Modeling and Performance Analysis of Microturbine Based Distributed Generation System, “A review”

D. N. Gaonkar, *Member, IEEE*, and Sanjeev Nayak

***Abstract*--Distributed Generation (DG) is predicted to play an important role in the electric power system in the near future. It is widely accepted that microturbine-generation systems are currently attracting lot of attention to meet users' need in the distributed generation market. In order to gain the benefits of interconnected operation of microturbine generation system (MTG) system with the utility network, their effective modeling and performance analysis are required. This paper presents the recent research efforts in accurate modeling of MTG System and the investigation on various issues related to their interconnected operation and control with the distribution network.**

***Index Terms*--The Distributed generation, microturbine, permanent magnet synchronous machine, power electronic interface, modeling, performance of MTG system**

I. INTRODUCTION

The deregulation of electric power utilities, advancement in technology, environmental concerns and emerging power markets are leading to increased interconnection of distributed generators to the distribution networks. Besides offering environmental benefits, integration of modular generating units to distribution network may bring other significant benefits such as increased reliability, loss reduction, load management and also the possibility of delaying the adjustment of transmission and distribution networks [1]. Various new types of distributed generator systems, such as microturbines and fuel cells in addition to the more traditional solar and wind power are creating significant new opportunities for the integration of diverse DG systems to the utility. The small DG systems based on microturbine technology are gaining popularity amongst industry and utilities in the last few years due to following salient features [2, 3].

- Relatively small in size compared with other DGs.
- High efficiency, fuel-to-electricity conversion can reach 25–30%. However, if waste-heat recovery is used, the combined heat and electric power could achieve energy-efficiency levels greater than 80%.
- They are environmentally superior: nitrogen oxide (NOx) emissions are lower than seven parts per million for natural-gas (NG) machines in practical operating ranges.
- Durable, designed for 11,000 hours of operation between major overhauls, and a service life of at least 45,000 hours.
- They are economical with system costs lower than \$500 per kilowatt and electricity costs that are competitive with alternatives (including utility-connected power) for market applications.
- Fuel flexibility: they can use alternative/optional fuels including natural gas, diesel, ethanol, landfill gas, and other biomass-derived liquids and gases.

The MTG system can generate power in the range of 25 kW to 500 kW and can be operated in stand alone, mobile, remote or interconnected with the utility applications. This generation system can be used for a wide range of applications. Some of the applications are, base load power (grid parallel), peak shaving, combined heat and power, stand-alone power, resource recovery and ups and stand by services [3, 4]. The microturbine generation system is new and a fast growing business and will likely become a dominant DG in the future power supply network [2, 3]. Thus dynamic modeling and performance studies are necessary to deal with issues in system planning, interconnected operation and management. Hence to ensure safe operation and security of the system, MTG must be seriously taken into consideration. This paper provides thorough review of the literature available on MTG system.

II. TYPES OF MTG SYSTEM

The microturbine operates on the same principles as traditional gas turbines and its basic components are the compressor, combustor, turbine generator and recuperator. Air is drawn into the compressor, where it is pressurized and forced into the cold side of the recuperator. Here, exhaust heat is used to preheat the air before it enters the combustion chamber. The combustion chamber then mixes the heated air with the fuel and burns it. This mixture expands through the turbine, which drives the compressor and generator. The combusted air is then exhausted through the recuperator

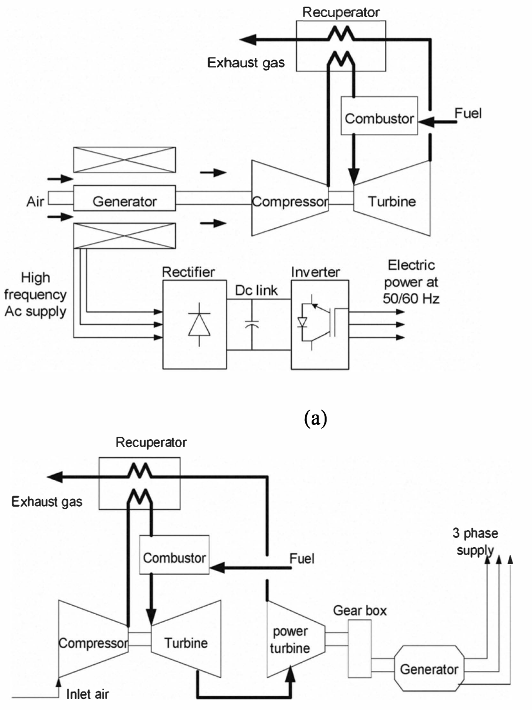
---

D. N. Gaonkar is an Assistant Professor at the Department of Electrical Engineering, National Institute of Technology Karnataka Surathkal, Mangalore-575025, Karnataka, india (e-mail: dngaonkar@ieee.org).

Sanjeev Nayak is a Research Scholar in the Department of Electrical Engineering, National Institute of Technology Karnataka Surathkal (e-mail: saneevnayak_82@yahoo.co.in).

978-1-4577-0776-6/11/\$26.00 ©2011 IEEE

before being discharged at the exhaust outlet.



(a)

(b)

Fig. 1 Schematic diagram of (a) single shaft MTG system (b) split shaft MTG system [3-5].

There are two types of micro turbine designs are available, based on position of compressor turbine and generator. Figure 1 (a) shows a high speed single shaft design with the compressor and turbine mounted on the same shaft along with the permanent magnet synchronous generator (PMSG). The generator generates the power at very high frequency ranging from 1500 to 4000 Hz. The high frequency voltage is first rectified and then inverted to a normal AC power at 50 or 60 Hz. Modeling of these DG systems is a significant challenge mainly due to the power electronic interface and control [3-5].

Another design is shown in Fig. 1 (b), in which the turbine on the first shaft directly drives the compressor while a power turbine on the second shaft drives the gearbox and conventional electrical generator (usually induction generator) producing 60/50Hz power. The two-shaft design features more moving parts but does not require complicated power electronics to convert high frequency AC power output to 60/50 Hz[4].

III. MODELING OF MTG SYSTEM

The modeling of a MTG system consists mainly of three parts; the microturbine, permanent magnet synchronous machine (PMSM) and power electronic interfacing circuit with control.

A. Microturbine

The model of a heavy duty combustion gas turbine has been presented in [6]. This is the basic model which has been used by several researchers to model the microturbine. An analog and PID governor control schemes for simple cycle, heavy duty gas turbines are described in [7]. The practical validation of these schemes is reported in [8]. In this it has been shown that the model structure given in [6, 9] is adequate to represent the combustion turbines of the different manufacturers. The Matlab/Simulink implementation of the microturbine model including all its control systems which is is shown in Fig. 2[5].

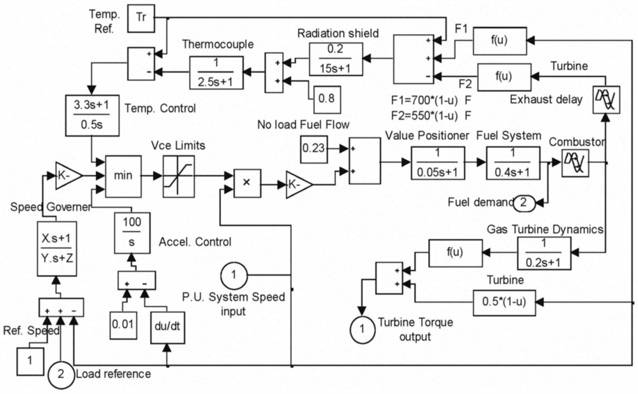
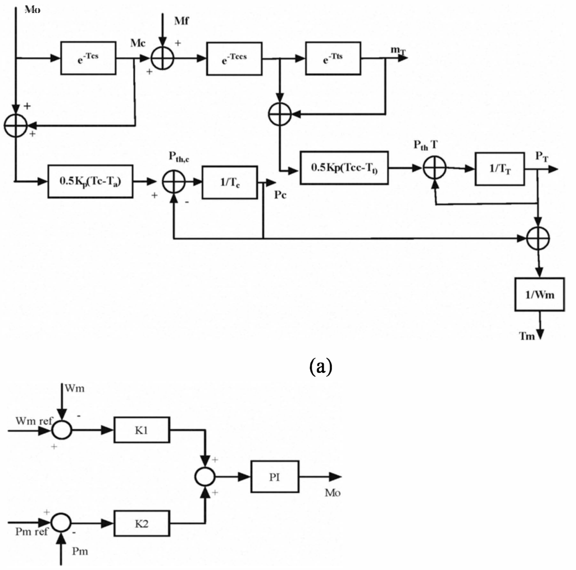


Fig. 2 Simulink/MATLAB implementation of microturbine model [5].

The model consists of temperature control, fuel control, turbine dynamics, and speed governor and acceleration control blocks [6] [7]. The droop governor is a straight proportional speed controller in which the output is proportional to the speed error. Speed control is usually modeled by using a lead-lag transfer function or by a PID controller [6-9]. The temperature control is the common method of limiting gas turbine output at a predetermined firing temperature, independent of variation in ambient temperature or fuel characteristics. Acceleration control is used primarily during gas turbine startup to limit the rate of rotor acceleration prior to reaching governor speed. This ameliorates the thermal stress encountered during startup. Fuel systems are designed to provide energy input to the gas turbine in proportion to the product of the 'Vce' times the per unit speed [6].where 'Vce' represents the least amount of fuel required for a particular operating point. A nonlinear dynamic model of the MTG system is reported [10]. In this simplified transfer functions are used to model the turbine and governor. The modeling of split shaft design of microturbine are reported in [4,11].

The micro-turbines are much smaller in physical dimension than a conventional gas turbine. The length of each component of relatively short and the gas moves relatively fast speed inside the micro-turbine compartment hence each compartment of micro-turbine has a small thermodynamic time constant[12-13]. Thus any change in the input of fuel or the air flow of a micro-turbine affects its output mechanical power in short period of time. Therefore, thermodynamics of micro-turbine should be considered in the analysis of a dynamic performance of the MTG, and input mechanical power to the generator cannot be considered as constant value during electro-mechanical dynamics of generator.



(a)

(b)

Fig. 3 (a) Block diagram of micro-turbine system. (b) Micro-turbine controller. [13].

The thermodynamic model reported in [13] is shown in Fig. 3. The differential and algebraic equation corresponding to each compartment of micro-turbine are given in terms of gas pressure p(t), mass flow rate m(t) temperature T(t) and generated thermal power pth(t). The differential equation that governs the thermodynamic of each compartment of a micro-turbine is briefly explained in [12].

B. PMSM

The important applications of permanent magnet synchronous machine are in the wind and microturbine based distributed generation systems. One of the major advantage of PMSM is the possibility of super high speed operation leading to a very small unit as the size of the machine decreases almost in directly proportion to the increase in speed. 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. The following assumptions are made in the modeling [14,-15].

- Saturation is neglected although it can be taken into account by parameter changes.
- The induced EMF is sinusoidal.
- Eddy currents and hysteresis losses are negligible.
- There are no field current dynamics.
- There is no cage on the rotor.

With the above assumptions the stator *dq*-axis voltage equations of the PMSM in the rotor reference frame are given by

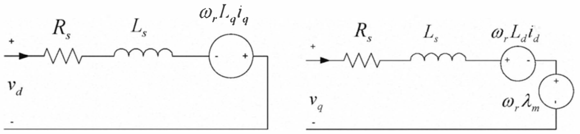
$$v_d = R_s i_d + L_d \frac{di_d}{dt} - \omega_r L_q i_q \tag{1}$$

$$v_q = R_s i_q + L_q \frac{di_q}{dt} + \omega_r L_d i_d + \omega_r \lambda_m \tag{2}$$

$$T_e = 1.5P\,(\lambda_m i_q + (L_d - L_q) i_q i_d) \tag{3}$$

$$\frac{d}{dt}\theta_r = \omega_r \tag{4}$$

T_e is the electromagnetic torque, B is combined viscous friction of rotor and load, ω_r is the rotor speed, and J is the moment of inertia, θ_r is rotor angular position and T_m is shaft mechanical torque. This is the standard current dynamics model (for control purposes) of a PMSM where, the stator resistance is denoted by R_s, the *d*-axis and *q*-axis inductances are L_d and L_q respectively, λ_m is the flux linkage due to the permanent magnets, v_d and v_q are *dq*- axis voltages, ω_r is the rotor speed, i_d and i_q are the *dq*-axis current components. The *d* and *q*- axis equivalent circuit of PMSM is shown in Fig.4.



(a) (b)

Fig. 4 *dq*-axis equivalent circuit model of the PMSM (a) *d*-axis(b) *q*-axis

C. Power Electronic Interface

The single shaft microturbine power electronic interface circuit is a critical component to convert the high frequency AC power produced by the generator into usable electricity. It represents significant design challenges, specifically in matching turbine output to the required load. There are different interface topologies available for connecting single shaft MTG systems to grid/isolated load. Figure 5 shows the passive rectifier and inverter combination with DC link [3, 5, 10]. In MTG system, the PMSM is required to operate as a motor during start-up and cool down cycles of microturbine engine [16]. To achieve the motoring operation of generator separate startup inverter is needed for passive rectifier and inverter topology as shown in Fig.5. This increases the cost of the system.

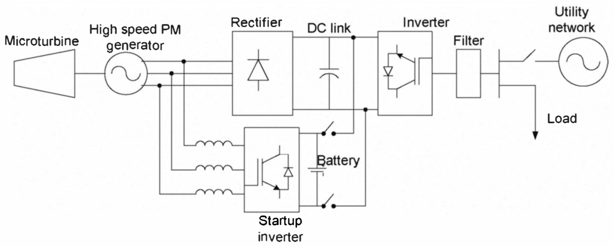
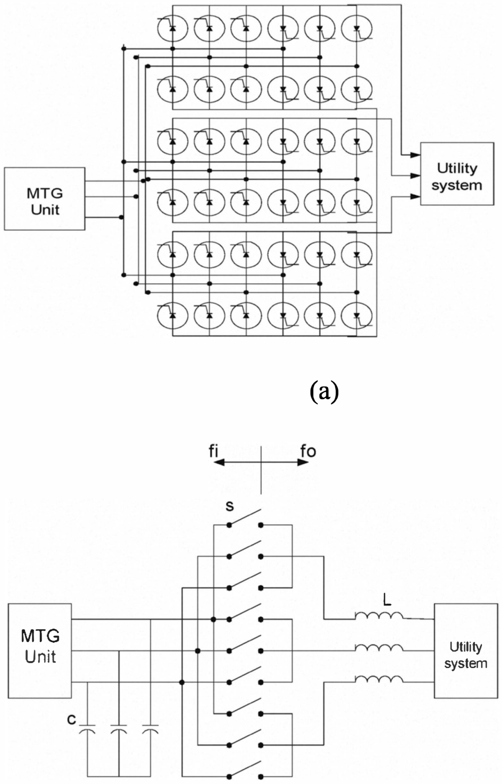


Fig. 5 Passive rectifier inverter interface with Starting and shut-down arrangements for MTG system.

A cycloconverter and matrix converter shown in Fig. 6(a) can be used to interface the MTG system to the grid [17, 13]. These converters directly convert AC voltages at one frequency to AC voltages at another frequency with variable magnitude. For this reason, they are also called frequency changers. The disadvantages of these converters are that they have double the number of switches compared to the DC link approach and energy storage is not possible. If there is no DC link, any fluctuation on either side of the converter will directly influence the other side. The matrix converter shown in Fig.6 (b) can be used at lower frequency compared to PWM based converters [13]. Some advantages of the matrix converters are less thermal stress on the semiconductors during low output frequency and absence of the DC link capacitors which increases the efficiency and life time. The drawbacks of this topology are the intrinsic limitation of the output voltage, the unavailability of a true bi-directional switch; absence of decoupling between the input and the output of the converter. This may lead to some instability issues.



(a)

Fig. 6 a) Cycloconverter interface model (b) Matrix converter interface model.

The back to back voltage source converters (VSC) interface topology used in the modeling of MTG is shown in Fig.7. This topology allows bi-directional power flow between the converter and the grid and hence no separate starting arrangement is required [18-21]. At the time of starting, PMSM acts as motor and draws power from the grid to bring the turbine to certain speed. In this mode grid side converter acts as controlled rectifier and machine side converter acts as inverter and provides AC supply to the motor. This is also referred to as motoring mode operation of PMSM. During the generating mode PMSM acts as generator and power flows from MTG system to grid. The machine side and grid side converters act as controlled rectifier and inverter respectively. In both the modes of operation the grid-side converter regulates the DC bus voltage, while the machine side converter controls the PMSM speed and displacement factor [18-21].

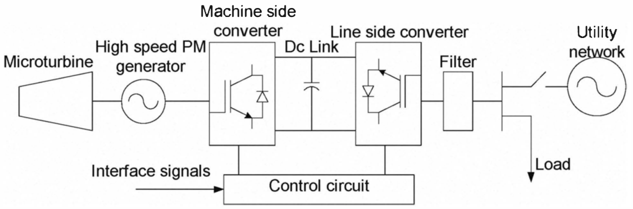


Fig. 7 MTG system with back to back converter interface [18-21]

IV. PERFORMANCE STUDY OF MTG SYSTEM IN UTILITY INTERACTIVE / ISOLATED MODE

The dynamic models of microturbine generation system for isolated operations are reported in [3, 5, 22]. In these references a combustion gas turbine model presented in [6] is used to model the microturbine. A passive rectifier and inverter combination with DC link is used for interfacing the MTG system to isolated loads. The grid connected performance of a split shaft MTG system is given in [4, 23].

The reduced order model of microturbine using auto-regression with exogenous signal (ARX) and nonlinear autoregressive exogenous (NARX) approaches are presented in [24,25] to analyze the dynamics of this micro-turbine. A new approach for power electronic interface control of utility interactive MTG system has been reported and tested in [26]. A grid connected model of MTG system with matrix converter and AC-DC-AC converters are reported in [13, 27] for the evaluation of the electromagnetic transients of MTG system. A novel power electronic interfacing topology combining three levels and two level converters in back to back connection for MTG system has been proposed in [28]. In [13, 27, 28] the thermodynamic model of the microturbine has been used for the simulation study using PSCAD/EMTDC software.The load following behavior of a MTG system with synchronous generator under islanded and grid-connected modes have been studied in [29] using simulation results with real life data.

The model of the MTG system with PV control (instead of normal PQ control) scheme for grid connected mode and stand alone operation with VF control and its performance study with rural distribution system is given in [30]. The Simulation of studies on MTG system in grid connected mode using PSCAD/EMTDC under different load conditions has been reported in[31] .The simulation and practical investigation on sensorless control of PMSM without position and speed sensor in the start process of a 30kW MTG system has been reported[32]. The modeling of back to back converter interface for MTG system is reported in [34].A study using dynamic model of a micro-turbine generation system for investigation of transient stability and voltage stability of distribution system is presented in [35]. A high efficiency drive system using micro-turbine generator based on current phase and revolving speed optimization has been given in [36]. The study results of an investigation regarding the voltage and current harmonic characteristics of a new three-phase, 480 volt, and 30 kW microturbine generators under various load levels are given in [37].

The efficiency comparison of two power conditioning systems one with a passive rectifier, a boost converter, an inverter and the other composes of an active rectifier and an inverter for MTG system has been reported in[38].The performance investigation on MTG system in multi-machine distribution network has been presented in [17].The Expected advantages to Customers, to utilities and to environment, from the connection of a microturbine to a low voltage grid, in Portuguese study case are reported in[39]. A simulation study on use of induction generator as a viable substitute for PMSM in microturbine based dispersed generation systems due to its various advantages has been presented in [40].The method to reduce harmonic current in high speed MTG system using active filter is proposed in [41].The detailed modeling of MTG system for grid connected/islanding mode of operation using back to back converter interface and its performance study has been presented in [19-21].

A seamless transfer of MTG system of operation between grid connected and islanding mode using simple PLL based technique and the performance study has been presented in [21]. The model of the MTG system consisting of microturbine, synchronous generator, and back-to-back power converters are presented in [42] along with the corresponding control methods. A controller based on artificial neural network (ANN) for standalone MT power plant has been proposed in [43]. In addition, the paper presents a comparison between the performance of the MT when using traditional PI and ANN controllers. The MTG system model with the double-SPWM control strategy for power electronic converters is presented in [44]. The simulation results reported in the same show that the model is suitable for transient study and analysis in island mode of the microgrid as well as grid connected operation.

In [45] an auto disturbance rejection control (ARDC) method has been presented and shown how ADRC can improve the stability of the microturbine system using load disturbance and robust simulation. A novel single neuron adaptive control algorithm is proposed in [46] for microturbine dynamics in combining with PID, based on radial basis function (RBF) neural network on-line identification. The algorithm has been applied in “100kW microturbine control and power converter system”. The results of simulation are shown that the algorithm is very valid. In [47] new grid code requirements related to MTG system are highlighted and solution for the same has been presented. In this study result show that with the proposed solution MTG system is capable of riding through low voltage events while adhere to new grid code requirements.

V. CONCLUSION

The use of MTG system strongly contributes to a clean, reliable and cost effective energy for future. However, Integration of this DG unit into distribution system can create a significant challenge for the successful operation of utility network. As the issues are new and are the key for sustainable future power supply, lot of research is required to study their impacts and exploit them to the full extent. This paper presented the various research efforts in modeling of MTG system, and investigations on issues related to their operation and control in grid connected and isolated mode. The literature study indicates that the design of power electronic interface circuits for MTG system and its control offers a significant challenge to meet the various performance standards. And also, there is a need for effective solution to ensure that the performance of MTG system will not degrade the power quality, safety and reliability of the distribution system.

VI. 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] W.G. Scott, “Micro-turbine generators for distribution systems,” *IEEE Industry Applications Magazine*, May/June 1998.

[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] 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] 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.

[6] W. I . Rowen, “Simplified mathematical representations of heavy duty gas turbines,” *Journal of Engineering for Power, Trans. ASME,* vol. 105, no. 4, pp. 865-869, Oct, 1983.

[7] L. M. Hajagos and G. R. Berube, “Utility experience with gas turbine testing and modeling,” *in Proceedings, IEEE PES Winter Meeting*, vol. 2, pp. 671-677 Jan. /Feb. 2001, Columbus, OH.

[8] L.N. Hannet and Afzal Khan, “Combustion turbine dynamic model validation from tests,” *IEEE Trans. on Power Systems,* vol.8, no.1, pp. 152-158, Feb.1993.

[9] Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies, “Dynamic models for combined cycle plants in power system studies,” *IEEE Trans. Power System*, vol. 9, no. 3, pp. 1698-1708, Aug.1994.

[10] R. H. Lasseter , “Dynamic models for micro-turbines and fuel cells,” *Proceedings ,IEEE PES Summer Meeting,* vol. 2, pp. 761-766, Jul. 2001, Vancouver, Canada

[11] A. Al-Hinai, K. Schoder, and A. Feliachi, “Control of grid-connected split shaft microturbine distributed generator,” *System Theory,Proceedings of the 35th Southeastern Symposium,* pp. 84 –88, *2003.*

[12] H. J. Nern, H. Kreshman, F. Fischer, and H. A. N. Eldin, “Modeling 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.

[13] Hassan Nikkhajoei, and M Reza Iravani. “A Matrix converter based micro-turbine distributed generation system” *IEEE Transaction on Power Delivery*, Vol, 20.No, 3. July 2005.

[14] P. Pillay and R. Krishnan, “Modeling, simulation, and analysis of permanent-magnet motor drives, part I: the permanent-magnet synchronous motor drive,” *IEEE Trans. on Industrial Applications*, vol.25, no. 2, pp. 265-273, March-April 1989.

[15] P. Pillay and R. Krishnan, "Control characteristics and speed controller design for a high performance permanent magnet synchronous motor drive," *IEEE Trans. on Power Electronics*, vol. 5, no.2, pp. 151-158, April 1990.

[16] Capstone Microturbine Documentation, Available at : www.capstoneturbine.com

[17] 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, June 2003, pp.1-6

[18] O. Fethi, L. A. Dessaint and K. Al-Haddad, "Modeling and simulation of the electric part of a grid connected micro turbine," in *Proc. IEEE PES general meeting, 2004,* pp. 2212-2219.

[19] D. N Gaonkar, R N Patel, and G N Pillai. "Dynamic model of microturbine generation system for grid connected/islanding operation," *IEEE International Conference on Industrial Technology (ICIT),* Mumbai, India, 15-17th December 2006.

[20] D. N. Gaonkar G. N. Pillai and R. N. Patel, "Dynamic performance of microturbine generation system connected to grid," *Journal of Electric Power Systems and Components,* Vol. 36, No. 10, October 2008, pp. 1031–1047.

[21] D. N. Gaonkar G. N. Pillai and R. N. Patel, "Seamless transfer of microturbine generation system operation between grid connected and islanding modes," *Journal of Electric Power Systems and Components,* Vol. 37, December 2008 pp.174-188.

[22] S. R. Guda, C. Wang and M. H. Nehrir, "Modeling of microturbine power generation systems," *Electrical Power System and Components*, vol. 34, no. 9, pp. 1027–1041.

[23] A. Al-Hinai, K. Schoder, and A. Feliachi, "Control of grid-connected split shaft microturbine distributed generator," *System Theory, Proceedings of the 35th Southeastern Symposium,* pp. 84 –88, *2003.*

[24] F. Jurado and A. Cano,"Use of ARX algorithms for modelling micro-turbines on the distribution feeder" *IEE Proc.-Gener. Transm. Distrib*., Vol. 151, No. 2, March 2004, pp 232-238.

[25] F. Jurado and J. Carpio ,"Modeling Micro-turbines on the Distribution System Using NARX Structures," *IEEE Latin America Transactions, (Revista IEEE America Latina),* Vol. 1 , No.1 , 2003 , pp: 34 - 39

[26] Fu-Sheng Pai "An Improved Utility Interface for Microturbine Generation System With Stand Alone Operation Capabilities" *IEEE Transaction On Industrial Electronics*, Vol. 53, No.5, October 2006, pp. 1529-1537.

[27] H. Nikkhajoei and M. R. Iravani, "Electromagnetic transients of a microturbine based distributed generation system," *In Proc. of International Conference on Power Systems Transients*, IPST05-070-8b, Montreal, June 2005.

[28] H. Nikkhajoei, M. Saeedifard, and R. Iravani ," A three-level converter based micro-turbine distributed generation system" *IEEE 2006 Power Engineering Society General Meeting,* 2006

[29] A. K. Saha, S. Chowdhury, S. P. Chowdhury, and P. A. Crossley, "Modeling and performance analysis of a microturbine as a distributed energy resource," *IEEE Transactions On Energy Conversion*, Vol. 24, No. 2, June 2009,pp. 529-538.

[30] S. Grillo, S. Massucco, A. Morini, A. Pitto, and F. Silvestro, Microturbine control modeling to investigate the effects of distributed generation in electric energy networks " *IEEE Systems Journal*, Vol. 4, No. 3, Sept. 2010,pp. 303-312

[31] G. Li, Gengyin Li, W. Yue, M.Zhou and K L Lo "Modeling and simulation of a microturbine generation system based on PSCAD/EMTDC" in *Proc IEEE 5th International Conference on Critical Infrastructure(CRIS),* 2010, pp. 1 – 6.

[32] Y.Li, H. Guo, Q. Xie and P.Yuan," Research on the control method for the start of microturbine generation system" in *Proc. of the IEEE International Conference on Information and Automation,2010* June 20 - 23, Harbin, China.

[33] F. Bertani, A. Bossi, C. and Massucco, S "A microturbine generation system for grid connected and islanding operation," In Proc. *IEEE power system conferences and Exposition*, Vol.1, 2004, pp. 360-365.

[34] O. Fethi, L. A. Dessaint and K. Al-Haddad, "Modeling and simulation of the electric part of a grid connected micro turbine," in *Proc. IEEE PES General Meeting, 2004,* pp. 2212-2219.

[35] A. Cano, F. Jurudo, and J. Carpio "Influence of micro-turbines on distribution networks stability," *IEEE Power Engineering Society GeneralMeeting,*2003.

[36] N. Urasakil, T. Senjyu', K. Uezatol, T. Funabashi, H. Fujita," High efficiency drive for micro-turbine generator based on current phase and revolving speed optimization," *5th Int. Conf. on Power Electronics and Drive Systems(PEDS)*, Vol. 1 , 2003 , pp. 737 – 742.

[37] M. Etezadi-Amoli K. Choma "Harmonic characteristics of a new 30 kw micro-turbine generator" in *Proc. 9th Int. Conf. on Harmonics and Quality of Power*, Vol. 3 ,2000 , pp. 816 - 820

[38] Z. Ye, T.C.Y. Wang, G. Sinha, R. Zhang," Efficiency Comparison for Microturbine Power Conditioning Systems," IEEE 34th Annual Power ElectronicsSpecialistConference,Vol. 4, 2003, pp. 1551 – 1556.

[39] A. Amorim, A. L. Cardoso, J. Oyarzabal, N. Melo "Analysis of the connection of a microturbine to a low voltage grid," *IEEE Int. Conf. on Future Power Systems,*2005 , pp: 5 pp

[40] A. M. Zarringhalam and M. Kazerani "Comprehensive analysis of a dispersed generation scheme based on microturbine and induction generator" *IEEE Power Engineering Society General Meeting,* Vol.2 ,2004 , pp 2206 - 2211

[41] Z. Ming, W. Fengxiang, W. Zheng, and Z. Fengge, "Research on active power filter for distributed power system of high speed generator driven by micro-turbine," in *Proc. Int. Conf. on Power System Technology* - POWERCON Singapore, 21-24 Nov, 2004.

[42] Xunwei Yu Zhenhua Jiang and Atideh Abbasi, "Dynamic Modeling and Control Design of Micro turbine Distributed Generation System" *IEEE Int. Conf. on Electric Machine and Drives*, pp,1239-1243, 2009.

[43] N.S. Sisworahardjo, M.Y. El-Sharkh, and M.S. Alam," Neural network controller for microturbine power plants," *Electric Power Systems Research* Vol.78, 2008, pp. 1378–1384.

[44] H. Wei, W. Ziping, N. Ming, and W. Chong, "Dynamic modeling and simulation of micro turbine generation system for parallel operation of microgrid" *9th IEEE Inter. Conf. on Sustainable Power Generation and Supply*, pp.1-8, 2009.

[45] T. Yu and Jia-Peng Tong, "Auto disturbance rejection control of micro-turbine system techniques" *IEEE Conference on Conversation and Dilivary of Electrical Energy in 21st Century,* Vol.1, pp. 1-6, .2008.

[46] Y. Shijie, W. Xu, "RBF neural network adaptive control of microturbine," IEEE Global Congress on Intelligent Systems Vol. 2, 2009, pp. 288 - 292

[47] M. Z. C. Wanik, and I. Erlich, "Simulation of microturbine generation system performance during grid faults under new grid code requirements," in Proc *IEEE Bucharest Power Tech Conference* 28th-July 2nd June ,2009,Bucharest, Romania.

VII. BIOGRAPHIES

D. N. Gaonkar (M'2008) is received his Ph. D. degree from the Indian Institute of Technology Roorkee, India; in the year 2008.He was a visiting research scholar at the University of Saskatchewan Canada in the year 2008. He has edited and written a chapter in the book titled DISTRIBUTED GENERATION, which is published by INTECH publication Austria. He has published papers in international journals and conferences. Presently he is working as an Assistant Professor in the Department of Electrical Engineering, National Institute of Technology Karnataka, Surathkal, India. His research interests are in the area of power system operation and control, power electronics and distributed generation systems.

Sanjeev K Nayak received his M Tech degree from Kuvempu University Simogga Karnataka, India in the year 2007; currently he is pursuing his PhD in the Department of Electrical and Electronics Engineering at National Institute of Technology Karnataka Surahakal. His research interests are in Distributed Generation and Power Quality.