Combined Model of Fuel Cell and Microturbine Based Distributed Generation System

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***Abstract*-- Distributed Generation (DG) play an active role in the distribution network due to its minimum loss, maximum efficiency and environmental impact. Moreover DG can supply base load power which improves the system stability, reliability and power quality. Among the different combined DG systems like solar with wind, tidal with geothermal and others, fuel cell with microturbine is the most economical due to fuel flexibility and inner relation between each other. The hybrid system can utilize exhaust fuel and heat from fuel cell to increase the system efficiency. This paper investigates combined model solid oxide fuel cell/microturbine generator (SOFC/MTG) hybrid system, in which the anode exhaust of SOFC contains reminder of fuel. The exhaust hot gas and waste fuel are mixed with fresh fuel and compressed air is burned inside the burner. The pressurized hot gas from the combustor is expanded through turbine driving the Permanent Magnet Synchronous Machine (PMSM). The governing schemes of combined SOFC/MTG (Fuel & air flow) are controlled by the DC link voltage and current. The generated power of MTG is converted to AC/DC/AC to combine with fuel cell and frequency conversion. The hybrid model of SOFC/MTG with power converter is developed in MATLAB/Simulink library and simulation result shows transient response of hybrid SOFC/MTG DG system.**

***Index Terms*—Distributed Generation, SOFC, Microturbine, Permanent Magnet Synchronous Machine (PMSM), Power Electronics Interfacing Circuit.**

I. INTRODUCTION

The electric power utilities, growth of technology, environmental impacts and emerging power markets are leading to increased interconnection of DG to the distribution networks. Besides offering environmental benefits, integration of modular generating units to distribution network may bring significant benefits such as increased reliability, loss reduction, load management and also the possibility of delaying the adjustment of transmission and distribution networks [1].

Among verity of DG source the fuel cell and microturbine show particular promise as they can operates on multiple fuel with low emissions, high efficiency and reliable. They are likely to become major source of DG in the future, the dynamic modelling is necessary to deal with issues in the system planning, operation and management. In particular, the development has been placed in the effective operations specifically operation issues in the provision of interconnected services or ancillary services under deregulation [4]. The combined model of SOFC/MTG power plant have a several significant advantage, such as, SOFC will operate at high temperature and its energy conversion efficiency is 56%, the overall efficiency reaches to 70% when it operated with CHP application[5].

There are several model of fuel cell and gas turbines are available in the literature survey i.e. the optimized hybrid SOFC/GT power plant based on internal reforming of fuel cell with radial centrifugal is presented in[2]. The department of heat and power engineering, Lund University in Sweden has conducting the theoretical studies of combined SOFC/GT system is analysed in Aspen Plus in[3], using Matlab in [6]. The simplified slow dynamic models for microturbine and fuel cell for standalone operation is performed in [4]. In addition, an integrated SOFC system defining appropriate control system for slow dynamics simulation. The hybrid SOFC/GT uses waste fuel and exhaust heat of fuel cell, using synchronous generator(SG) and the control parameter are speed(w) and output power is proposed in [5][12].

This paper presents the model of SOFC/MTG system, where it utilizes the exhaust heat of turbine as well as waste fuel of fuel cell in order to increase the system efficiency. The PMSM is used to generate the electrical power by the mechanical power of turbine. The high frequency AC power is converted to DC and then inverted back to AC using suitable converter. The control strategy of combined SOFC/MTG system includes the fuel and air flow controlled by reference DC link voltage and actual DC voltage. The fuel cell power is controlled by the DC link current in prescribed limit.

A Capstone microturbine generator (MTG) model 330 is a recuperative single stage radial flow compressor and turbine used in this work. These rotating components are mounted on a single shaft of a PMSM is supported by air bearings. The combined model of fuel cell and microturbine generation system composed of the following elements a turbo generator, fuel cell (SOFC) a power converter (AC/DC/AC), Fuel and air controller. The turbo generator includes compressor, heat exchanger, combustion chamber and turbine coupled to synchronous generator. The fuel cell includes, SOFC and suitable converter coupled to common DC bus.

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II. COMBINED MODEL OF FUEL CELL AND MICROTURBINE

The combined model of fuel cell and microturbine power plant simplified block diagram is shown in Fig.1. The design layout of combined power plant, first the air pressurized by the compressor and it is passed to the heat exchanger which uses the exhaust gas from the turbine to preheat. The pressurized preheated air enters to the fuel cell. The chemical reaction between fuel and oxidizer produces the electricity and the operating temperature of fuel cell is taken away. The anode exhausts of fuel cell contains reminder of fuel which is mixed with the cathode exhaust and catalytic oxidiser. This air is passed inside the burner with additional fuel burned to create high pressure gas. The mechanical power produced by the expansion of high temperature gas inside the turbine is converted to equivalent torque to drive the PMSM coupled to the shaft.

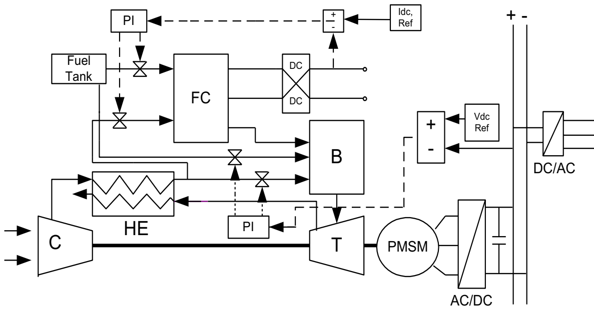


Fig.1 Schematic layout of SOFC/MTG hybrid system

The air flow $m'_{o(t)}$ and fuel flow rate $m'_{f(t)}$ are differed by the proportionality constant K, it is given as [10].

$$\dot{m}'_o(t) = k\, m'_f(t) \tag{1}$$

A. Compressor and heat exchanger model

The compressor is used to compress the air required for the fuel cell and turbine. The thermal power required to drive the compressor P_{th} can be calculated from the equation [12].

$$P_{th,c} = \frac{1}{\eta th,c}\left[m_{out,c} C_p \left(\dot{T}_{out,c} - T_{in,c}\right)\right] \tag{2}$$

During the compression of air, there is an increase in temperature and pressure of a gas. The input and output temperature of a gas is related with the following equation [12].

$$T_{out,c} = T_{in,c}\left[PRc\right]^{\left(\frac{\gamma-1}{\gamma}\right)} \tag{3}$$

Where, PRc is the pressure ratio of the compressor, $T_{in,c}$ and $T_{out,c}$ are the compressor input and output air temperature respectively, *'y'* is specific heat ratio of air.

The mechanical power Pm,c required to drive the compressor is given by[10][12].

$$\tau_c \frac{dP_{m,c}}{dt} = P_{th,c} - P_{m,c} \tag{4}$$

The compressor air mass flow rate $m'_{c(t)}$ and the fuel flow rate $m'_{f(t)}$ are given as input to the fuel cell and burner of turbine respectively. Based on energy mass balance theory with assumption of input and output mass flow rates of compressor remains unaltered are given as,

$$\dot{m}'_{in,c}(t) = m'_{o,c}(t) \tag{5}$$

The energy balance in the recuperator (heat exchanger) is written as[12],

$$\dot{m}'_{out,t}\, C_{p,gas}\left(T_{out,t} - T_{exhaust,he}\right) = m'_{out,c}\, C_{p,gas}\left(T_{out,he} - T_{out,c}\right) \tag{6}$$

Also by assuming the mass flow rate for input and output of heat exchanger remains same,

$$m'_{out,c} = m'_{out,he} \tag{7}$$

$$m'_{out,t} = m'_{exhaust,he} \tag{11}$$

B. Fuel cell model

Considered that, hydrogen is obtained from an internal reforming. A SOFC produces DC voltage directly by the reaction of hydrogen with oxygen and heat as a byproduct. The pressurized and preheated hydrogen is passed to the anode of fuel cell. The hydrogen ion moves across the electrolyte to the cathode, while the electrons flow through an external circuit [12].

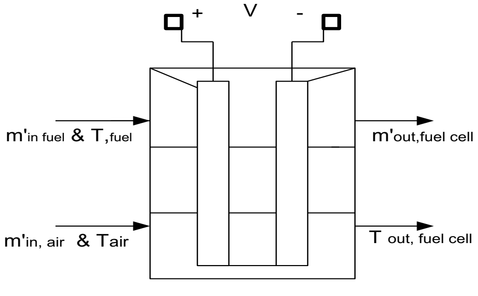


Fig.2 schematic of fuel cell

The schematic model of fuel cell is show in Fig.2, used in combined with microturbine. To explain the mathematical model of SOFC, two parts are considered, one is electrical model and another is thermal model.

$$V_{stack} = NE_0 - V_{act} - V_{con} - V_{ohm} \tag{12}$$

It is observed from the equation (12), the voltage loss in the fuel cell can cause by the activation polarization (V_{act}), the ohmic polarization (V_{ohm}) and concentration polarization (V_{con}) which are the resultant outcome of electrochemical reactions [9].

The output voltage of single fuel cell stack is obtained by the equation.

$$V_{stack} = NE_0 - V_{act} - \frac{RT}{2F}\ln\left[1 - \frac{I_{stack}}{AJ}\right] - I_{stack}r \tag{13}$$

Where E_0 is standard potential of fuel cell, N is the number of cell connected in series, T is the fuel cell temperature, *'r'* is a ohmic resistance, I_{stack} is stack current and V_{act} is the activation loss can be calculated with equation[12].

$$V_{act} = \left\{\frac{RT_F I_{stack}}{4FAJ_0} - \right\} \qquad \frac{I_{stack}}{A} \angle = J_0$$

$$V_{act} = \left\{\frac{RT_F}{2F} lan\left\{ \frac{I_{stack}}{AJ_0} \right\} + \frac{RT_F}{4F}\frac{I_{stack}}{AJ_0} - \right\} \qquad \frac{I_{stack}}{A} >= J_0 \tag{14}$$

The fuel cell current i.e. stack current can be obtained from the equation [12].

$$I_{stack} = \frac{2Fm'_{fuel}}{N * M_{H2}} \tag{15}$$

Where, m'_f is the mass flow rate of fuel cell. The output power of the fuel cell can be defined by the equation [9].

$$P_{e,f} = I_{stack} V_{stack} \tag{16}$$

But in realty, not all the hydrogen fuel is utilized in the fuel cell, it depends on the utilization factor. The fuel utilization factor is defined as ratio between the reacting fuel and input fuel [12].

$$U_z = \left[\left(\frac{I_{stack} * N}{2F}\right) * \left(\frac{M_{H2}}{m'_{fuel flow}}\right)\right] \tag{17}$$

The thermal model of fuel cell can be described as the following first order equation [12][13].

$$\frac{dT}{dt} = \frac{1}{C_{fc} m_{fc}}\left[m'_f \Delta H_f - P_{e,f} - A_{ex} h_{ex}\left(T - T_{amb}\right) - m'_{air}\left(T - T_{air}\right)\right] \tag{18}$$

The generated temperature inside fuel cell due to exothermal reaction is recovered and is passed to the combustion chamber of the turbine.

C. Burner and turbine

The burner is used to burn the waste fuel of fuel cell as well as additional fresh fuel mixed with air. This is done so to run the shaft at constant speed for load variation on the system. The mathematical mode of burner is denoted as first order equation [12][13],

$$\begin{aligned}\frac{dT_b}{dt} = \frac{1}{C_b m_b}&\left[\left(m'_{fuel} + \left(1 - Uz\right) m_{fuel,fc}\right) LHVf * \eta_b\right] \\ &- \left[m'_{out,b} C_{p,air}\left(T_{out,b} - T_{fuel}\right)\right] \\ &- \left[m'_{waste,fuel} {}^{*}C_{p,gas}\left(T_{out,b} - T_{wastefuel}\right)\right]\end{aligned} \tag{19}$$

By considering the mass balance theory, the output mass flow rate out of burner is,

$$\dot{m}'_{out,b} = m'_{fuel} + m'_{air} + m'_{out,fc} \tag{20}$$

The output temperature of the turbine has the relationship with the pressure ratio of the turbine [12][13].

$$\frac{T_{out,t}}{T_{out,b}} = \left[PR_T\right]^{\left(\frac{\gamma - 1}{\gamma}\right)} \tag{21}$$

The thermal power produced by the turbine can be calculated based on the algebraic equation,

$$P_{th,t} = \eta_{th,t} m'_{out,t} C_{p,gas}(T_{out,t} - T_{out,b}) \tag{23}$$

Converting the thermal power in to mechanical power can be expressed by the first order equation [13].

$$\tau_t \frac{dP_{m,t}}{dt} = P_{th,t} - P_{m,t} \tag{24}$$

The output mechanical power from the gas turbine is the difference between mechanical power produced by the gas turbine and power consumed by the compressor.

$$P_{m,gt} = P_{m,t} - P_{m,c} \tag{25}$$

III. PERMANENT MAGNET SYNCHRONOUS MACHINE

The electrical and mechanical part of the PMSM with non-salient rotor is represented by a second order state space model. The model assumes that the flux established by the permanent magnet in the stator is sinusoidal, which implies that electromotive forces are sinusoidal. The following equation expresses in the rotor reference frame (dq frame) are used to implement PMSM [14].

A. Electrical System,

$$\frac{d}{dt} i_d = \frac{1}{L_d} v_d - \frac{R}{L_d} i_d + \frac{L_q}{L_d} p\omega_r i_q \tag{26}$$

$$\frac{d}{dt} i_q = \frac{1}{L_q} v_q - \frac{R}{L_q} i_q + \frac{L_d}{L_q} p\omega_r i_d - \frac{\lambda p\omega_r}{L_q} \tag{27}$$

$$T_e = 1.5p\left(\lambda i_q + \left(L_d - L_q\right) i_q i_d\right) \tag{28}$$

B. Mechanical System,

$$\frac{d}{dt}\omega r = \frac{1}{J}\left(T_e - F\omega_r - T_M\right) \tag{29}$$

$$\frac{d}{dt}\theta = \omega_r \tag{30}$$

Where, Lq, Ld : q and d axis inductance
R: Stator resistance
iq, id : q and d axis currents
Vq, Vd: q and d axis voltages
P: Number of poles
Te: Electromagnetic torque
F: Viscous friction of rotor and load
Tm: Mechanical torque

IV. DESIGN OF CONTROLLER

The control system plays an important role for reliable operation of the system under all circumstances. It must be able to respond quickly and accurately for the change in the external system. In a combined model of fuel cell and microturbine DG system, there are two possibilities of controller [11]. One is fuel and air control of the burner to meet the power demand and to maintain the constant DC link voltage irrespective of load variation. Second is fuel control for the fuel cell by the DC current reference.

A. Fuel and air controller of burner,

When the loads demand power changes, the microturbine will change its out power by controlling the fuel and air valve of burner. The air flow rate has a linear relation with fuel and air flow rates. As the DC link voltage changes will change the fuel flow and air flow ratio correspondingly. This is reason behind the DC link voltage is used to control the burner value as shown in Fig.3. This control system keeps the DC link and AC voltage constant by controlling the fuel flow to burner.

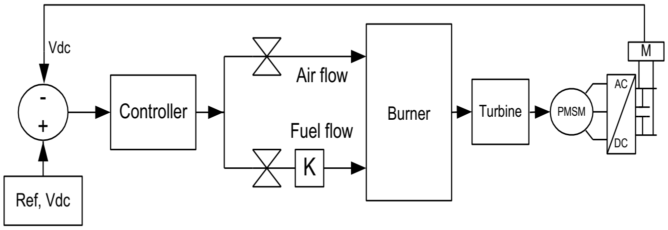


Fig.3. Fuel and air control of burner

B. Fuel flow control of fuel cell,

The fuel cell output voltage is regulated by the DC link current I_{dc} which control the fuel flow ratio within a permissible limit as shown in Fig.4. Based on the fuel cell model the important point in controlling the output voltage by fuel and air control it is possible within comparing the reference DC current and actual DC current.

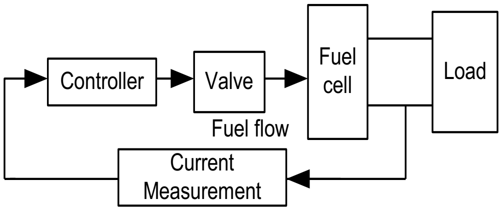


Fig. 4 Fuel flow control of fuel cell

V. POWER ELECTRONICS INTERFACING CIRCUIT

For a single shaft microturbine the power converter converts are used to convert high frequency AC power produced by the PMSM into usable electrical power. The power conditioning circuit is one of the critical components in single shaft microturbine design and represents significant challenge in design. Specially, in matching turbine output to required load. Power conditioning unit consist of a three phase diode rectifier, a voltage source inverter (VSI) and LC filter are used. A 166 Hz, voltage source feeds a 50Hz, 50kW load through a AC/DC/AC converter. The 480V, 166Hz AC power is first rectified by six pulse diode bridge rectifier and filtered. DC link voltage is given to an IGBT two level inverter generating 50Hz. The IGBT inverter uses Pulse Width Modulation (PWM) with 2 kHz carrier frequency.

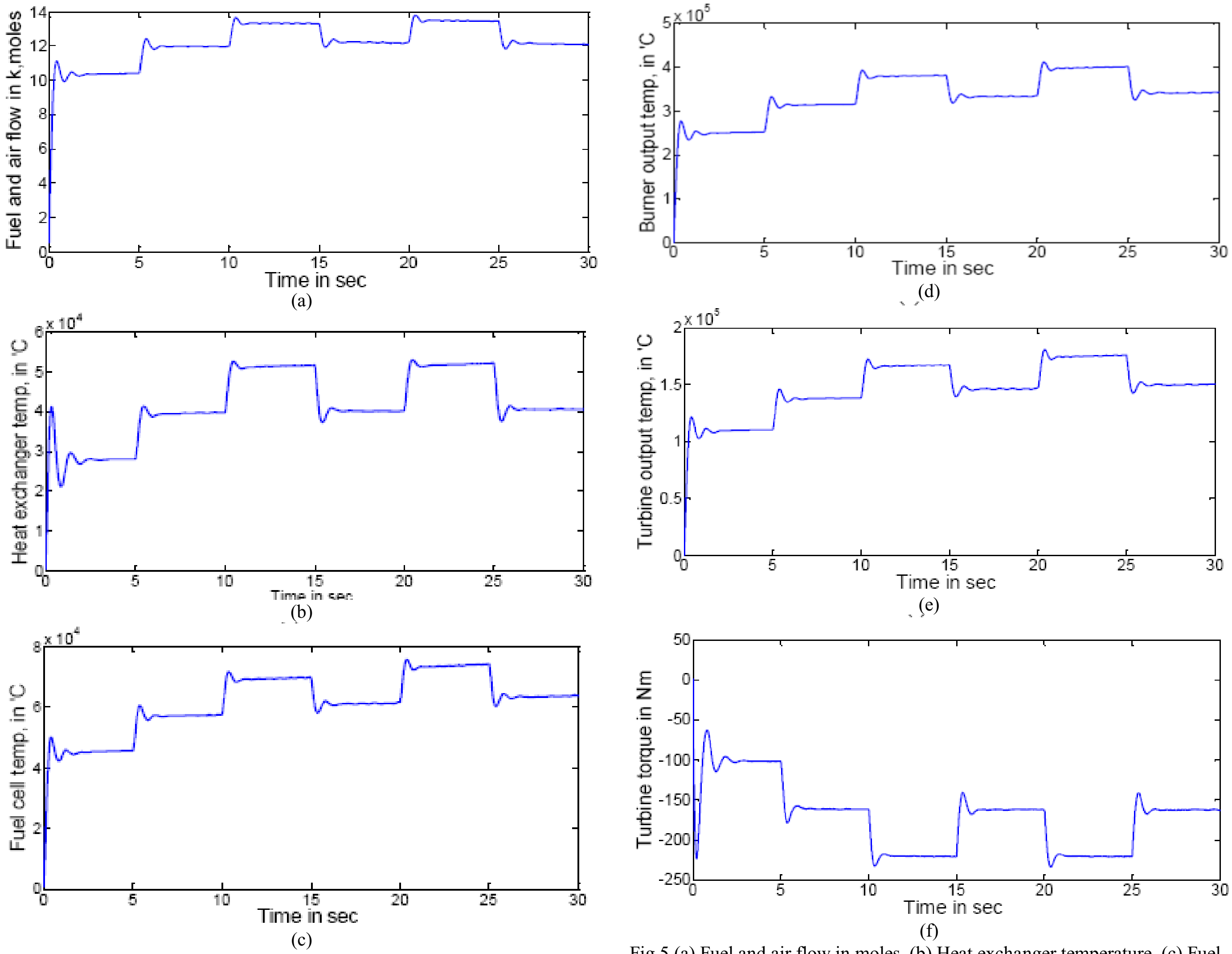
The voltage is regulated at 1p.u.(480 Vrms) by a PI voltage regulator using abc to dq and dq to abc transformation. The first output voltage regulator is a vector containing the three modulation signals used by the PWM generator to generate six IGBT pulses.

VI. RESULTS AND DISCUSSION

The hybrid fuel cell and microturbine based DG system is assumed to be running at rated speed (i.e. start up and shut down of the combined system is not considered). Initially the combined SOFC/MTG system is driving an electrical load of 10kW. The load varies at an interval of five seconds, i.e. at t=5, 10 & 20 secs the load is increased by 10kW and at t=15 & 25 secs the load is decreased by 10kW respectively. This variation in load is done to obtain the performance of hybrid DG system.

The fuel and air flow ratio of a burner is controlled by the reference DC link voltage and actual DC voltage. The fuel and air flow have a linear relation with the variation in the DC link voltage. As the DC link voltage decreases with increase in load, the fuel and air flow ratio is also increased in order to keep the DC voltage constant, and vice versa. The variation of the fuel and air flow with respect to variation of load on the DG system is shown in Fig.5 (a).

The heat exchanger for microturbine is mainly used to increase the system efficiency by recovering the exhaust heat of the turbine. Due to variation of the load on the DG system the variation in the heat exchanger temperature is shown in Fig.5 (b). The pre-heated air of heat exchanger is passed through the fuel cell and to recover the heat generated inside fuel cell due to exothermal reaction, thus fuel cell efficiency increases. The recovered temperature of fuel cell is shown in Fig.5(c).



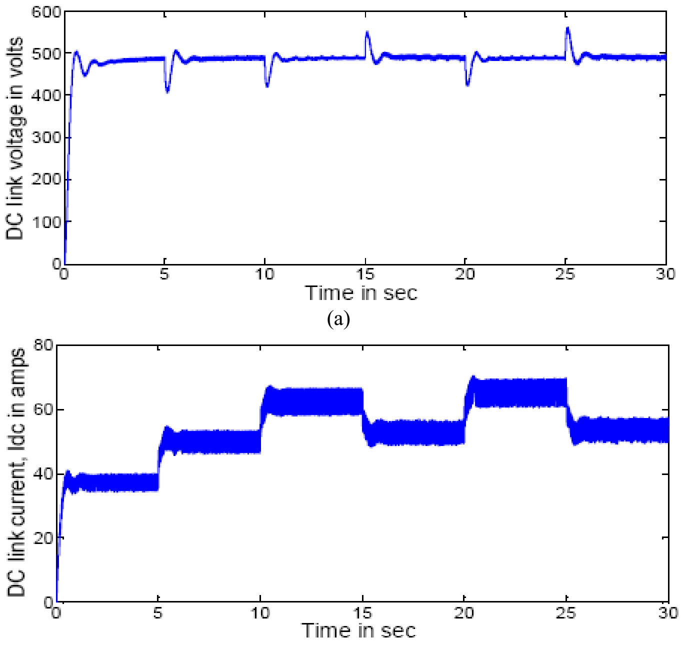
(a) (b) (c) (d) (e) (f)

Fig.5 (a) Fuel and air flow in moles, (b) Heat exchanger temperature, (c) Fuel cell temperature, (d) Burner temperature, (e) Turbine output temperature, (f) Turbine torque.

The recovered temperature of fuel cell and additional amount of fuel with air are burned inside the burner to increase the temperature and pressure further, the temperature output of burner is shown in Fig.5 (d). The pressurized hot air coming out of the burner is passed through the turbine to convert the potential energy into mechanical energy. While doing so, there is a drop in pressure and temperature of gas coming out of the turbine.

The variation of temperature of gas coming out of turbine depends on the load on the system as shown in Fig.5 (e). The torque developed due to rotation of turbine depends on the load intensity. As the load increases the torque developed by the turbine also increases and it is vice versa. The negative torque is required for the generator mode of operation of PMSM due to different load on PMSM is shown in Fig. 5(f).

The DC link voltage V_{dc} is used to control the fuel and air flow for a burner, i.e. by comparing the DC link voltage of a rectifier and reference DC voltage. While doing so, the DC link voltage is kept constant even for variation in the electrical load. The constant DC link voltage irrespective of load variation is shown in Fig.6 (a). The DC link current I_{dc} varies as the load varies as shown in Fig. 6(b).



(a) (b)

Fig. 6 (a) DC link voltage in volts, (b) DC link current in amps

Since it is single shaft microturbine, a part of power is transmitted to drive the compressor. The required compressor power depends on the air flow control and turbine power as shown in Fig.7 (a). The shaft mechanical power is subtraction of compressor power and internal losses of the combined system, the variation of shaft power is shown in Fig.7 (b). In order to meet the power demand and to keep the DC link voltage constant the turbine speed varied. The variation of turbine speed with variation of load is as shown in Fig.7(c).

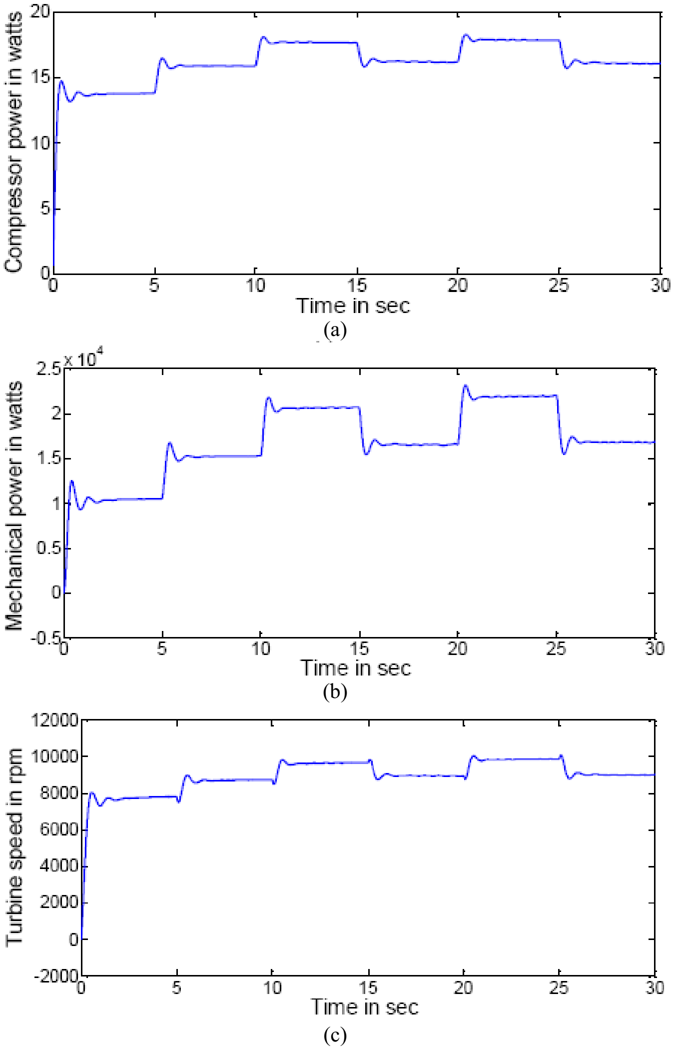


Fig.7. (a) Compressor power in watts, (b) Mechanical power in watts, (c) Turbine speed in rpm

The modulation index of voltage source inverter (VSI) is shown in Fig. 8(a) and the fuel cell terminal DC voltage V_{dc} is shown in Fig. 8(b). The fuel cell output voltage is appeared after the time t =10 sec, this is due to the slow response of fuel cell.

The rms value of load voltage in per unit varies due to variation of load at an interval of every five seconds is shown in Fig. 9(a). The load voltage in per unit is shown in Fig.9 (b). The dip and rise of load voltage during every interval of load variation and it is controlled within small amount of time as shown in Fig.9(c). The maximum sag time varies between half to one seconds as shown, the generated sinusoidal voltage is shown in Fig.9 (d).

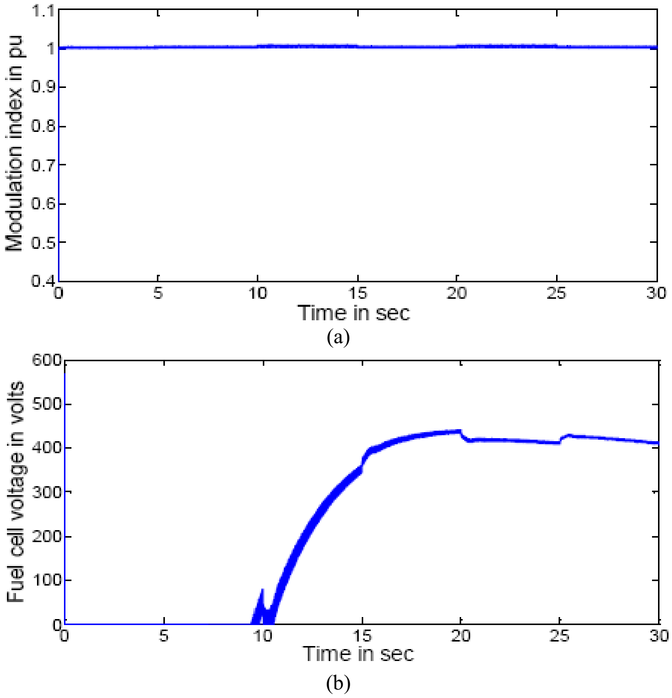
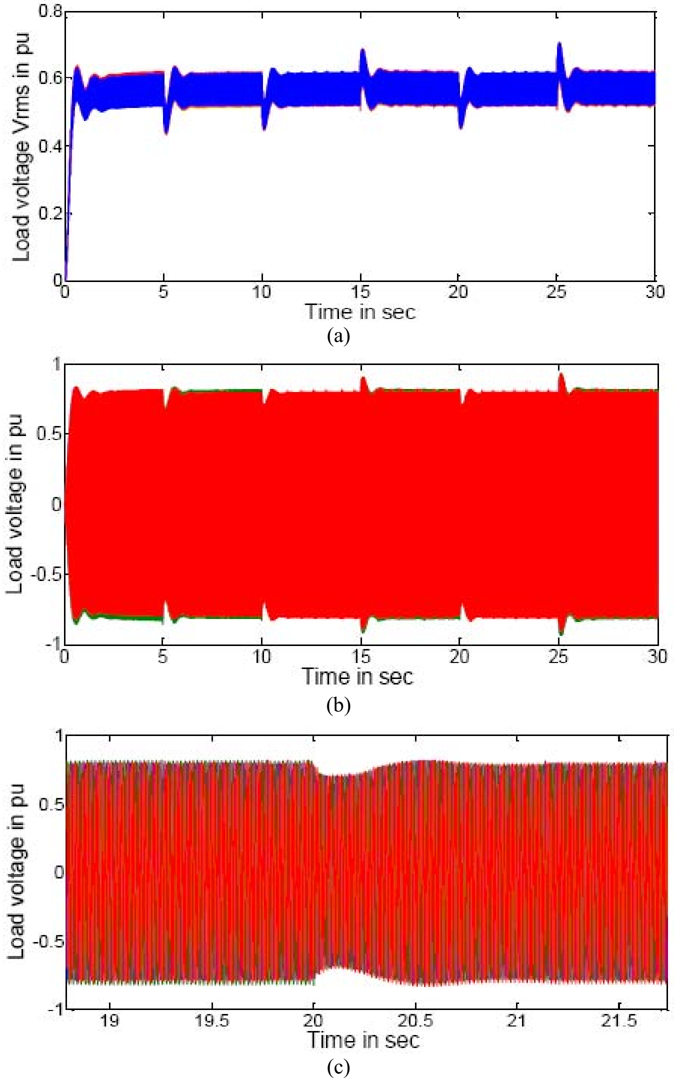
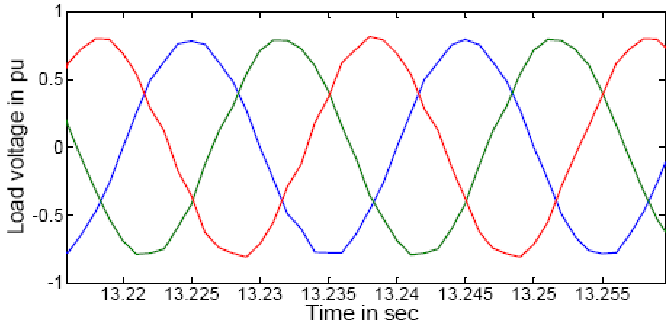


Fig.8 (a) Modulation index (b) Fuel cell output voltage



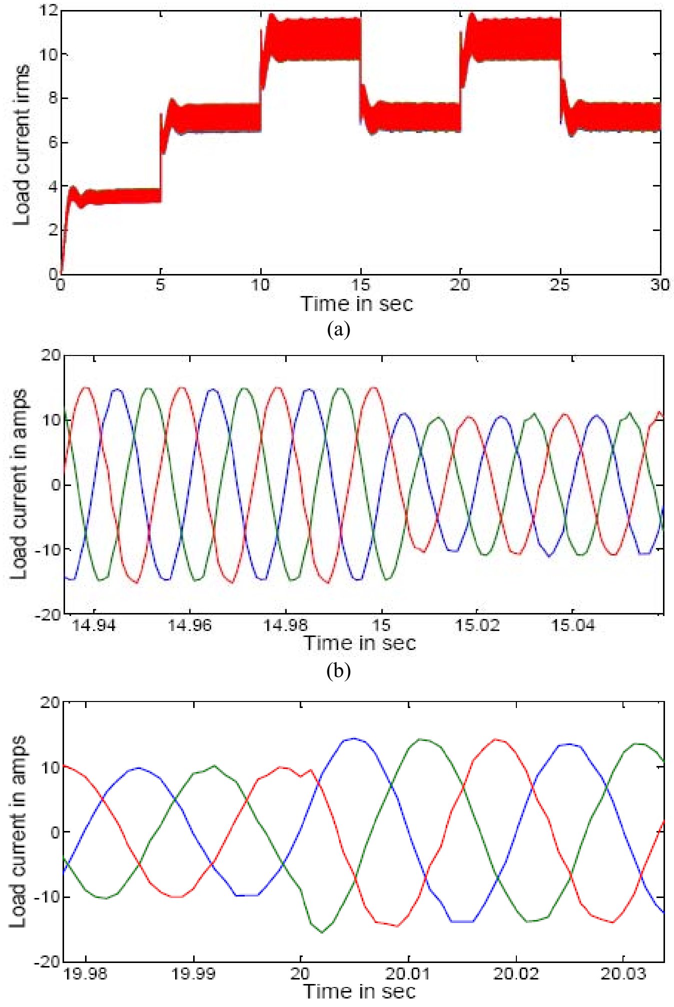


(c)

Fig.9 (a) Load voltage Vrms in pu, (b) Load voltage in pu, (c) Variation of load voltage in pu, (d) Sinusoidal voltage in pu

The variation in the load current I_{rms} at every five second interval of time is shown in Fig.10 (a) and the variation of sinusoidal load current at t=15 sec and at t= 20 sec are shown in Fig.10(b) and Fig.10(c) respectively.

The active and reactive powers are the important component of the DG system for the load sharing. Since DG system is operating for isolated mode and driving a purely resistive load. Thus only the active power will appears and reactive power is almost zero and the power generation is only the contribution of DG system as shown in Fig.11.



(a)

(b)

(c)

Fig10. (a) Load current Irms (b) Load current in amps (c) Variation of load current in amps

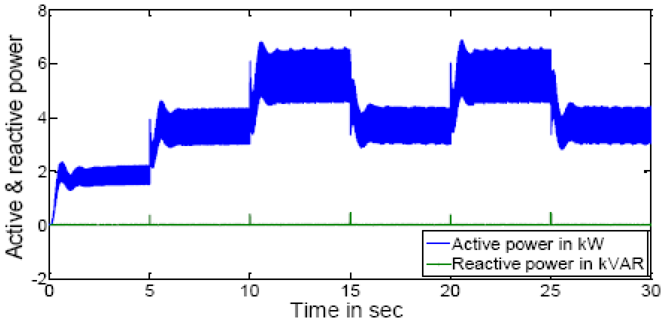


Fig.11 Active power and reactive power kVAR

VII. CONCLUSION

The combined model of SOFC/MTG based generation system has been modeled and simulated for the isolated mode of operation. The combined model utilizes the waste fuel of fuel cell and exhaust heat are recovered in the microturbine in order to increase the overall system efficiency. The MTG system uses the PMSM for the electrical power generation and the control strategy of fuel and air are performed with DC link current and DC link voltage respectively. The future scope of this work is to combine the fuel cell and microturbine electrical power at common DC point and operate with grid integration using suitable power electronics converters.

VIII. REFERENCES

[1] P. P. Barker, and R. W. de Mello "Determining the impact of distributed generation on power systems: Part 1—Radial distribution systems," in Proc. *IEEE Power Eng. Soc. Summer Meeting,* vol. 3, 2000, pp. 1645–1656.

[2] F. Calise, M. Denticed, Accadiaa, L.Vanoli, M. R. Spakovsky, "Full Load Synthesis/Design Optimization of a Hybrid SOFC–GT Power Plant", *18th International Conference on Energy Cost, optimization, simulation and evaluation of Energy System*, Energy Vol.32, issue.4, pp. 446–458, 2007.

[3] J. Palsson, A. Selimovic, L Sjunnesson, "Combined Solid Oxide Fuel cell and Gas Turbine Systems for Efficient Power and Heat Generation" *Journal of Power Sources*, Vol.86, Issue.1-2, pp.442-448, March 2000.

[4] Y. Zhu and K. Tomsovic, "Development Of Models For Analyzing The Load-Following Performance of Microturbines And Fuel Cells," *Journal of Electric Power Systems Research,* vol. 62, pp. 1-11, 2002.

[5] S. Chan, H. Ho, Y. Tian, "Modelling for part load operation of solid oxide fuel cell–gas turbine hybrid power plant*" Journal Power Sources*, Vol. 114, pp.213-227.2003.

[6] M. Xu, C. Wang, Y. Qiu, B. Lu, F. C. Lee, "Control and Simulation for Hybrid Solid Oxide Fuel Cell Power Systems," *IEEE 21st International Conference on Applied Power Electronics, Centre for Power Electronics System*, pp.7, 13-19 March 2006.

[7] M. Fleming, A. Hiskens, "Dynamics of a Microgrid Supplied by Solid Oxide Fuel Cells", *IEEE 2007 IREP Symposium Charleston, South Carolina*, USA, Aug 2007.

[8] H. J. Nern, H. Kreshman, F. Fischer, and H. A. N. Eldin, "Modelling of the long term dynamic performance of a gas turbo generator set," in *Proc. IEEE Conf. Control Applications*, vol. 1, Aug. 1994, pp. 491–496.

[9] C. Wang, and M. H. Nehrir, "A Physically Based Dynamic Model for Solid Oxide Fuel Cells" *IEEE Transactions on Energy Conversion,* Vol. 22, NO. 4, pp.887-897, Dec 2007.

[10] P. Li, P. Degobert, B. Franvois, B. Robyns, "Modeling and Control of a as Micro Turbine Generator by Using a Causal Ordering Graph," IMACS-2006 Multiconference, Computational Engineering in Systems Applications"(CESA), 2006.

[11] Xunwei Yu, Zhenhua Jiang, and Atideh Abbasi "Dynamic Modelling and Control Design of Microturbine Distributed Generation System"

IEEE International Conference on Electric Machine and Drives IEMDC'09, pp.1239-1243, Miami, FL, 3-6 May 2009.

[12] Atideh Abbasi, and Zhenhua Jiang "Multidisciplinary Modelling and Simulation of a Fuel Cell/Gas Turbine Hybrid Power System*" IEEE Power and Energy Society General Meeting. PES'09*, Calgary,AB, pp.1-7, 26-30 July 2009.

[13] R E Sangatong and G V Wylen "Introduction to Thermodynamics Classical and Staticals" New York; Johan Wiley & Sons, 1982.

[14] J B Ahn, Y H Jeong, D H Kang and J H Park "Development of high speed PMSM for Distributed Generation Using Microturbine" *IEEE 30th Annual Conference on Industrial Electronics Society*-IECON-2004, Vol.3, pp.2879-2882,2004.

IX. BIBLIOGRAPHY.

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