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Control and Simulation of Hybrid Micro turbine for Smart Grid System

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Abstract

This paper presents a simulation model of the electric part of a grid connected micro turbine (MT). Analyses of load following behaviour of micro turbine as distribution energy resource have been performed the model representation of the main components of the electric system that are the permanent magnet synchronous machine, fuel control temperature control and speed control. The micro turbine is controlled so that the energy is exchanged with unity displacement factor. The simulation results obtained with the model using SimPower Systems software the simulation model is used to analyze the micro turbine the model is built from the dynamics of each part with their interconnections. This simplified model is a useful tool for studying the various operational aspects of micro turbines. The performance of developed model is studied by connecting it to an isolated load.
Keywords: Distributed Generation, Fuel Control, Microturbine, Permanent Magnet Synchronous Machine, Speed Control, Temperature Control

I. INTRODUCTION

At present, the bulk of the world's electricity is generated in central power stations. This approach, one of economy of size, generates electricity in large power stations and delivers it to load centers via an extensive network of transmission and distribution lines. An alternative approach, that of distributed generation, which can be described as economy of mass production, generates electricity by many, smaller power stations located near the load centers. One such form of small power generation system is that based on microturbines. A major advantage of a microturbine is its ability to provide firm power, provided that it is kept supplied with fuel. The primary source of fuel is currently based on fossil fuels. However, gas turbines have the ability to accept various fuels, such as those based on liquid or gas. Microturbines are small combustion turbines that produce between 25 kW and 500 kW of power.

Most microturbines are single-stage, radial flow devices with high rotating speeds of 90 000 to 120 000 revolutions per minute (rpm). Distributed generation (DG), which includes fuel cells, wind turbine generators, photovoltaic cells and micro turbines with the distribution network. The micro turbine has a high potential of Penetration especially to its flexibility. However its grid connected performance must be analyzed carefully and its impacts quantified precisely. This paper deals with the modeling and simulation of a microturbine generation (MTG) system comprising of a permanent magnet synchronous generator driven by a micro gas turbine, suitable for stand-alone as well as grid connected operation. Microturbines are small gas turbines which burn gaseous or liquid fuels to create a high energy gas stream that turns an electrical generator. Other applications include remote power, combined heat and power (CHP) systems by utilizing the heat contained in the exhaust gases to supply thermal energy needs in a building or Industrial process [2]-[3].

In MTG system, PMSM does not start as a generator. So, the PMSM start as a motor and it drives the microturbine. When the micro-turbine gets the ignition speed then the PMSM runs as a generator. The configuration of MTG system is a three phase diode rectifier, a voltage source inverter (VSI) via DC link and with a filter. The MTG system eliminates the start up inverter and uses back to back voltage source converter in the place of diode rectifier The converter controllers are built on the *dq* synchronous Frame. The converter controller models are implemented in the MATLAB / SIMULINK using SIMPOWER Systems library. The performance of the implemented MTG model with new converter control has been studied with an isolated load. The impact of RL filter without and with reactive power injection has also been studied on the load end side voltage and current waveforms.

II. MODEL DESCRIPTION

A. Microturbine

The basic components of a microturbine generation system are the compressor, turbine, recuperator, high speed generator and power electronics interfacing. Fig. 1 shows the schematic diagram of a single-shaft microturbine based generation system. Microturbines, like large gas turbines, operate based on the thermodynamic cycle known as the Brayton cycle [4]. In this cycle, the inlet air is compressed in a radial (or centrifugal) compressor. The compressed air is mixed with fuel in the combustor and burned. The hot combustion gas is then expanded in the turbine section, producing rotating.

Mechanical power to drive the compressor and the electric generator, mounted on the same shaft (single-shaft design). In a typical microturbine, an air to gas heat exchanger (called a recuperator) is added to increase the overall efficiency. The recuperator uses the heat energy available in the turbines hot Exhaust gas to preheat the compressed air before the Compressed air goes into the combustion chamber thereby reducing the fuel needed during the combustion process.

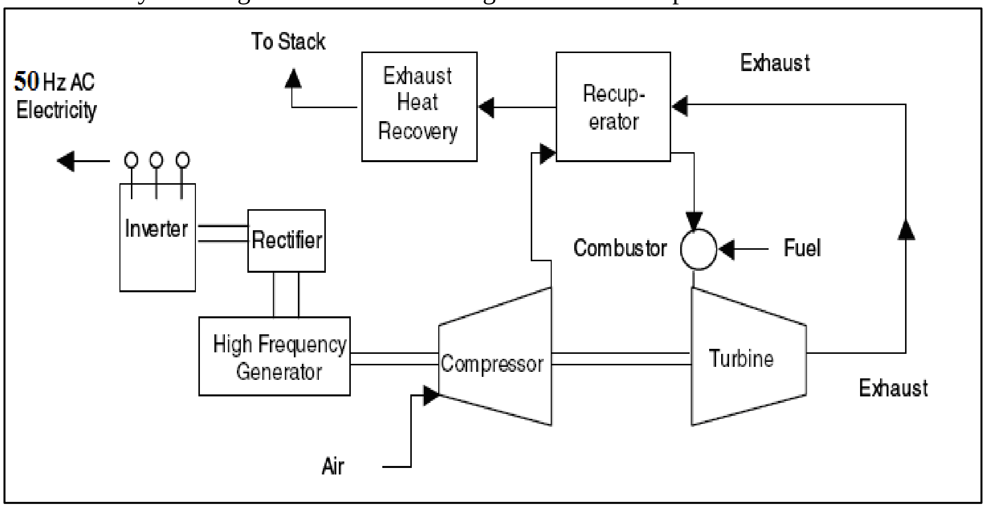

Fig. 1: Basic component of Microturbine

B. Turbo Compressor

The basic components of a microturbine are the compressor, turbine generator, and recuperator. The heart of the microturbine is the compressor-turbine package, which is commonly mounted on a single shaft along with the electric generator. Two bearings support the Microturbines Single shaft. The single moving part of the one-shaft design has the potential for reducing maintenance needs and enhancing overall reliability. There are also two-shaft versions, in which the turbine on the first shaft directly drives the compressor while a power turbine on the second shaft drives a gearbox and conventional electrical generator producing 50 Hz power. The two shaft design features more moving parts but does not require complicated power electronics to convert high frequency AC power output to 50 Hz. Moderate to large-size gas turbines use multi-stage axial flow turbines and compressors, in which the gas flows along the axis of the shaft and is compressed and expanded in multiple stages. However, micro turbine turbo machinery is based on single-stage radial flow compressors and turbines. Radial flow turbo machinery handles the small volumetric flows of air and combustion products with reasonably high component efficiency.1 Large-size axial flow turbines and compressors are typically more efficient than radial flow components. However, in the size range of microturbines -- 0.5 to 5 lbs/second of Airgas flow -- radial flow components offer minimum surface and end wall losses and provide the highest efficiency. In micro turbines, the turbo compressor shaft generally turns at high rotational speed, about96, 000 rpm in the case of a 30 kW machine and about 80,000 rpm.

C. Generator

The microturbine produces electrical power either via a high-speed generator turning on the single turbo-compressor shaft or with a separate power turbine driving a gearbox and conventional 3,600 rpm generator. The high-speed generator of the single-shaft design employs permanent magnet (typically Samarium-Cobalt) alternator, and requires that the high frequency output be converted to 50 Hz for general use. This power conditioning involves rectifying the high frequency AC to DC, and then inverting the DC to 50 Hz AC. Power conversion comes with an efficiency penalty (approximately five percent).To start-up a single shaft design, the generator acts as a motor turning the turbo-compressor shaft until sufficient rpm is reached to start the combustor. Full start-up requires several minutes. If the system is operating independent of the grid (black starting), a power storage unit (typically battery UPS) is used to power the generator for start-up.

D. Recuperators

Recuperators are heat exchangers that use the hot turbine exhaust gas (typically around 1,200ºF)to preheat the compressed air (typically around 300ºF) going into the combustor, thereby reducing the fuel needed to heat the compressed air to turbine inlet temperature. Depending on microturbine operating parameters, recuperators can more than double machine efficiency. However, since there is increased pressure drop in both the compressed air and turbine exhaust sides of the recuperator, power output typically declines 10 to 15% from that attainable without the recuperator. Recuperators also lower the temperature of the micro turbine exhaust, reducing the micro turbine's effectiveness in CHP applications.

III. MICROTURBINE SYSTEM MODELING

In this section a model for dynamic analysis of a microturbine generation system is developed.. The model is suitable for transient simulation and analysis and the final model can be used in a distribution network to the microturbine system on the distribution network stability and the effect of network transients on the microturbine stability. In order to model a microturbine system, major parts are considered high speed gas turbine, high speed permanent magnet generator, power conditioning unit which itself consist of a rectifier and an inverter and the final part is load connected to microturbine terminal.

A. *Fuel control*

The fuel system consists of the fuel valve and actuator. The fuel flow from the fuel system results from the inertia of the fuel system actuator and of the valve position whose equations are given below. The valve positioned transfer function is :

$$\sum_1 = \frac{K_v}{T_{vS} + c} F_d$$

And the fuel system actuator transfer function is :

$$Wf = \frac{K_f}{T_{vS} + c} E_l$$

K. and (Kf) is the valve positioner (fuel system actuator) gain, T, ,Tf are the valve positioner and fuel system actuator time constants, c is a constant, Fd and El are the input and output, respectively, of the valve positioner and Wf is the fuel demand signal in p.u. The output of the LVG, Vce, represents the least amount of fuel needed for that particular operating point and is an input to the fuel system. Another input to the fuel system is the per unit turbine speed N (limited by the acceleration control). The per-unit value for Ve corresponds directly to the per-unit value of the mechanical power from the turbine in steady state. The fuel flow control as a function of Ve

B. *Temperature Control*

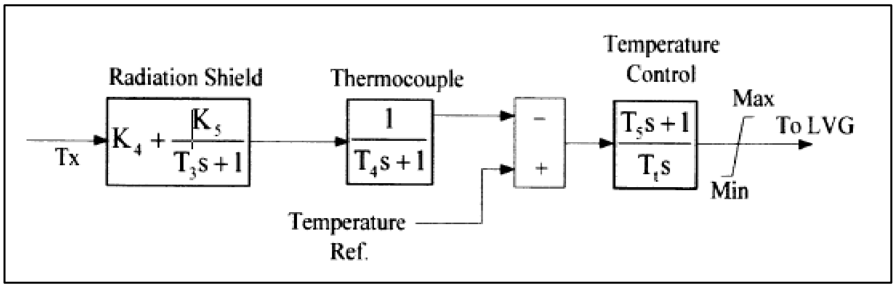

Fig. 2: temperature control of microturbine

Temperature control is the limiting gas turbine output power at a predetermined firing temperature, independent of variation in ambient temperature or fuel characteristics. The fuel burned in the combustor results in turbine torque and in exhaust gas temperature. The exhaust temperature is measured using a series of thermocouples incorporating radiation shields as shown in the block diagram of the temperature controller T, is the temperature controller integration rate and T3, T4 are time constants associated with the radiation shield and thermocouple, respectively. K4 and K5 are constants associated with the radiation shield and T5 is a constant associated with the temperature controller. The output from the thermocouple is compared with a reference temperature, which is normally higher than the thermocouple output. This forces the output of the temperature control to stay on the maximum limit permitting the dominance of speed control through the LVG (Fig.2). When the thermocouple output exceeds the reference temperature, the difference becomes negative, and the temperature control output starts decreasing. When the temperature control output signal (Fig. 2) becomes lower than the speed controller output, the former value will pass through the LVG to limit the turbine's output, and the turbine operates on temperature control. The input to the temperature controller is the exhaust temperature (TX) and the output is the temperature control signal to the LVG

C. *Speed Control*

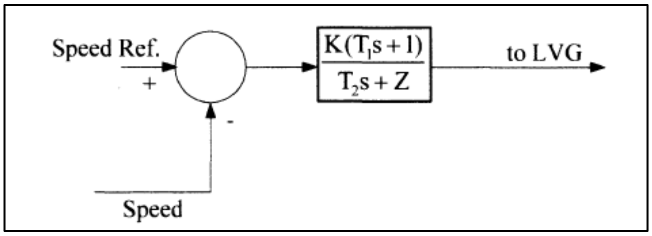

Fig. 3: speed control of microturbine

The speed control operates on the speed error formed between a reference (one per-unit) speed and the MTG system rotor speed. It is the primary means of control for the microturbine under part load conditions. Speed control is usually modelled by using a lead-lag transfer function or by a PID controller In this paper a lead lag transfer function has been used to represent the speed controller, as shown in Fig. 3. In this figure K is the controller gain, T1 (T2) is the governor lead (lag) time constant, and Z is a constant representing the governor mode (droop or isochronous). A droop governor is a straight proportional speed controller in which the output is proportional to the speed error. An isochronous speed controller is a proportional-plus-reset speed controller in which the rate of change of the output is proportional to the speed error. Acceleration control is used primarily during turbine started limit the rate of the rotor acceleration prior to reaching operating speed. If the operating speed of the system is closer to its rated speed the acceleration control could be eliminated in the modeling.

D. *Permanent Magnet Synchronous Machine*

The model adopted for the generator is a 2 pole permanent magnet synchronous machine (PMSG) with non salient rotor the machine output is 30kw and is terminal line voltage is 480v the electrical and mechanical parts of the machine are each represented by the second order state space model. The model assumes that flux established by the PMSG in the stator is sinusoidal. The development of advanced magnetic materials, power electronics and digital control systems are making permanent magnet (PM) machine as an interesting solution for a wide range of applications. The advantages of PMSM compared to other AC machines are its simple structure, high-energy efficiency, reliable operation, high power density and Possibility of super high speed operation. Recent important applications of permanent magnet Energy efficiency, reliable operation, high power density and Possibility of super high speed operation. Recent important applications of permanent magnet synchronous machine are in the area of distributed generation, mainly in wind and Distributed Generation microturbine generation systems. An advantage of a high speed generator is that the size of the machine decreases almost in directly proportion to the increase in speed, leading to a very small unit. Super high speed PMSM is an important component of single shaft MTG system. The mathematical model of a PMSM is similar to that of the wound rotor synchronous machine.

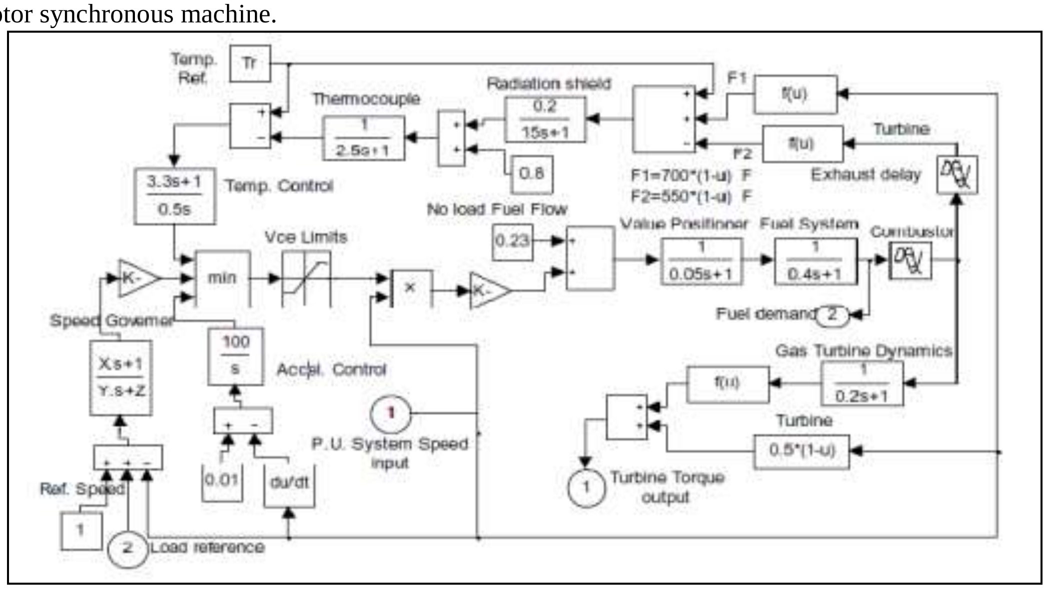

Fig. 4: Simulink implementation of microturbine

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

$$\frac{d}{dt} i_q = \frac{1}{L_q} V_q - \frac{R}{L_q} i_q + \frac{L_d}{L_d} p \omega_r i_q - \frac{\lambda p \omega_r}{L_q}$$

$$Te = 1.5p(\lambda i_q + (L_d - L_q)i_d i_q)$$

Mechanical equation

$$\frac{d}{dt}\omega_r = \frac{1}{J}(T_e - F\omega_r - T_m)$$

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

Where

Lq, Ld : q and d axis inductances
R : Resistance of the stator windings
iq, id : q and d axis currents
vq, vd : q and d axis voltages
ωr: Angular velocity of the rotor
λ: Flux induced by the permanent magnets in the Stator windings.
P: Number of pole pairs
Te: Electromagnetic torque
j: Combined inertia of rotor and load
F: Combined viscous friction of rotor and
Te: electromagnetic torque
Θ: rotor angle position

IV. CONVERTOR CONTROL

The converter is IGBT / Diode based 3-phase circuit. It is available in the MATLAB /SIMULINK SIMPOWER systems library. The converter controlling is a critical component in the single shaft micro-turbine design and represents significant design challenges, specifically in matching turbine output to the required load. The configuration used in this paper, this topology allows bidirectional power flow between the PMSM to DC source and Load, and hence no separate start up arrangement is required. During the starting of PMSM, acts as motor and draws power from external source to bring the turbine to ignition speed. In this period the machine side converter acts as inverter. Once the microturbine gets the ignition speed, the PMSM will be run as a generator. In this period the machine side converter acts as rectifier.

A. Power Electronics Controller

Power electronics (rectifier-inverter) interface is used to control the output power of the MTG system by controlling the inverter output voltage and angle as well as maintaining the frequency at a prescribed level. This is realized by converting the AC power output from the generator to DC and then to 50 Hz

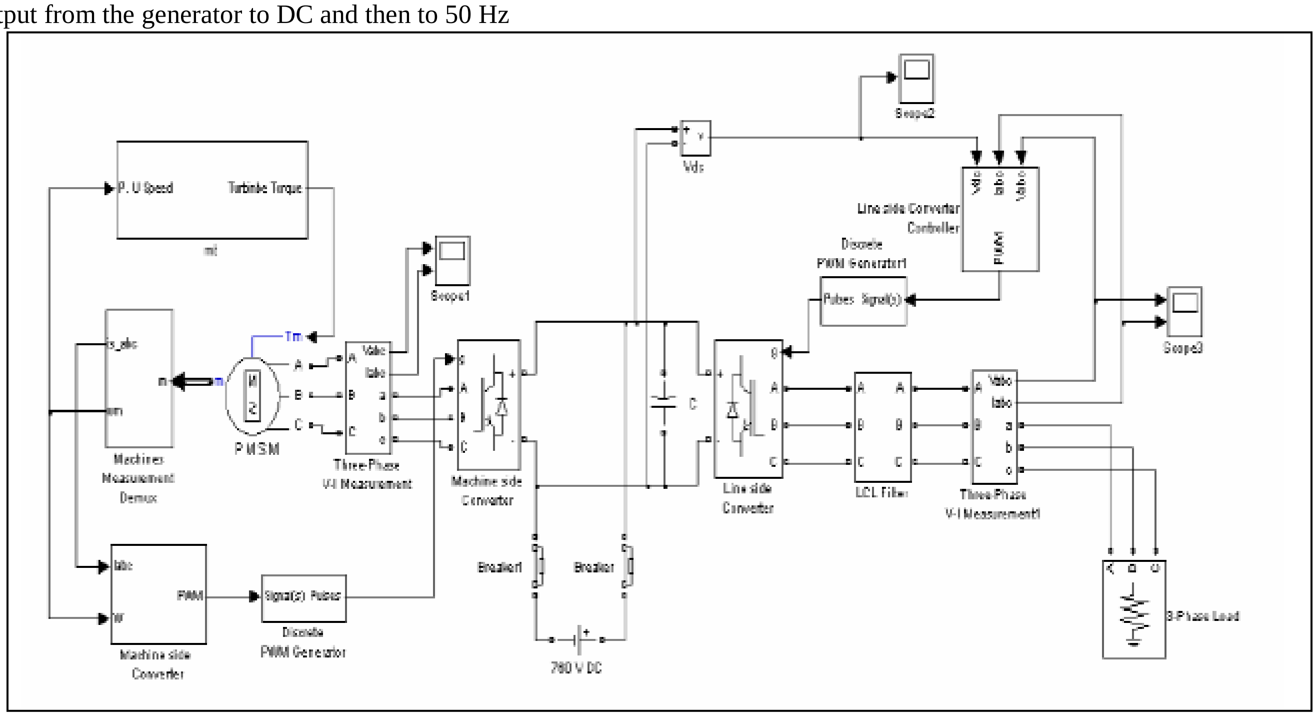

Fig. 5: microturbine generator system implementation in SimPower system

V. SIMULATION RESULTS

Grid parameters 480V, 50Hz, Rs=0.4Ωand Ls=2mH
Filter Parameters L=0.97mH, R=0.21Ω
Switching Frequency
Grid side converter = 8 Khz
Machine side Converter =20 KHz
DC link capacitance 5000 µF
PI controllers sampling time 100µsec
PMSM parameters 480 V, 30 kW, 1.6 KHz, 96000 rpm Rs=0.25 Ω, Lq=Ld=0.0006875H
Microturbine parameters Gain(K)=25,X=0.4,Y=0.05 and Z=1

Figure-5 shows the simulation model implemented in the Simulink of the MATLAB to study the performance of the MTG system operation in grid connected mode A simulation model of the microturbine and permanent magnet synchronous machine, based on the equations given in section is used to simulate the PMSG by applying negative torque to the model. Speed reference was kept constant at 1 p.u. for all simulations. All values are referred to a base power rating of 1 MVA. Simulation results for the operation of MTG without and with power electronic control are given below. The series RL filter is used at the grid side of the MTG system. The simulation parameters of the model are given the micro turbine generation system takes per unit speed of the PMSM as input. The torque output of the microturbine is given as an input mechanical torque (Tm) to the PMSM. The direction of the torque Tm is positive during motoring mode and made negative during generating mode of the PMSM. The machine side converter controller takes the rotor angle Performance of Microturbine Generation System in Grid Connected Mode speed and 3 phase stator current signals of the PMSM as inputs. In all the presented cases the voltage across the capacitor is zero, at the starting of simulation. During the start up, the PMSM operates as a motor to bring the turbine to a speed of 30,000 rpm. In this case power flows from the grid to MTG system.

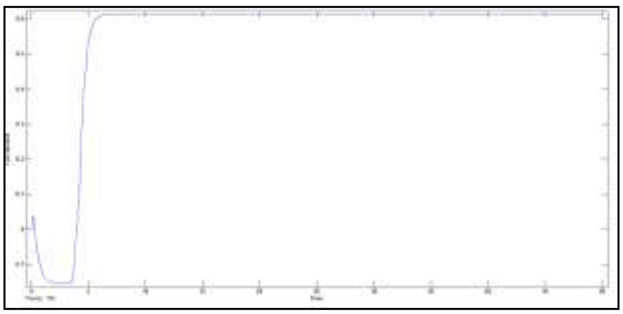

Fig. 6: MTG system for fuel demand

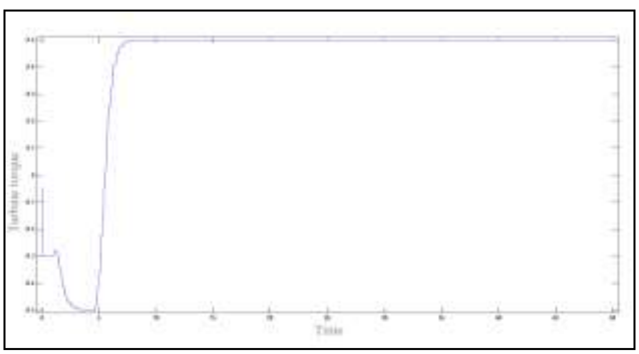

Fig. 7: MTG system for Turbine torque

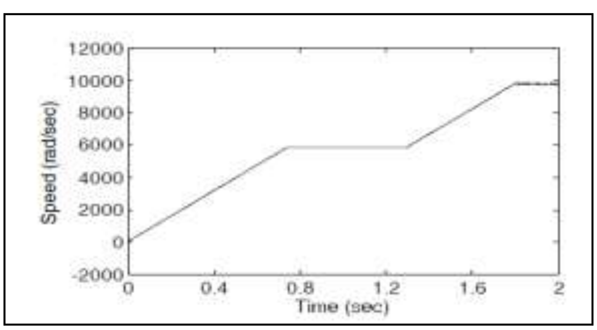

Fig. 8: motoring and generating operation speed variation of PMSG

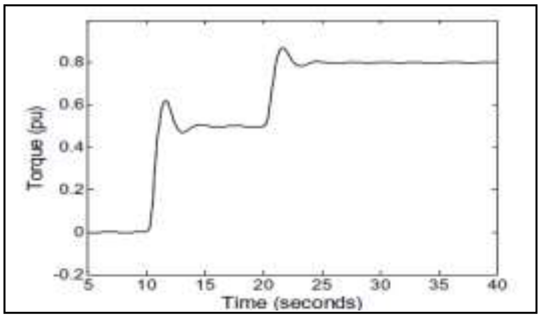

Fig. 9: variation of shaft torque

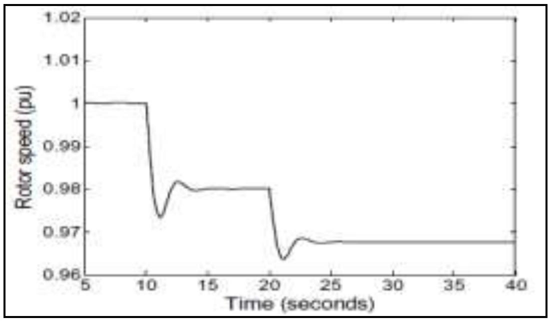

Fig. 10: Rotor speed variation with load

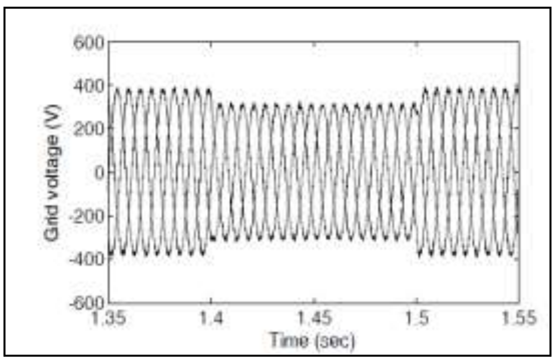

Fig. 11: MTG system for grid voltage

VI. CONCLUSION

The modeling of microturbine generation system suitable for DG applications. Modeling and simulation of microturbine are performed for its operation of grid-connected mode and mathematical modeling of the control systems of the microturbine is given and following that the detailed simulation model of the MTG system is developed using MATLAB's Simulation has also been performed with a Fuel control, temperature control and speed control, system incorporated to the MT-synchronous generator to keep the speed control for varying load. The load following characteristics observed from the simulation studies carried out in Matlab-Simulink environment are analyzed and presented in this paper. It has been observed that the MT can be used grid-connected mode as a distributed energy resource to supply customer load demands as and when required.

REFERENCES

[1] Thomas Ackermann, Goran Andersson and Lennart Soder,' Distributed Generation: a definition,' Electric Power Systems Research, vol. 57, 2001, pp. 195 - 204.
[2] S. R. Guda, C. Wang and M. H. Nehrir, 'A Simulink-based microturbine model for distributed generation studies,' IEEE Tran. On Electrical Power System, pp. 269-274.
[3] A. Al-Hinai and A. Feliachi, 'Dynamic model of microturbine used as a distributed generator,' in Proc. 34th South Eastern Symposium on system Theory, Huntsville, Alabama, 2002, pp. 209-213.
[4] D. N. Gaonkar and R. N. Patel, 'Modeling and simulation of microturbine based distributed generation system,' in Proc. IEEE Power India Conference, New-Delhi, India, April 2006, pp. 256- 260.
[5] W. I. Rowen, 'Simplified mathematical representations of heavy duty gas turbines,' ASME Trans. Journal of Engineering for Power, vol. 105, no. 4, pp. 865-869, Oct. 1983.

[6] L. M. Hajagos and G. R. Berube, 'Utility experience with gas turbine testing and modeling,' in Proc. IEEE PES winter meeting, vol. 2, Jan/Feb 2001, pp. 152-158, Feb 1993.
[7] Chee-Mun Ong, 'Dynamic Simulation of Electric Machinery Using Matlab / Simulink,' Prentice Hall 1998.
[8] MATLAB / Simulink SimPower Systems Documentation. http://www.mathworks.com
[9] M. Liserre, F, Blaabjerg and S. Hansen, 'Design and control of an LCL filter-based three-phase active rectifier,' IEEE Trans. On Industry Applications, vol. 4, no. 5, pp.1281-1291, September October 2005.
[10] A. Bertani, C. Bossi, F. Fornari, S. Massucco, S. Spelta and F. Tivegna, 'A microturbine generation system for grid connected and islanding operation,' in Proc. IEEE PES Power Systems Conference and Exposition, 2004, pp. 360-365.
[11] S. Morimoto, M. Sanada and Y. Takeda, 'Wide speed operation of interior permanent magnet synchronous motors with high performance current regulator,' IEEE Trans. Industrial Applications, vol. 30, pp. 920-926, July / Aug. 1994.
[12] S. K. Chung, 'Phase locked loop for grid connected three-phase power conversion systems,' Proc. Inst .Electrical Engineering, vol. 147, no 3, pp. 213-219, May 2000.
[13] grid connected micro turbine,' in Proc. IEEE PES general meeting, 2004, pp. 2212
[14] A. M. Azmy and I.Erlich, 'Dynamic simulation of fuel cells and microturbine integrated with a multi-machine network,' in Proc IEEE Bologna Power Tech Conference, Bologna, Italy, June2003,pp.1-6.