\cos\theta \tag{11}$$

Where δ the difference between the phases and is described as the power angle. By considering the impedance of inductive equations will change as

$$P = \frac{EV_0}{Z_0}\sin\delta \tag{12}$$

$$Q = \frac{EV_0}{Z_0}\cos\delta - \frac{V_0^{\ 2}}{Z_0} \tag{13}$$

The Power angle is assumed as a small value. So

$$E_i = E^* - n_i Q_i \tag{14}$$

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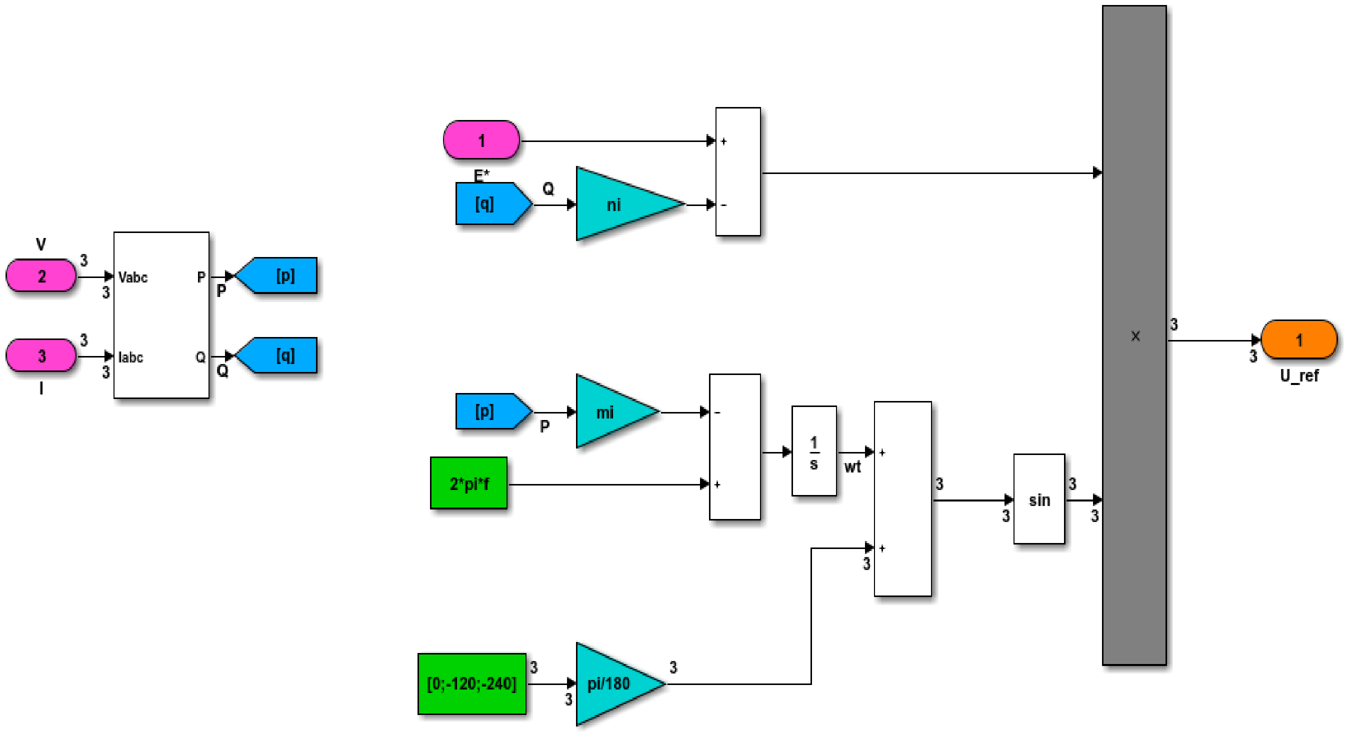

Figure (4): Simulated droop control strategy

$$\omega_i = \omega^* - n_i P_i \tag{15}$$

Where the reference voltage E* is called and the frequency reference ω*. the produced voltage will be presented by E, and as the generated frequency as ω. the coefficients for the droop controller are given as n and m which can be uncovered base on the capacity of [19] – [20].

TABLE I
PARAMETERS

VARIABLES	Values
Voltage rms	320 (V)
Frequency	5 Hz
Lf	35 mh
CF	3µf
FC Active Power	10 KW
DG Active Power	8 KW
FC Reactive Power	1 Kvar
DG Reactive Power	1 Kvar
Load	16 KW, 2 Kvar

IV. SIMULATION RESULTS

Table (1) presents the parameters for defined microgrids. Based on those values load will be fed by resources. Figure (5) shows the simulated microgrid in the MATLAB/Simulink environment which gives a great tool for designing and model of microgrids.

The simulation results are presented in (6-8). The inverters successfully convert the DC voltage from the FC and DG rectifier into three phases voltage and current in island mode operation. The main point to be mentioned is the capability of the system to maintain the right voltage and frequency applied to the load while delivering all the required power the goal for the DCMF with a droop controller. is to provide 8kw for load and the goal here is to provide 8kw for load Injected of Diesel Generator.

Figure (6), (7) depicts the: Produced Active and Reactive power and current and voltage by Fuel Cell and Diesel Generator. While the Provided Active and Reactive power for the load with an acceptable range of current and voltage is given in Figure (8).

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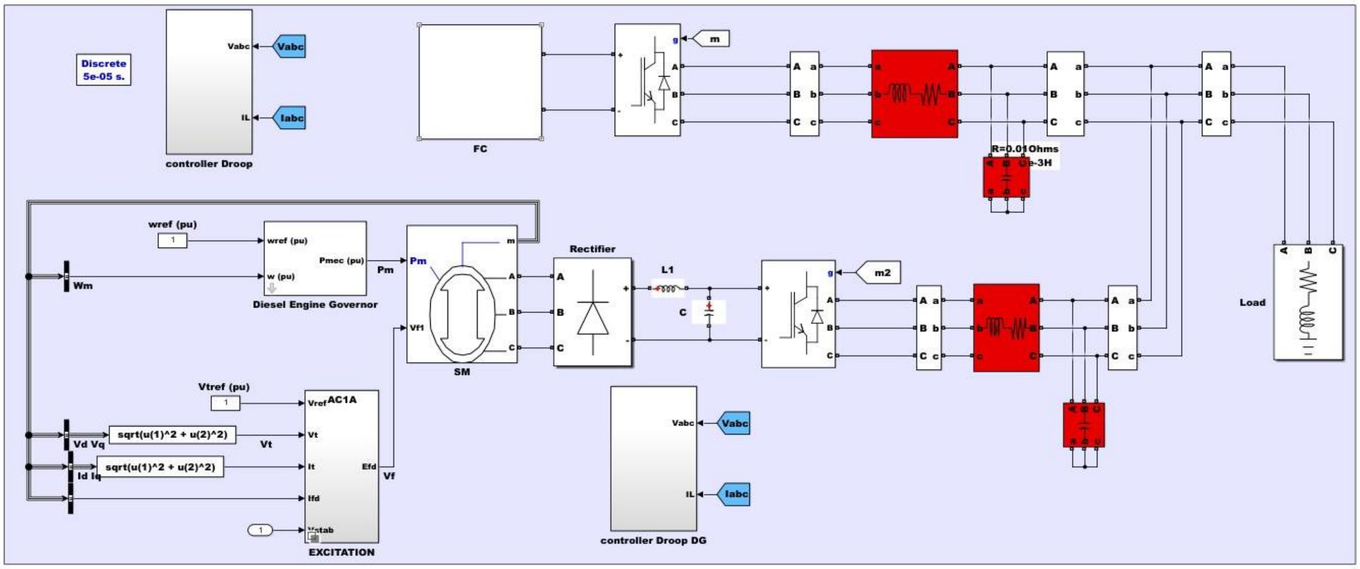

Figure (5): Simulated Microgrid in SIMULINK

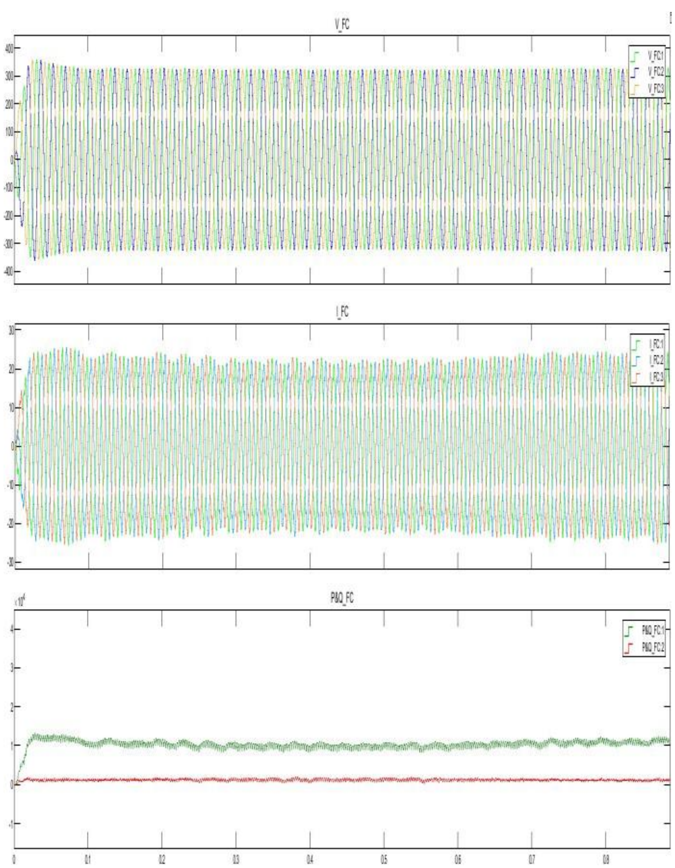

Figure (6): Produced Active and Reactive power and current and voltage by Fuel Cell

Figure (7): Produced Active and Reactive power and current and voltage by Diesel Generator

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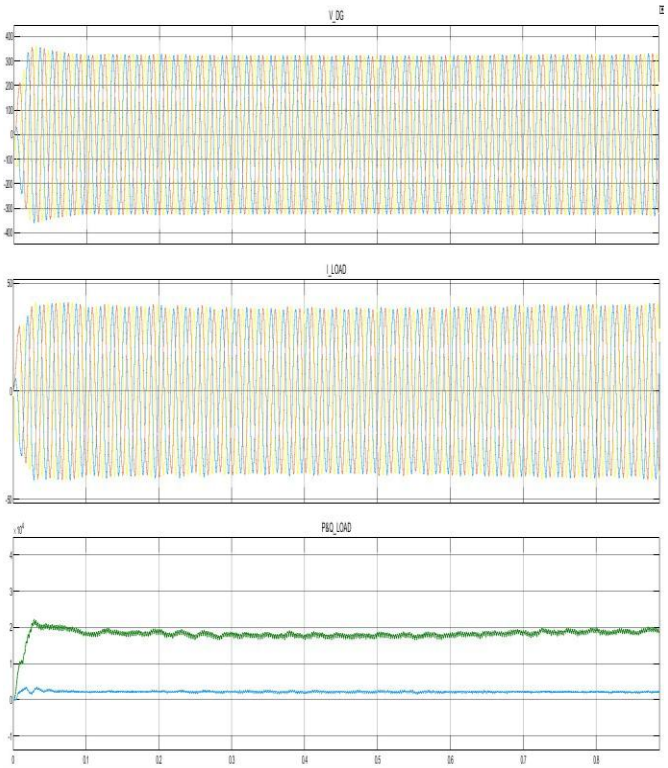

Figure (8): Provided Active and Reactive power for the load with acceptable range of current and voltage

V. CONCLUSION

In this research, an islanding microgrid including a diesel generator and the Direct Methanol Fuel Cells (DMFC) has the resources and a load is designed. The diesel generator with its systems and power electronic interfaces such as rectifier, filters, and inverter were explained comprehensively. The sources were responsible to deliver pre-defined powers to the load. A conventional droop controller was used to supervise the power delivery process. The designed model was simulated in the MATLAB/Simulink environment and the desire results were achieved.

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