



# Short Circuit Computation At Multi Faults Situation For Solid Oxide Fuel Cell Power Generators Grid

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## Abstract

Fuel cell generators takes more attention today due to its performance to operation as friendly for the environment and been one of the main sources of green energy. The subject of fuel cells has been evolved in recent years which contribute to reduce the cost of manufacturing with the increasing of durability and capacity to produce an increased amount of electrical power capacity. In this work a proposed fuel cell grid consist from ten fuel cell generators connected to a grid. As the power produced from the fuel cell is DC power, so a three-phase power inverter is connected with the fuel cell through DC link capacitor. Short circuit computation is performed at each bus-bar where short circuit current is calculated. Also, a proposed fault is considered at fuel cell terminal and the current at all branch of the grid is computed and the contribution current of every fuel cell generation is obtained and the bus-bar voltage at per unit value is computed. Fault current values can be used for defined the capacity of each component of the proposed grid in order to be able to confrontation high current during severe fault conditions. The program used in this work is CYME 7.1

**Keywords** – Solid Oxide Fuel Cell, Short Circuit, Fault Current, Bus-Bar, Grid

## 1. Introduction

Nowadays the renewable energy takes more attention due to the effects of the impact of fossil fuels which is the main fuel for the operation of traditional power plants and its emitting of carbon dioxide at a decent rate and the negative impact on the environment and global warming which is considered as a global phenomenon that need to join efforts to search for sources of green energy environment. Fuel cells are one of the promised sources of renewable energy for future days due to their high efficiency and environmentally friendly properties [1]. Solid oxide fuel cell (SOFC) is an electrochemical device of several types of fuel cells that produce electrical power as a result of internal chemical interaction between two electrode throw an electrolytic barrier between them [2]. The typical fuel cell is made up from cathode and anode where the chemical reaction occur and at the same time, the current flow between them. The electrical current generated in the fuel cell is the result of the chemical reaction between the anode and the cathode of the cell and produces electrical power. The generated power depend on the capacity of fuel cells which influence by many internal factors that directly effect on the efficiency of the fuel cell including high conductivity of the cathode and anode, high porosity, chemical computability, and in addition to high oxygen conductivity for the electrolyte, high ion conductivity and no porosity [3]. The fuel cell components must be chemically stable in order to limit chemical interaction. A number of research has been conducted on the use of fuel cells in power systems. A new control system for grid feeding power convertor is designed [4]. The dynamic behavior of SOFC is considered for double layer charging effect. A micro grid SOFC power plant in a hybrid alternative energy based on coordinated control strategies is designed to providing a fast load tracking [5].

This technique show that the high nonlinear SOFC plant may behave like a linear system.

## 2. Operation of Solid Oxide Fuel Cell

The SOFC operate at extremely high temperature in the range from 700 to 1000 degrees Celsius. This high temperature is due to the benefit of interaction proceed more quickly and no need for noble metal catalysts. This high temperature is adequate to enable hydrogen extraction. The anode is made from a metal with high electrical conductivity and high porosity and the electrochemical oxidation for fuel gas ( $H_2$ ) is occurs as shown in the reaction [6]:

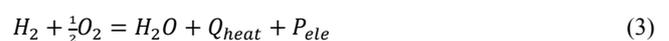


Anode metal inhibit sintering of the metal particles and provides a comparable thermal expansion coefficient.

For the cathode a decrease for oxygen is occur due to the reaction with the hydrogen as show below [6]:



The cathode metal must be oxygen ion conductivity with high electronic and stabile at different working temperature. The electrolyte is the mediator between the anode and cathode where it is allow the ion transportation must be high oxygen conductivity with no porosity. Chemical reaction inside fuel cell produce electrical current, water, and heat as show in the equation [7]:



The electrolyte have a characteristic of chemical stability in order to limit the interaction with the other cell components, morphological, and also been dimensional stabile. The solid oxide electrolyte is worst conductive of cell component and cell interconnected. The basic of energy conversion is show as [6]:

$$\text{Chemical energy} = \text{Electrical Energy} + \text{Heat Energy}$$

The efficiency of energy conversation can be measured depending on the following relation [6]:

$$\eta = \frac{\text{on load voltage}}{\text{open circuit voltage}}$$

For this type of fuel cell, the efficiency is with the limits from 60 to 80%.

### 3. Solid Oxide Fuel Cell Grid Configuration

The proposed grid considered in this work is consist from ten solid oxide fuel cell connected to the grid. The rated active power for each cell is 1000 KW (see Appendix A) and the system dynamic model for the cell explain the details for the operation and control and the hydrogen fuel and the oxygen in addition to all internal block diagram connection (see Appendix B). As the generated power is DC, so that a 3-ph inverter is connected to each cell terminal and a DC link between the cell terminal and inverter ( 15000  $\mu$ F Capacitor). The inverter capacity is the same that for the cell with the reactive power control, DC voltage control, current control for proportional and integral control, also, the protection from over current opening time, over voltage, under voltage, voltage limit, over frequency, and under frequency. The grid configuration is shown in Appendix C.

### 4. Short Circuit Computation

Short circuit computation is very important for any power system or grid because the protection criteria depend essentially on the short circuit level for all grid equipment in order to withstand or break the fault current. Different types of short circuit can take place in power system. The most common type is line to ground short circuit which represent about 80% of fault and the second type is line to line fault which represent an a bout 15% of the initial fault while three line fault represent about 5% as initial fault in the system.

The importance of short circuit depend mainly on the type of fault and also the time interval of the fault. When a fault take place between two point a fault current is flow under transient condition and its value depend on the short circuit impedance:

$$Z_{sc} = \sqrt{(\sum R)^2 + (\sum X)^2} \quad (4)$$

The fault current at any point of the grid is computed depending on the value of resistance and reactance of the fault loop and the current is calculated using the relation [8] :

$$I_{sc} = \frac{V_n}{\sqrt{3} \sum(Z)} \quad (5)$$

All the characteristic of the various grid component and element must be known in order to compute short circuit current where its value depend on the type of short circuit. For three lines, fault current is computed using equation 5 and the impedance in the equation represent all the impedance through which short circuit current is flow. For line to line fault the fault current is computed by using the equation:

$$I_{sc} = \frac{V}{2Z_{sc}} \quad (6)$$

For line to neutral fault, the fault current is computed using the equation:

$$I_{sc} = \frac{V/\sqrt{3}}{Z_{sc}+Z_0} \quad (7)$$

Where  $Z_0$  is zero sequence impedance and in some cases this impedance is less than short circuit impedance, and due to that the fault current may be greater than that for three lines fault.

All the above cases is taken into consideration depending on the computation of short circuit current.

### 5. Fault Simulation and Result

The SOFC grid model is taken into short circuit level computation at different fault conditions and the analysis is performed using CYME 7.1 power engineering software. For LLL fault at each bus-bar, the short circuit current at each fuel cell terminal is about 27187 A to 27326 A as show in figure 1 and reduced at other bus-bar to 1202 A, where these values is acceptable values for this types of power system. The short circuit current at the nodes after transformer 0.57/11 KV is less than that from its value at SOFC terminal. This reduction is due to the increasing of impedance fault due to the stay away from the main source.

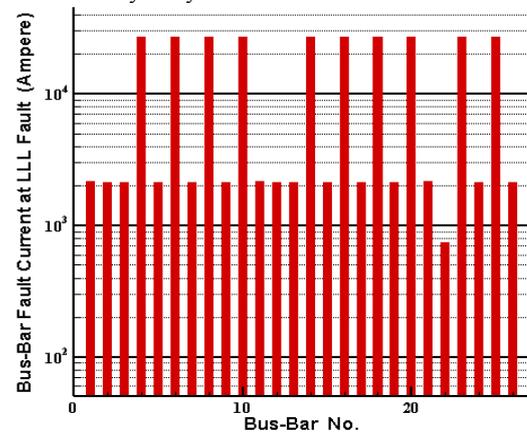


Fig.1. Fault Current at Each Bus-Bar During LLL Fault

The second type of fault is applied at each bus-bar and node of the grid is LLG fault. In this type, the short circuit current is greater than that for LLL fault and its value varies from 33801 A to 33954 A at SOFC terminals. These values reduced to from 1202 A to 1693 A at the nodes after 0.57/11 KV transformer. This reduction is considered due to the delta connection of primary winding where there is no earthed neutral and at the same time, the impedance of the transformer. Figure 2 explain this behavior.

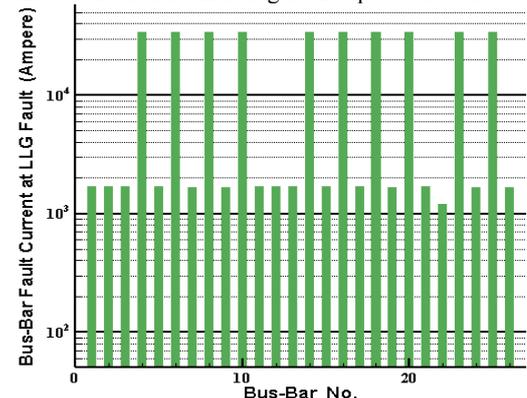


Fig.2. Fault Current at Each Bus-Bar During LLG Fault

The third type of fault is LL fault explain in figure 3 where the fault current at all of SOFC terminal is less than that for LLG fault and its value between 21902 A to 22018 A and at the same time the fault current at the nodes after 0.57/11 KV transformer is the same value for LLG current.

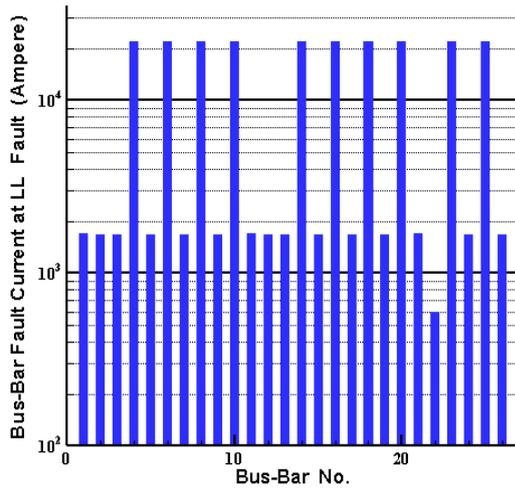


Fig.3. Fault Current at Each Bus-Bar During LL Fault

For LG fault, the short circuit current value is approximately the same that for LLG fault but this value reduce to about 9 A after step up transformers. Figure 4 explain the current values during this fault.

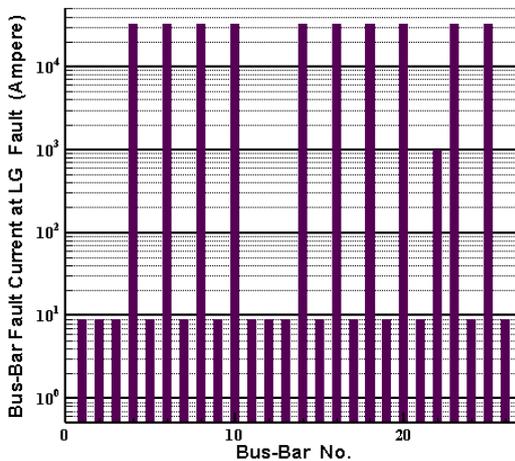


Fig.4. Fault Current at Each Bus-Bar During LG Fault

The distance of each bus-bar and node from the main substation is shown in figure 5 where the maximum distance is 2296.6 meter and this distance have an effect on current value.

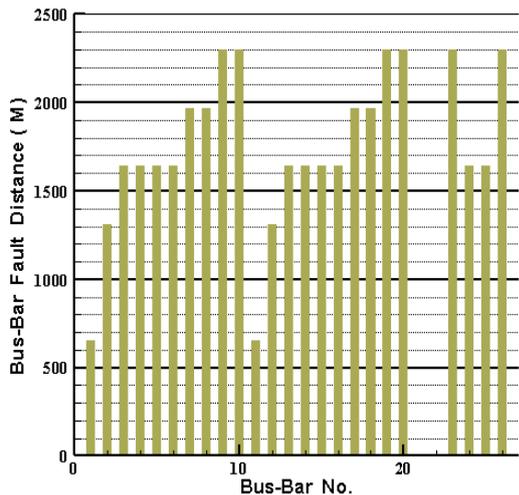


Fig.5. Fault Distance for Each Bus-Bar

The second section of this work is compute fault current when a fault occur at accretion SOFC terminal. When LLL fault occurs at SOFC No. 1, the result for this fault shown in figure 6 where the maximum fault current shown at node 25 at SOFC terminal. For the other bus-bar and node, current value depend on the location of that node and bus-bar.

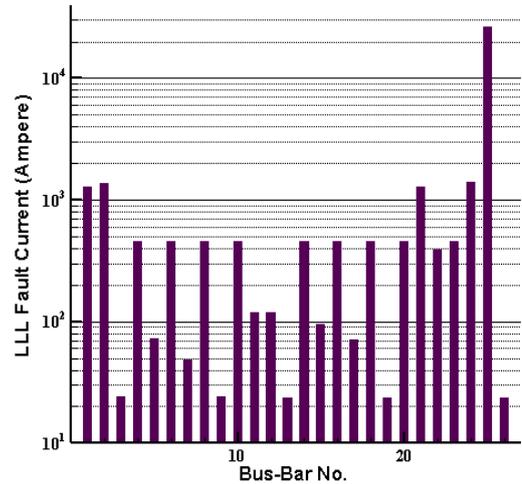


Fig.6. LLL Fault at Generator 1 Terminal

SOFC generators current contribution during LLL fault at generator 1 terminal is demonstrated in figure 7.

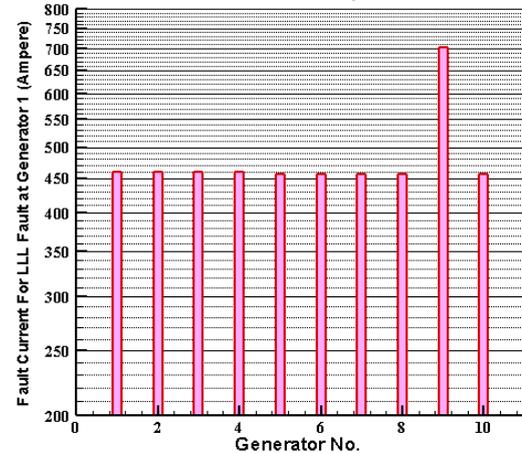


Fig.7. SOFC Gen. Current Contribution for LLL Fault at Gen. 1 Terminal

For LL fault at SOFC No. 3 terminal, the maximum fault current is at the fault location while for the other SOFC the current reduced to 0.6% as show in figure 8. At the same time the current in some far nodes reduced 0.05% from that for SOFC faulted generator.

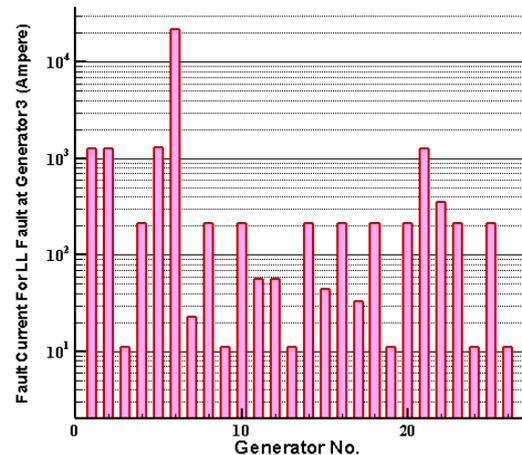


Fig.8. Fault Current at Generator 3 Terminal During LL Fault

The voltage at each bus-bar and nodes is calculated when LG fault occur at SOFC 0.415 to 0.637 p.u from its pre-fault value and the voltage at faulted SOFC is zero as show in figure 9.

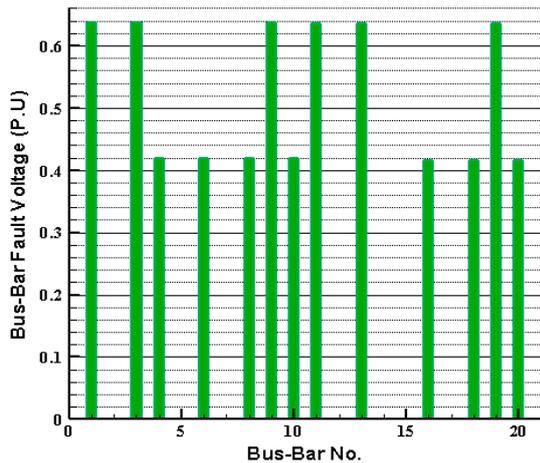


Fig.9. Bus-Bar Voltage for LG Fault at Generator 6 Terminal

Also, for LL fault at the terminal of SOFC No.9 the voltage is reduced 0.32 to 0.609 p.u form its pre-fault condition but for the faulted generator the voltage during the fault is 0.535 p.u as explain in

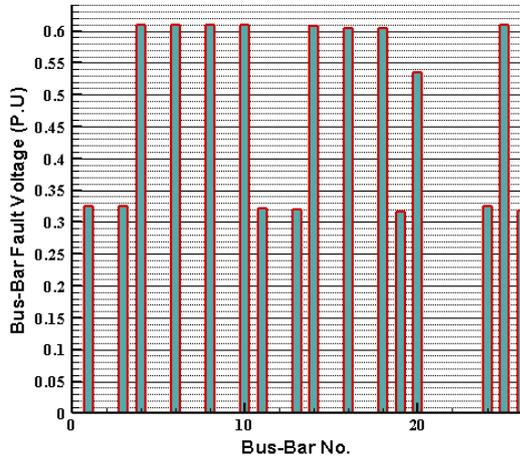


Fig.10. Bus-Bar Voltage for LL Fault at Generator 9 Terminal

### 6. Conclusion

Short circuit current calculation is very important for any grid power system in order to defined the breaking capacity of each circuit breaker and the electro dynamic withstand capacity of the wiring system and switchgear in order to insure reliable operation at any intense condition. In this work the short circuit current at each bus-bar and node is computed where the most severe cases when the short circuit is at SOFC terminal and specially for LLG fault. Study of different fault types at some of SOFC show that the maximum value pf fault current is at the terminal of faulted case. The voltage at each bus-bar reduced depending of the type of fault.

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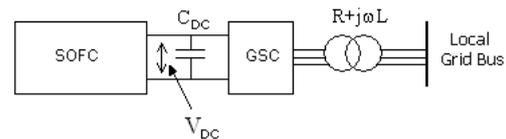
### Appendix A

#### Solid Oxide Fuel Cell Data

Generator Data	Value
Apparent Power	500 KVA
Rated Voltage	570 Volt
Frequency	60 Hz
Active Power	500KW
Rated Current	705 Ampere
Power Factor	1.0
No. of Series Cell	1875

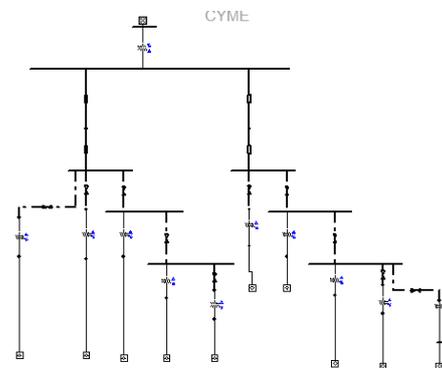
### Appendix B

#### Internal Blok Diagram Connection



### Appendix C

#### Grid Configuration



Mehdi F. Bonneya born in Iraq in 1958. He received the B.S.C degree in Electrical Engineering at 1979, the M.Sc. degree at 1986, and Ph.D. degree at 2009 from the University of Technology, Baghdad, Iraq in Power System Engineering. Currently he is an Assistance Professor in Middle Technical University, Baghdad, Iraq