5.1. INTRODUCTION

The deregulation of electric power utilities, environmental concerns, market uncertainty and growing concern about availability and quality of electrical power has led to development of distributed generation system. One of the prominent DG sources is a fuel cell, which can be operated in utility interconnected mode or installed in a remote area to supply stand-alone power. Recently, much work has been focused on interfacing DG with the grid, its operation and control. A flexible DG can be used to improve the power factor and voltage fluctuations of the utility [132]. SOFC based DG System is normally interfaced with the utility network through a set of power electronics devices. The interface is very important as it affects the operation of the fuel cell system and the power grid. Various control schemes have been proposed in the recent work to interface different energy sources to utility grid [122], [133]. Pulse-width modulation voltage source inverters are widely used to interconnect a fuel cell energy system to a utility grid for real and reactive power control purpose [134].

A number of literatures mainly reported about the modeling of SOFC system. But a few have reported about the connections of fuel cell DG system to the grid. When connected to utility grid, important operation and performance requirements are imposed on fuel cell DG system. In [80], the main focus has been given on the dynamic behaviour of SOFC under a grid connected condition. In this paper, the strategies of changing the output power level of a SOFC power plant connected to an AC grid through a voltage source inverter have been explored with the objective to minimize the time that required for achieving power changes while guaranteeing safe operation of the plant. More-over, the concept of feasible operating area (FOA) of the FC has been introduced. After identifying FOA of FC stack in steady state, the
concept of three control variables that can be used to control the real and reactive power flow from SOFC power plant to the grid are formulated. These are input flow of natural gas, the modulation index $m_a$ and the phase shift $\delta_i$ associated with the VSI. The natural gas input to the plant was controlled proportionally with the current to operate the stack with a constant utilization factor in steady-state and to reduce the variations in terminal voltage. The phase shift and modulation index of VSI were utilized to regulate the stack current and to keep the power factor of the plant constant for all power levels [135].

Different strategies in which the stack current can be changed were studied to achieve the objectives. The analysis carried in paper [80] illustrates that the maximum safe step in stack current to the initial stack operating current is equal to the maximum allowed excursion of the utilization factor as a ratio to the steady-state utilization factor. For larger power ranges, the stack current should be varied using a feedback control loop so that the utilization factor is maintained at its limit value until the target power level is achieved. For this method of control, the controller is independent of the model of the fuel processor and with all the strategies of current control; the controller is independent of the model of the FC.

In paper [85], a 5-kW SOFC dynamic model developed by the authors [57] has been used for a grid-connected SOFC based DG operation. Also the modeling and controller design methodologies for the power electronic interfacing circuits between the SOFC and the grid are studied. A conventional PI controller has been used for DC–DC converter to control the DC bus voltage. In order to meet the requirements for interconnecting the SOFC DG system to a utility grid and control the real and reactive power flow between them, a control scheme consisting of an outer voltage regulator with an inner current control loop, reported in [136] has been adopted in this paper for three phase voltage source inverter control. The inner current control loop is designed to respond faster than the outer voltage control loop such that the two control loops can be designed independently. The outer voltage controller takes the error signals and generates the reference current signals for the current control loop. The inner current controller produces control signals in $dq$ coordinate, which are
converted back into the control signals in $abc$ coordinates using the $dq/abc$ “transformation” block. These control signals are used to control the SPWM pulse generator to produce pulses for the inverter switches so as to control the inverter output voltage. Thereby the case study reported in this paper indicates that the real and reactive power delivered from the fuel cell to the utility grid can be controlled as desired, while the dc bus voltage is maintained well within the prescribed range.

In this chapter of the thesis a control strategy for connecting SOFC based DG to the grid has been developed. In a grid connected SOFC power plant, the decoupling of real and reactive power from fuel cell is necessary for proper functioning of the grid, because any difference between the supply and demand will lead to variations in frequency and voltage of the grid. Therefore, independent regulation of real and reactive power is essential. In this perspective, a control strategy using decoupling method has been developed to independently control the real and reactive power injected to grid from an SOFC plant. The performance of the grid connected SOFC DG system is studied for changes in the load and also for changes in the DG operation capacity. A study is also made when the system experiences severe fault conditions like a 3 phase line to ground fault while supplying different loads.

### 5.2 GRID INTERFACE TOPOLOGY OF SOFC

Fuel cells are electrochemical energy conversion devices similar to batteries. They generate variable and low output voltage (current). Thus, they are unable to connect to the utility directly. However, they can be interfaced and can supply power to the utility by means of power electronic converters [137], [138]. Fig. 5.1 shows system integration of fuel cell and power electronics unit which comprises of a solid oxide fuel cell stack associated with a DC–DC converter and a widely used DC–AC pulse width modulation (PWM) inverter with RL output filter connected to the utility grid. In this chapter of the work, the case of a SOFC based DG connected to a grid is considered wherein the capacity of power supply by the DGs is less than the load demand i.e., the active power demand of load is more than DG capacity and hence grid and DG both will supply active power to the load. Thus, in this mode of
operation a certain amount of power is scheduled to the load from the fuel cell DG and remaining power to load is supplied from the utility grid.

![Fig.5.1 Schematic diagram of grid connected DGs](image)

The DGs autonomously operate with load until it reaches the steady-state. The phase difference between the DGs output voltage and the grid voltage decreases until the DGs output voltage is in phase with the grid voltage. After the DGs output voltage is synchronized with the grid voltage, the grid is connected to DGs and then the grid starts providing electric power to the load. There are various control strategies for interfacing DGs to the distribution system. The DG is operated either to control DG output current, active power and voltage at the point of common coupling (P-V mode) or active and reactive power output of DG. The two main important control techniques for interfacing DGs to the utility grid are,

- P – V controlled inverter
- Constant power controlled inverter (PQ control strategy)

In P–V controlled interface, the active power and voltage are controlled but there is no direct control on the reactive power. In this interface control, reactive power is supplied to maintain the voltage at 1 p. u. In case of constant power controlled inverter, the interface is designed to supply constant active and reactive powers [138]–[140]. In order to achieve full decoupling of active and reactive power control loops, the inverter is current controlled and control system is implemented in $dq$-reference frame. A Phase Locked Loop (PLL) is needed to determine the frequency...
and angle reference in order to implement the Park’s transformation within the control scheme.

5.3 REAL POWER (P) AND REACTIVE POWER (Q) CONTROL

For real and reactive power control of the DGs connected to the grid, an equivalent circuit is represented by two voltage sources through line impedance with pure inductances L as shown in Figure 5.2. It is considered that $V_s$ is the DGs output voltage and $V_g$ is the grid voltage in general.

![Equivalent circuit of DG connected to the grid](image)

Fig 5.2 Equivalent circuit of DG connected to the grid

The complex power delivered from the DGS to the grid is given by:

$$S = P + jQ = V_s I^*$$

(5.1)

Where $I$ is the complex conjugate of current $I$, given as

$$I^* = \left[ \frac{V_s \cos\delta + j V_s \sin\delta - V_g}{j\omega L} \right]$$

(5.2)

$$S = V_g \left[ \frac{V_s \cos\delta + j \sin\delta - V_g}{j\omega L} \right]$$

(5.3)
Where, $\delta$ denotes the phase angle between the DGs output voltage and the grid voltage.

From (5.3), the active and reactive power flowing from the DGS to the grid can be obtained as below:

$$P = \frac{V_g V_s}{\omega L} \sin \delta \quad (5.4)$$

$$Q = \frac{V_g V_s \cos \delta - V_g^2}{\omega L} \quad (5.5)$$

From equations (5.1) through (5.5), it can be seen that, if $\delta$ is small enough, then the real power flow is mostly influenced by the power angle $\delta$ while the reactive power flow predominantly depends on the DGs output voltages $V_s$. This means that to a certain extent the real and reactive power flow can be controlled independently. Since controlling the frequencies dynamically controls the power angles, the real power flow control can be equally achieved by controlling the frequencies of the voltages generated by the DGs. Therefore, the power angle and the DGS output voltage magnitude are critical variables that can directly control the real and reactive power flow. However, in this case study reactive power $Q$ is set to zero. For higher power applications i.e., commercial or industrial applications, a three-phase fuel cell power condition system is preferable. In order to supply high quality power to utility grid from fuel cell based DG, the control of grid side converter is discussed below.

### 5.4 GRID SIDE CONVERTER CONTROL SCHEME

A vector control approach is used here, with the reference frame oriented along the supply voltage vector position. This enables independent control of the active and reactive power flowing between the supply and the grid side converter. Fig. 5.3 shows the schematic of the supply-side converter. The PWM converter is current regulated, where the direct axis current component is used to regulate the DC-link voltage and the quadrature axis current component is used to regulate the reactive power.
5.4.1 Current Controller Design

The voltage balance across the inductors and resistors is given by

\[ v_{an} = L_f \frac{d}{dt} i_a + R_f i_a + v_{gan} \] (5.6)

\[ v_{bn} = L_f \frac{d}{dt} i_b + R_f i_b + v_{gbn} \] (5.7)

\[ v_{cn} = L_f \frac{d}{dt} i_c + R_f i_c + v_{gcn} \] (5.8)

\[
\begin{bmatrix}
  v_{an} \\
  v_{bn} \\
  v_{cn}
\end{bmatrix} = L_f \frac{d}{dt} \begin{bmatrix}
  i_a \\
  i_b \\
  i_c
\end{bmatrix} + R_f \begin{bmatrix}
  i_a \\
  i_b \\
  i_c
\end{bmatrix} + \begin{bmatrix}
  v_{gan} \\
  v_{gbn} \\
  v_{gcn}
\end{bmatrix} \] (5.9)

where \( L_f \) and \( R_f \) are the filter inductance and resistance respectively. Using the Park’s transformation, this equation can be transformed to the \( dq \) reference frame.
The last terms in both equations (5.10) and (5.11) cause coupling of the two equations, which makes it difficult to control both currents independently. The last terms can be considered as a disturbance on the controller. Fig. 5.4 shows a simplified block diagram of closed loop synchronous frame current control. The inverter currents transformed to a synchronous frame \((i_d, i_q)\) are compared to the current references \((i_{dref}, i_{qref})\) and the resulting error is regulated by proportional integral (PI) controller. The utility voltage \((v_d, v_q)\) and decoupled terms \((-\omega L_i_d)\) and \((\omega L_i_q)\) are added in a forward path to cancel effect of the utility and the cross-coupling voltage.

\[
v_d = L_f \frac{di_d}{dt} + R_f i_d - \omega L_f i_q \tag{5.10}
\]

\[
v_q = L_f \frac{di_q}{dt} + R_f i_q + \omega L_f i_d \tag{5.11}
\]

\[
\begin{bmatrix} v_d \\ v_q \end{bmatrix} = L_f \frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega L_f \begin{bmatrix} -i_q \\ i_d \end{bmatrix} \tag{5.12}
\]

Fig.5.4 Control block diagram of \(dq\) current controllers of grid side converter
Thus the reference voltages to obtain the desired currents $dq$-axis can be written as:

\[ v^*_d = v_d - u_d + \omega L_f i_q \]  
\[ (5.13) \]

\[ v^*_q = -u_d - \omega L_f i_d \]  
\[ (5.14) \]

where, \( u_d = G_d(s)(i_d^* - i_d) \) and \( u_q = G_q(s)(i_q^* - i_q) \).

\( G_d(s) \) and \( G_q(s) \) represented by simple PI controllers are as follows

\[ G_d(s) = K_{pd} + \frac{K_{sd} \cdot s}{s} \]  
\[ (5.15) \]

\[ G_q(s) = K_{pq} + \frac{K_{sq} \cdot s}{s} \]  
\[ (5.16) \]

A Simulink model is developed with reference to above mathematical modeling for three phase inverter to connect SOFC based DG in parallel to the utility grid to share the load demand is shown in Fig.5.5. However, the complete Simulink model of SOFC based DG connected to grid is not shown here as it is similar to SOFC based DG model built up for isolated load in chapter 2 except the inverter control strategy.

The \( abc/dq \) transformation block takes the current and voltage value in \( abc \) coordinate form voltage and current meter and convert them in \( dq \) values. \( I_{dqref} \) is obtained by dividing \( P_{ref} \) by \( V_{dq} \) as indicated in Fig. 5.5. The controller finally produces \( dq \) control signals which are converted back into control signal in \( abc \) coordinates through \( dq/abc \) transformation block. Theses control signals are used to modulate the SPWM pulse generator to produce the proper pulse of the inverters switches which control the inverter output voltage.
The simulation parameters are given below in Table 5.1

<table>
<thead>
<tr>
<th>Table 5.1</th>
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<tbody>
<tr>
<td><strong>Boost Converter parameters</strong></td>
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<tr>
<td><strong>Inverter parameters</strong></td>
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<td><strong>Filter parameters</strong></td>
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<td><strong>Grid parameters</strong></td>
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</table>
5.5 **SERIES RL FILTER**

Grid side filter consists of inductance $L$ and resistance $R$. Applying Kirchhoff’s voltage law to the circuit in the Fig. 5.6. The resulting equation is given in (5.15)

![Series RL Filter Diagram](image)

Fig. 5.6 Series RL filter at the grid side of the interface

$$v_g = -(R_f + j\omega L_f) i_f - L_f \frac{di_f}{dt} + v_c$$ \hspace{1cm} (2.17)

Where $v_g$ is the grid voltage, $i_f$ is the filter current and $v_c$ the voltage at the terminals of grid side converter. The transfer function of the grid filter can be expressed as

$$G_f(s) = \frac{i_f(s)}{v_f(s)} = \frac{1}{sL_f + R_f}$$ \hspace{1cm} (5.18)

The damping of the grid filter is given by

$$|G_f(j\omega)| = \frac{1}{\sqrt{L_f^2 \omega^2 + R_f^2}}$$ \hspace{1cm} (5.19)

If $L_f \omega \gg R_f$ the gain can be approximated as $|G_f(j\omega)| \approx 1/(L_f \omega)$.

5.6 **SYNCHRONIZATION BASED ON THREE PHASE PLL**

One of the important requirements in the interconnection design of power electronic converter interfaced DG system is that of synchronization to the utility system. Synchronism of converter control with grid is achieved by using a PLL. The converter control needs measurements of the frequency and line-angle of the utility to properly
ensure that it can regulate the real and reactive power flow to the grid. These measurements are obtained through the implementation of Phase locked loops (PLL), which will use voltage at the point of common coupling and grid to track the frequency and angles [141]. Since a PLL is a central component in a control structure for the grid-side converter, it will be presented in this section. A generalized three phase PLL structure is shown in Fig 5.7. The phase difference between the input and the output signals is measured using a phase detector (PD) and passed through a loop filter (LF). The error signal drives the voltage controlled oscillator (VCO) which generates the output signal. In the power system applications, the voltage-controlled oscillator usually is implemented as an integrator.

![Fig. 5.7 Generalized three phase PLL structure](image)

The loop filter is a low pass filter which suppresses noise and high frequency terms, in the output of the phase detector. To avoid stationary error in phase angle, after a step change in the input signal frequency a PI controller is added. The performance of the PLL depends on the phase detector and the selected bandwidth of the loop filter. Slow dynamics in the PLL loop results in lesser disturbances, although there is a poor tracking of the grid angle. The loop is closed by feeding the estimate angle into the phase detection scheme. As long as the phase angle is correct, the output of the phase detector is zero. Thus the frequency input to the integrator is constant and the PLL is in lock. If the estimated angle is not correct, the frequency is adjusted and the phase angle of the grid voltage phasor is changed.
5.7 SIMULATION RESULTS

A study on the performance of a SOFC based DG in grid connected mode has been investigated. System under study deals with the following case in which the active power supplied by the DGS is smaller than the active power demand of the load. Hence, both grid and SOFC based DG will supply power to load. The performance of the developed control scheme has been investigated and discussed under various cases as below,

5.7.1 Case I: Without Fault on system

- DG is set to operate with 90% of its capacity

In this case study, the resistive load is connected to a point of common coupling between SOFC based DG and grid as illustrated in Fig. 5.1. The SOFC based DG is set to operate with 90% of its capacity with a balanced three phase resistive load of 150 kW.

From Fig. 5.8 (a) it is observed that the grid voltage is not influenced by SOFC DGs. Fig.5.8 (b) shows the balance three phase inverter currents when SOFC is made to operate at 90% of its capacity. The current supplied from grid to load is shown in Fig.5.8 (c).
Fig. 5.8 Simulation results (a) three phase grid voltage (b) three phase inverter current

(c) Three phase grid current

Fig. 5.9 shows the frequency response of terminal voltage. It requires about 250ms to gain the original value. During transient state, the frequency of the terminal voltage fluctuates between 60.1 Hz and 59.1Hz, but after the transient state it attains the actual value as it is apparent from simulated results. Fig. 5.10 shows the power delivered to the load from SOFC DG as well as from utility grid. Since $P_{LOAD} > P_{DG}$, therefore only certain amount of power is fed to the load from fuel cell DG and remaing power is supplied to
load from the grid. From the power response it is seen that during the initial transient, the active power to the load is supplied by the grid. As the fuel cell starts generating power, the active power of the load is shared between the DG and grid utility. From the power response curve it is evident that the no reactive power is injected to grid by SOFC.

![Fig.5.9 Frequency of terminal voltage](image)

Fig.5.9 Frequency of terminal voltage

![Fig.5.10 Power supplied to three phase resistive load by SOFC DGs and grid.](image)

Fig.5.10 Power supplied to three phase resistive load by SOFC DGs and grid.

Fig.5.11(a) shows the terminal voltage of a three phase resistive load which is equal to the grid voltage. The three phase load current is as depicted in Fig 5.11. The total load on system is 150 kW which draws a current of 255A (peak value).
Fig. 5.11 (a) Load voltage (b) Load current.
The variation in the $i_d$ and $i_q$ components of the injected grid current is shown in Fig.5.12 (a). From the response it is evident that $i_q$ component is approximately zero. The total harmonic distortion (THD) of the voltage is about 3.5% during the simulation as shown in Fig.5.12(b) and it is well within the limits.

**DG is set to operate at 45%, 60% and 90% of its capacity during simulation**

The simulation is carried out to study the various performance of SOFC DG system with DG set to operate from at 45%, 60% and 90% of its capacity. The load connected to DG system is considered same as in case I.
Fig. 5.13  Response of DG system with change in DG operation capacity 
(a) grid voltage  
(b) variation in inverter current  
(c) variation in grid current.

The grid voltage shown in Fig. 5.13(a) is not influenced by the SOFC DG even though DG is set to operate with its different capacity. Fig. 5.13 (b) and (c) illustarte the current responses of DG and grid. The current supplied to the load by the inverter increases in steps with percentage increase in DG operating capacity. But at the same time the value of current to the load supplied by grid also decreases as the load on the system remains unchanged.
Fig. 5.14 Response of SOFC of DG system with change in DG operation capacity (a) frequency of terminal voltage (b) load voltage (c) load current
From Fig 5.14 it is observed that there is no influence of variation in DG percentage capacity on the load voltage and load current. However, Fig.5.14 (a) shows that there is change in the frequency of terminal voltage whenever there is a change in DG capacity. There is a transient variation in frequency at time \( t = 0.65 \) sec and \( t = 0.75 \). At these two instants the capacity of DG operation is changed from 45% to 60% and then to 90%. It is observed from Fig.5.14 (a) that after initial transients the frequency of terminal voltage attains the actual value of 60 Hz and same is true after time \( t = 0.65 \) and \( t = 0.75 \) sec.

![Graph showing \( i_d \) and \( i_q \) components of grid current](image)

(a)

![Graph showing power contribution by grid and SOFC DG to load](image)

(b)

Fig.5.15 Variations in DG operation (a) \( i_d \) and \( i_q \) components of grid current (b) Power contribution by grid and SOFC DG to load.
The response curve of load power and power contributed by both grid and DG with variation in DG operation is shown in Fig.5.15 (b). With the percentage change in DG operating capacity, the change in power contributed by both DG and grid is depicted in Fig 5.15 (b). At any point of time, except during initial transient the load power is completely met by DG and the grid, which indicates that the control unit designed and built in MATLAB/SIMULINK environment, is working satisfactorily and efficiently. The variation in the $i_d$ and $i_q$ components of the injected grid current are shown in Fig.5.15 (a). From the response it is evident that $i_q$ component is approximately zero and no reactive power is injected to the grid by the SOFC based DG.

5.7.2 Case II: SOFC Based DG System under Fault Conditions

- DG is set to operate with 90% of its capacity

The performance of SOFC based DG is investigated during the fault conditions. In this case, the fuel cell DG is considered to be operating with 90% of its capacity wherein it is connected to the utility grid. A three phase balanced load of 150 kW is also connected to point of common coupling. The grid and fuel cell DG are feeding power to the load prior to the fault on the system. A three phase line to ground fault is simulated with the fault occurring at time $t=0.7$ sec and lasting for 5 cycles. It is important to know whether the fuel cell DG system will return to stable state after the fault is cleared which is evident from Fig.5.16 (a). Various related performances of the DG system are analyzed to understand the system behavior. The moment the fault is cleared, the grid voltage attains the pre-fault value which shows that DG system connected to grid remains in stable state after the fault is cleared. The magnitude of inverter current and grid currents are very high during fault condition compared to its pre and post fault values which are depicted in Fig.5.16 (b) and Fig.5.16(c).
Fig. 5.16 Response under fault (a) grid voltage (b) grid current (c) inverter current
The voltage across the load is maintained at grid voltage during pre and post fault conditions. However, it remains negligibly small during fault which is as depicted in Fig.5.17 (a). Thus fuel cell DG system remains stable under an electrical fault of short duration. Under fault condition, the power response is shown in Fig.5.18 (a). The SOFC DG system and the grid deliver power to load before the fault. A simulated three phase fault occurs on the system at time t=0.7sec at the point of common coupling. The fault lasts for 5 cycles and is cleared at time t= 0.7833sec. The fuel cell system remains stable after the clearance of fault. Though the system is stable, there is a rush of power from the SOFC DG to the load when the fault is cleared. The frequency response of terminal voltage under fault condition is shown in Fig.5.18 (b). The frequency attains the pre fault value after the fault is cleared. Thus the system frequency remains unchanged ever after a fault of small duration.

Fig. 5.17 Response under fault (a) load voltage (b) load current
Fig. 5.18 Simulation results (a) power response (b) frequency of terminal voltage

5.7.3 Case III: SOFC DG System under Fault with Step Change in Load from 150kW to 300kW.

- DG is set to operate with 90% of its capacity

A study is carried out with fault on fuel cell DG system with there is a step change in the load. A three phase balanced load is connected to a point of common coupling as shown in Fig. 5.1. Load is changed from 150 kW to 300 kW at t=0.7sec during simulation. Various simulated results in this mode of operation are analyzed. The response of grid voltage with a fault on fuel cell DG system and step change in the load is shown in
Fig. 5.19 (a). It is observed that even with step change in load, the voltage across the load is same before the fault and after the fault. Fault in this case is considered to occur at time $t=0.6$ sec and the fault is cleared at time $t=0.6833$ sec. The grid current and inverter currents are shown in Fig. 5.19 (b) and Fig. 5.19 (c) as in case II. However, the current delivered by grid to load in this case is more than that delivered by inverter. It is because the current to be contributed by fuel cell DG is scheduled even though there is a step change in load and it is clearly illustrated in Fig. 5.19 (b) as the change in step load from 150 kW to 300 kW is simulated at time $t=0.7$ sec.
Fig. 5.19 Response under fault with change in load from 150 kW to 300 kW (a) grid voltage (b) grid current (c) inverter current (d) inverter voltage

Fig. 5.20 (a) shows the voltage across the load under fault conditions with step change in load. The fault lasts on the DG system for 5 cycles. During this period the voltage across the load is almost zero. At time $t=0.7$ sec, the load on system is changed from 150 kW to 300 kW and the voltage across the load attains its nominal value. Load current response for step change in load is depicted in Fig. 5.20 (b). It is seen that due to change in load at $t=0.7$ sec, the value of load current also changes in magnitude and this additional current is supplied by grid as fuel cell is scheduled to supply a fixed amount of power to the load.
However, no current is supplied by DG and grid to the load during short circuit and the same is evident from the load current response shown in Fig.5.20 (b).
Under fault condition, the power response of the SOFC DG and grid is shown in Fig.5.18 (d). The frequency response of terminal voltage under fault condition and with step change in the load is shown in Fig.5.20 (d). The frequency attains the pre fault value after the fault is cleared. As there is a step change in load at time t=0.7 sec, a transient response is observed on the system frequency.

5.8 CONCLUSION

The performance of SOFC based DG system connected to grid has been carried out. In grid-connected mode, the voltage and frequency are controlled by the grid. Thus, the DG units are controlled to provide specified amount of real power depending upon the rating of the units. A control strategy has been developed using decouple method to control the active and reactive powers independently from the solid oxide fuel cell. The developed control system is implemented in the $dq0$ reference frame. The complete model is simulated using SimPowerSystem blockset of MATLAB and various results under
decoupled control strategy have been studied and analyzed. The simulation results show that the developed control strategy is able to manage the power sharing between grid and DG and is able to tolerate the rapid changes in various modes of operation and also maintains voltage quality at the grid and load. The results also show that the fuel cell system is capable of remaining stable under occurrence of severe faults. The simulation results also demonstrate the robustness of the developed controller in maintaining the active power constant.