MICROTURBINE BASED DISTRIBUTED GENERATOR IN SMART GRID APPLICATION

A.K.SAHA
Jadavpur University, India
akshay_ksaha@yahoo.com

S.CHOWDHURY
Women's Polytechnic, Calcutta
sunetra69@yahoo.com

S.P.CHOWDHURY
Jadavpur University, India
spchowdhury@theiet.org

P.A.CROSSLEY
University of Manchester, U.K.
p.crossley@manchester.ac.uk

ABSTRACT

Microturbines (MTs) are currently being deployed as small scale on-site distributed generators for microgrids and smart grids. This calls for extensive off-line and real-time research for analyzing the load following performance of MTs under islanded and grid-connected modes of operation at distribution voltage level. This paper presents development and simulation of MT models to analyze its load following performance with general as well as critical priority loads. Load following analysis of the models are carried out through Matlab simulations for both stand-alone and grid-integrated modes of operations. Two MT models are considered for performance analysis. MT Model-1 comprises speed governor, acceleration control and temperature control blocks. It is assumed that MT is operating under normal operating conditions (neglecting its fast dynamics). Speed control operates on the speed error formed between a reference speed and rotor speed. Speed control is usually modelled by using a lead-lag transfer function or by a PID controller. MT Model-2 is based on the standard GAST model. The real power control is described as conventional PI-control function. The MT-generator unit consists of the MT coupled to a synchronous generator. The unit is integrated to the utility distribution system at the point of common coupling (PCC). It can be connected/disconnected to distribution system by operating the PCC circuit breaker.

INTRODUCTION

DERs have received significant attention as a means to improve the performance of the electrical power system, provide low cost energy, and increase overall energy efficiency [1]. DERs are constituted by a variety of small, modular distributed generation (DG) technologies that can be combined with energy management and storage systems [2]. Recent technology improvements in various types of DERs, including MTs, fuel cells, mini-hydro, battery storage, and so on, have created the opportunity for large-scale integration of DERs into distribution systems. Such on-site supply may be the most practical approach to address increasing power demand and power quality requirements, given the current electric utility restructuring as well as public environmental policy [3]. MTs are small and simple-cycle gas turbines. The outputs of the MTs range typically from around 25 to 300 KW. They are part of a general evolution of gas turbine technology. Techniques incorporated into the larger machines for improving the performance can be typically found in MTs as well. These include recuperation, low NOx emission technologies and the use of advanced materials, such as ceramic for the hot section parts [4, 5]. Unlike traditional backup generators, MTs are designed to operate for extended periods of time and require little maintenance. They can supply a customer's base-load requirements or can be used for standby, peak shaving and cogeneration applications. In additions, the current generation MTs has the following specifications [6, 7]:

- Relatively small in size, compared to others.
- High efficiency, fuel-to-electricity conversion can reach 25%-30%.
- NOx emissions below 7 p.p.m.
- Durable, designed for 11,000 hours of operation.
- Economical, system costs lower than \$500 per kW.
- Fuel flexible.

Ref. [8] reported the development of a single stage axial flow MT for power generation. Nichols, D.K. et al. discussed the MT technology, its facilities and relevant test results [9]. Guda, S.R. demonstrated the development of a MT model and its operation with a permanent magnet synchronous generator [10]. Suter M. reported an active filter for MT [11]. Adaptive control of fuel cell and MT is well described in ref. [12]. Gaonkar, D.N. et al. demonstrated the development of a MT model from the dynamics of each part which is suitable for studying various operational aspects of the same [13]. Ho, J.C. et al. presented the performance of a MT system for cogeneration application [14]. Ref. [15] proposed a control system for dispersed generators based on PI control and which was verified by control simulations.

There are several issues related to the operation and integration of a MT to a distribution system . In particular its load following characteristics is of great importance. In this paper, the operating performance of a MT and its load following characteristics are validated and presented as it has been simulated in islanded and grid-connected mode via a distribution system.

MICROTURBINE MODELS

There are essentially two types of MTs. One is high speed single shaft unit with a compressor and turbine mounted on the same shaft as an electrical synchronous machine. In this case, the turbine mainly ranges from 50,000 r.p.m. to 120,000 r.p.m. The other type of MT is split-shaft designed which uses a power turbine rotating at 3,000 r.p.m. and a conventional generator connected via a gear box [4, 5].

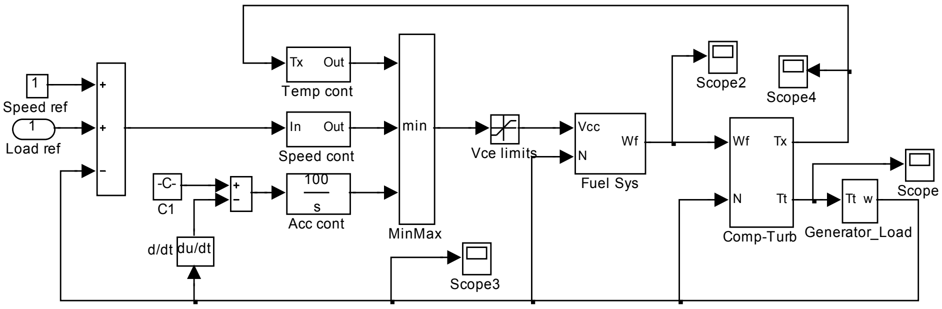

Figure (1): MT model with generator

The designs of MTs are composed of the following parts [4, 5]:

(a) *Turbine*: There are two kinds of turbines, single shaft turbines and split shaft turbines. All are small gas turbines.

(b) *Alternator*: An alternator is directly coupled to the single shaft turbine. In the split shaft design, induction or synchronous machine is used along with a gearbox.

(c) *Power electronics*: In the single shaft design, the alternator generates a very high frequency three phase signals. The high frequency voltage is first rectified and then inverted to a normal 50 or 60 Hz voltage. In the split shaft design, the power inverters are not required.

(d) *Recuperator*: It transfers heat from the exhaust gas to the compressor discharge air before it enters the combustor.

(e) *Control and communication*: Control and communication systems include full control of the turbine, power inverter and start-up electronics.

Two different models of MT are simulated and their load following characteristics is described.

MT Model-1

This model comprises speed governor, acceleration control and temperature control blocks as illustrated in figure (1). Speed control operates on the speed error formed between a reference speed and MT-generator rotor speed. It is the primary means of the control for the MT under part load conditions. Speed control is usually modeled by using a lead-lag transfer function or by a PID controller [16]. Lead-lag transfer function has been used in this work to represent the speed controller.

MT Model-2

The MT model-2 considered is based on the following assumptions:

(a) The recuperator is not included in this model as it is mainly used to raise the efficiency of the system.

(b) The temperature control and acceleration control have no impact on the normal operating conditions. Therefore, they can be omitted in the turbine model.

(c) The micro turbine does not use any governor, so, the model is not included in the model [4, 5].

For load following analysis purposes a simplified block diagram for the MT is represented as shown in figure (2).

The real power control variable P_{in} is then applied to the input of the MT.

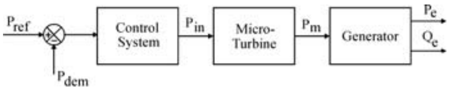

Figure (2): Microturbine Model

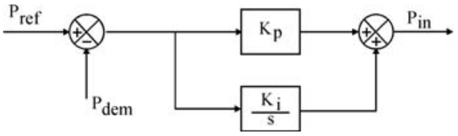

Figure (3): Control System Model

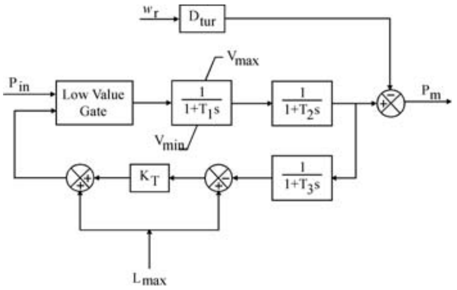

Figure (4): Turbine Model

In control system of the MT, P_{dem} is the demanded power, P_{ref} is the reference power, P_{in} is the power control variable to be applied to the input of the MT, K_p is the proportional gain and K_i is the integral gain of the proportional-integral controller. The real power control is described as conventional PI-control function as illustrated in figure (3). For turbine model GAST model as shown in figure (4) is simple and it follows typical guidelines and most commonly used dynamic models of gas turbines [4, 5].

MODEL DESCRIPTION

The synchronous machine used is based on Matlab-SimPower system block set. The distribution network is of 11 kV rating and modeled by a simple R-L equivalent source of short circuit level 500 kVA with a load of 5 kW. It has a wye-delta connected transformer. Simulations of MT-generator system were carried out in Matlab-Simulink environment with the system configuration as shown in figure (5). The MT-generator system can be connected/disconnected to distribution system by closing/opening a circuit breaker (PCC) which is called point of common coupling as shown in figure (5). The parameters of model-1 are adopted from [13] and the parameters used for simulations of model-2 are based on [5].

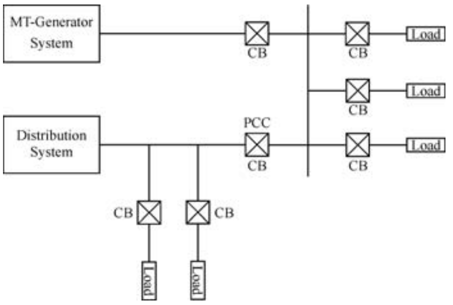

Figure (5): System block diagram

SIMULATIONS AND RESULTS

The simulations of MT models have been performed in Matlab-Simulink environment and those are presented as follows:

Case(1): Model-1

The MT-generator is initially running at no load up to 5 seconds. At t=5 seconds, a load of 30 KW was applied to it and at t=25 seconds another load of 90 KW was connected to the system. The simulation time is 50 seconds. Figure (6) shows the changes in loads on the generator which were connected to it. The output torque of the turbine is represented by figure (7). It shows that the turbine torque closely follows the generator within a very short period of time.

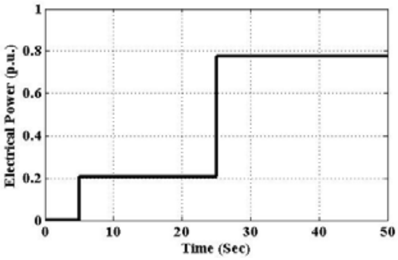

Figure (6): Generator electrical power

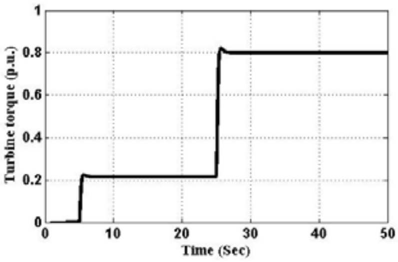

Figure (7): Turbine torque

Case(2): Model-2

(2A) *Islanded mode*: (*i*) The MT is initially running with a load of 30 kW applied to the generator bus up to t=150 seconds. Another load of 90 kW has been applied at t=150 seconds. Figure (8) illustrates the output power of the MT. It has been observed that the output power of the MT takes a time of 80-100 seconds to reach the input power demand. The power output of the generator is shown in figure (9) and it has been found that it follows the power demand as desired.

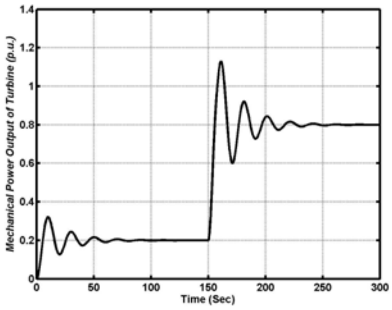

Figure (8): Power output of MT

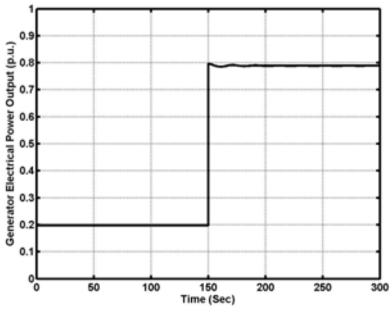

Figure (9): Generator power output

(*ii*) At time t=50 seconds a load of 0.2 p.u. is applied from no-load and at t=200 seconds another load of 0.6 p.u. is applied. The mechanical power output of the MT is shown in figure (10) which displays that the MT follows the input power demand but with some time lag.

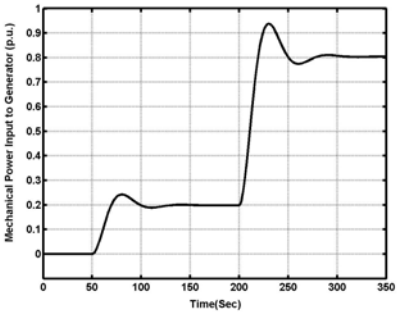

Figure (10): MT output to generator

The MT-generator speed is represented in figure (11) which shows that the speed drops at the instant the load demand increases but it reaches 1 p.u. and maintained at that level as desired at steady-state.

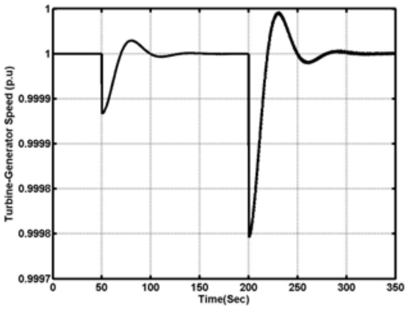

Figure (11): MT-generator speed

(2B) *Grid-connected mode*: From no-load, at time t=5 seconds, 0.2 p.u. load is applied to MT-generator system and a load of 160 kW is connected to the distribution system. At time t=125 seconds another load of 0.6 p.u. is applied to MT-generator system. At time t=250 seconds, the MT-generator system is interconnected with the distribution system and at time t=375 seconds the MT-generator is disconnected from the distribution system.

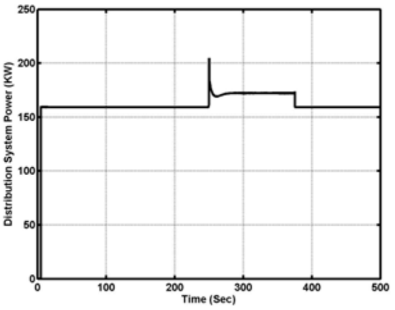

Figure (13): Distribution system power

Figure (13) shows the variation of distribution system power which demonstrates that it is at zero up to 5 seconds; after that it maintains 160 kW up to 250 seconds. It shares a load of about 12 kW from the other system. The shared load is again transferred to MT-generator system as it is disconnected at t=375 seconds.

CONCLUSIONS

Simulations of MT models are performed for its operation both in islanded mode and grid-connected mode. 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 both in islanded and grid-connected mode as a distributed energy resource to supply customer load demands as and when required. Since MTs are mainly used for CHP systems with very high energy efficiency, its use is highly appealing.

REFERENCES

[1] R. Esmaili, D. Das, D.A. Klapp, O. Dernici, and D.K. Nichols, 2006, “A novel power conversion system for distributed energy resources,” *IEEE Proc. PESGM*, 1-6.

[2] M. Brenna, E. Tironi, and G. Ubezio, 2004, “Proposal of a local dc distribution network with distributed energy resources,” *Proc. Int. Conf. on Harmonics and Quality of Power*, 397-402.

[3] Y. Zhu, and K. Tomsovic, 2007, “Optimal distribution power flow for systems with distributed energy resources,” *Electrical Power and Energy Systems*, vol. 29, 260-267.

[4] N. Hatziargyriou, G. Kariniotakis, N. Jenkins, J. Pecas Lopes, J. Oyarzabal, F. Kanellos, X. Pivert Le, N. Jayawarna, N. Gil, C. Moriera, and Z. Larrabe, 2004, “Modelling of microsources for security studies,” *Proc. CIGRE Session*, Paris, France, (pages) 7 pp.

[5] Y. Zhu, and K. Tomsovic, 2002, “Development of models for analyzing the load-following performance of microturbines and fuel cells,” *Electric Power System Research*, 62, 1-11.

[6] A. Al-Hinani, A. Feliachi, 2002, “Dynamic model of a microturbine as a distributed generator,” *IEEE Proc. System Theory*, 209-213.

[7] U.S. Department of Energy, 2006, ‘Advanced microturbine systems’, *Program plan for fiscal years 2000 through 2006*.

[8] J. Peirs, D. Reynaerts, F. Verplaetsen, 2004, “A microturbine for electric power generation,” *Sensors and Actuators*, A 113, 86-93.

[9] D.K. Nichols, and K.P. Loving, 2003, “Assessment of microturbine generators,” *IEEE PESGM*, vol. 4, 2314-2315.

[10] S.R. Guda, C. Wang, and M.H. Nehrir, 2005, “A simulink-based microturbine model for distributed generation studies,” *IEEE, Proc. Power Symposium*, 269-274.

[11] M. Suter, 2001, “Active filter for a microturbine,” *IEE Proc. Telecom. Energy Conf.*, 162-165.

[12] F. Jurado, and J.R. Saenz, 2003, “Adaptive control of a fuel cell-microturbine hybrid power plant,” *IEEE Trans. on Energy conversion*, vol. 18, no. 2, 342-347.

[13] D.N. Gaonkar, and R.N. Patel, 2006, “Modeling and simulation of microturbine based distributed generation system,” *IEEE Proc. Power India Conf.*, 5 pp.

[14] J.C. Ho, K.J. Chua, and S.K. Chou, 2004, “Performance study of a microturbine system for cogeneration application,” *Renewable Energy*, vol. 29, 1121–1133.

[15] T. Senjyu, H.Takara, K.Uezato, T. Funabashi, T. Ito, 2003, “Load-following control for dispersed generators using a PI controller”, *Electrical Eng. in Japan*, Vol. 145, No 2, 58-66.

[16] L.N. Hannet, A. Khan, 1993, “Combustion turbine dynamic model validation from tests”, *IEEE Trans. on Power Systems*, Vol. 8, No. 1, 152-158.