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Modeling and Performance Analysis of Distributed Generation when Connected to Load and Grid.

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Abstract— **To overcome the disadvantages of centralised generation, to improve the quality of life and to minimise the gap between power demand and supply , has become necessary to make use of available Distributed Generation(DG). DG plays a significant role in distribution network of power system. Due to reduction in transmission loss as availability near to end users, load sharing property and provides reliable and better quality of power . Among the different Distributed Energy Resources(DER), the micro turbine generation (MTG) has a good record of improving efficiency, system stability, reliability and power quality of network when operated in Combined heat and power (CHP) mode with low emissions . This paper explains about the modelling and performance analysis MTG system when connected to load and grid under normal conditions, such that generated power should dynamically follow the power demand without wastage of power and no damage to the generating unit**s.

***Keywords*: Micro turbine Generation System, Fuel cell, CHP, Distributed generation, Power Demand, DER, Reliability, Stability, Grid.**

I. INTRODUCTION

Distributed Generation can be defined as stand alone or integrated small modular electric generation of the range 50 KW to 100 MW located near to the end user terminals.. It is powered by DER[1],[2]. Such as Non-Renewable, Renewable and Non-Generating sources. Renewable DER include wind, PV cells ,small hydro and geothermal. Non-renewable DER are IC engines, Diesel engine, fuel cell and micro turbine. Non-Generating DER include power storage devices such as super capacitors, battery and flywheel. Concentrating on the usage of Non-renewable DER for the generation of electric power as Renewable DER require large surface area for the installation investment is high ,weather dependent thus efficiency is not uniform over a period of year (not reliable). Among available Non-renewable DER[3][4], gas micro turbine and fuel cells are taken for the generation of power as these show good record of improving system efficiency, stability, reliability and power quality when connected to load or micro grid.

Micro turbines are small simple gas turbines. Operating principle for the generation of electricity is same as of large gas turbines. Output ranging from 25 – 500KW. These are fuel flexible for the generation of power, uses renewable and non renewable fuels such as hydrocarbons, natural gas, landfill gas respectively with less or no emission. Micro turbines can be integrated to other DGs to increase the efficiency. Two types of micro turbines are available based on their shaft construction. 1.High speed Single shaft turbine and 2.Split shaft turbine . Single shaft turbine, the compressor and turbine are mounted on same shaft as generator and turbine speed ranges from 50,000 rpm to 120,000 rpm. The other type of micro-turbine is a split-shaft design that uses a power turbine rotating at 3600 rpm and a generator connected via a gearbox [5].

From modeling viewpoint, Micro turbines have extremely low inertia and damping. Accordingly, it is necessary to develop the DG models, appropriate for investigating the performance. Addition of DG affects the overall dynamics of the power distribution network[2], such as voltage regulation and power degradation etc. thereby, accurate modeling of DG systems and its control have become inevitable to predict its grid and off-grid interaction in advance. So as to supply the demand effectively.

In this paper, Matlab- Simulink is used to model and simulate dynamic response of a micro turbine with power demand when connected to load and grid under normal conditions.

As previously mentioned, there are essentially two types of micro turbines [5]. We are considering Split shaft microturbine for the generation of power. The components of the Split shaft micro turbine model are explained in [5]. S N Singh et.al [3], gave the distributed generators with available size and thus MTG and Fuel cells (SOFC) have High generation capacity when operated in CHP mode with less emission. Sanjeev K Nayak [7], Presented the modelling and performance analysis of MTG system in grid connected and islanding modes of operation and modelling, simulation and control of load-following performance for grid/off-grid operations of MTG are explained in [8],[9]. These describe with high speed single-shaft microturbine coupled with permanent magnet synchronous generator (PMSG). Electrical power generated by PMSG will be at frequency in the range of 1400-4000HZ, eventually, cannot be directly used by the consumer devices. As a result, interfacing of power electronic devices are required between the MTG and the end user terminal. The usage of power electronic components results in conversion losses and generation of harmonics thus makes the overall system operation and control more complex, to overcome these complexities, diverts to the usage of split-shaft MTG. In this paper modelling and simulation of split-shaft MTG is done

DG's are used to supply the consumer appliances and selling the extra energy to utility grid at the secondary circuit. It has load sharing property and provides uninterrupted, better quality of power to the consumers but these systems generate small amount of power compared to centralized generation plants. These systems are connected to the grid to improve the voltage regulation and also to share the load and then it is essential to check their performance

II. Modelling of Split-Shaft Micro Turbine Generation

The simple split shaft gas micro turbine generation system is shown in figure1, where power turbine is connected to generator via gear box, generates power at frequency of 50HZ. and modelling is explained below.

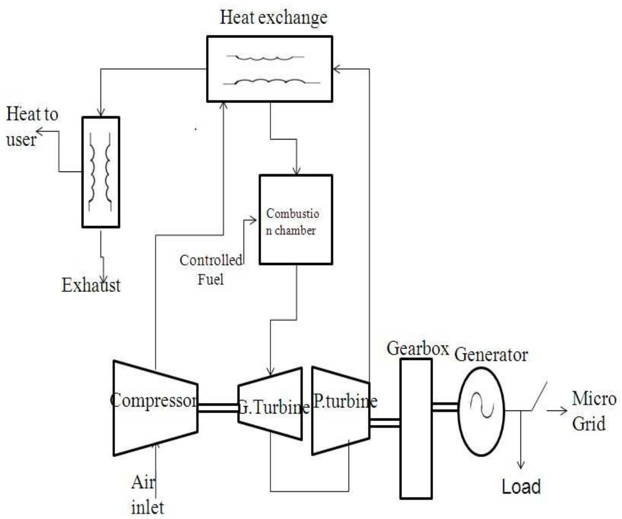

Fig 1. Schematic diagram of Split shaft micro turbine Generation System

The MTG system consists of following components,

Control System ,.Micro turbine and Permanent Magnet Synchronous Motor .Gas micro turbine modelling is carried out with the assumptions[10]. MTG system with individual components are explained with block diagram following subsections

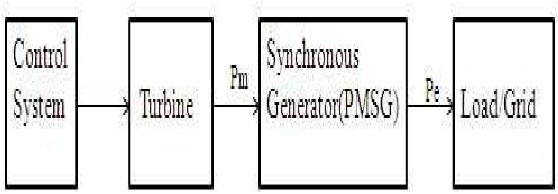

Fig 2. Block diagram of MTG system

A. *Control System*

Real power is controlled as function of controllers, and the controllers are simplified as active power controller, temperature controller, fuel controller and speed controller as shown in figure 2. Controllers with influencing parameters are given as follows,

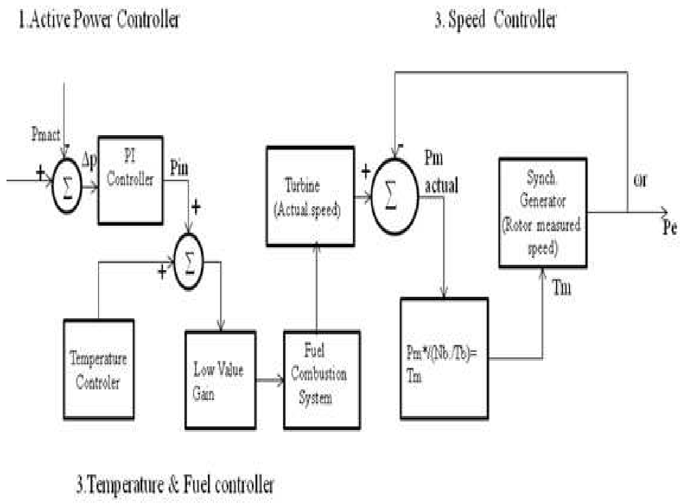

Fig 3. Control system model.

B. *Micro turbine*

Considering the simple split-shaft gas micro turbine, neglecting the governor in the modelling of micro turbine. The designing and modelling of gas micro turbine done without the droop and with controllers as explained, and is described in figure 4.

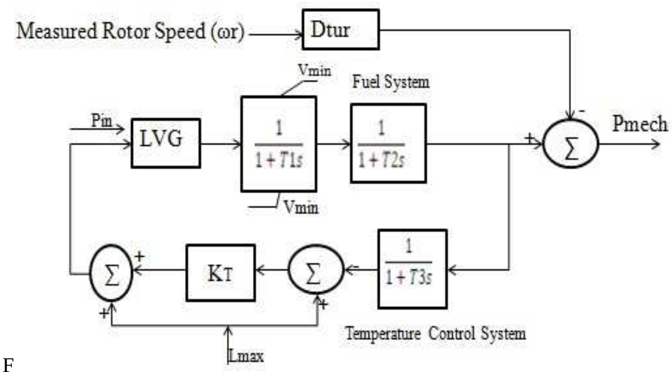

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Fig 4. Micro turbine model

C. *Synchronous Generator(PMSG)*

Micro turbine produces electrical power through generator. In split shat micro turbine, power turbine rotates at 3600 rpm and it is coupled to permanent magnet synchronous motor via gear box, power generated is at frequency of 50HZ. In PMSM external excitation by dc field of rotor is omitted and excited by permanent magnet. The advantages are, elimination of losses, power density increment, robust in construction and rotor inertia of lower value of rotor and higher efficiency than induction generator, reactive power can be controlled by adjusting the excitation. In PMSM no need of external excitation but costlier machine. The following equation described in the rotor reference frame (*dq* frame) are used to model the PMSM[11]

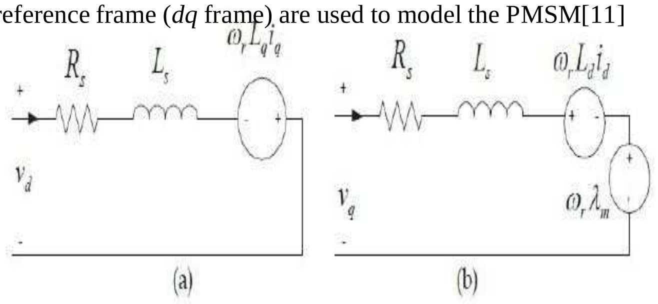

Fig 5. d- q axis equivalent circuit of PMSM

The modelling of PMSM is done with the assumption that neglecting the distributed windings and saturation, least values of eddy currents and hysteresis losses. With these assumptions the stator d-q equations of PMSM in the rotor reference frame [11].

D. Model Parameters

A).Gas micro turbine model parameters[10] ,B). PMSM model parameters from Sim Power systems of Matlab-Simulink and Grid Parameters from Sim Power systems of Matlab-Simulink are given

Table 1. Simulation parameters of MTG System Model

A. Gas micro turbine model parameters[7]

Parameter	Description	Quantity
P_{rated}	Rated power	4 KW
V_{rated}	Rated voltage	53.8 V
P_{ref}	Real power reference	1 p.u.
K_p	Proportional gain in PI control	1
K_i	Integral gain in PI control	1.08
D_{tur}	Damping of turbine	0.03
T_1	Fuel system lag time constant 1	10.0 s
T_2	Fuel system lag time 2	0.1 s
T_3	Load limit time constant	3.0 s
L_{max}	Load limit	1.2
V_{max}	Maximum value position 1	1.2
V_{min}	Minimum value position 2	-0.1
K_T	Temperature control loop gain 1	1

B .PMSM parameters:

P_{rated}	Rated power	4 KW
P	No. of poles	4
Rs	Resistance of Stator phase	0.18 Ω
Lab(H)	Inductances at Armature	1.67e-3
Λ	Flux linkage	0.071439Wb
J	Inertia,	0.0006214 kg.m^2
F	friction factor	0.000303N.m.s

C . Grid Parameters

X/R ratio	7
Base voltage (Vrms ph-ph):	25KV
3-phase short-circuit level at base voltage(VA):	100MVA
Frequency	50HZ

E. Matlab Simulation of Split Shaft MTG System.

Simulation of MTG is done with all components, in Matlab-Simulink environment, with modelling parameters in table 1, In figure 6.Modeling of MTG carried out using Sim Power Systems of the MATLAB-Simulink to analyze the performance of MTG system under load and grid connections in figure 7. Simulation parameters of this micro turbine model are listed in table 1. PMSG generates electric power and can be connected to load or interfaced to grid. considering the micro turbine's rated power is 4KW and the rated line voltage is 53V. Details of model developed for implementing the micro turbine generation system at load and grid connection through circuit breaker is shown in Figure7. Taking this micro turbine has 120% peak power capacity(loading capacity), So
Lmax = Vmax = 1.2

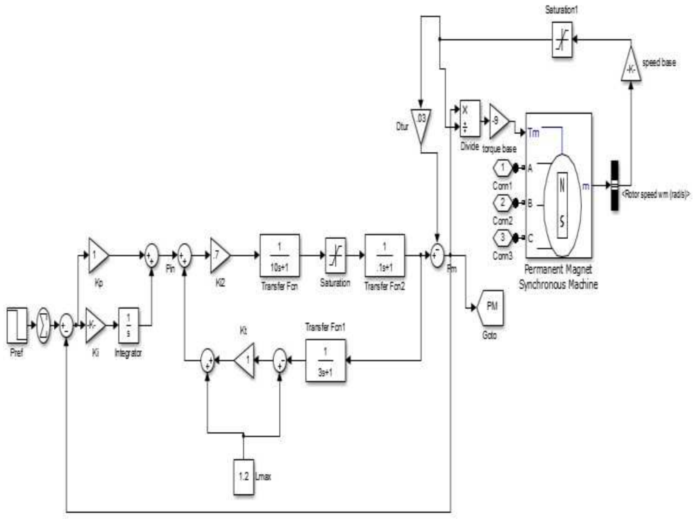

Fig 6 .Matlab -Simulink model for gas micro turbine Generation system

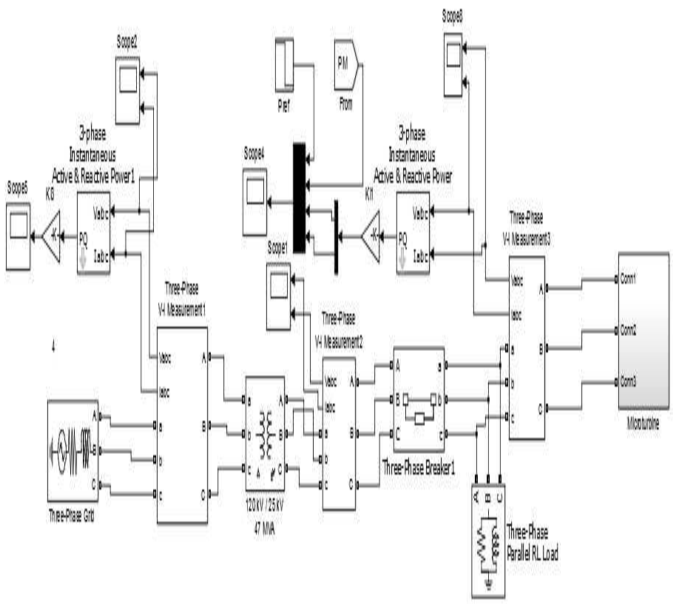

Fig 7. Matlab -Simulink model for MTG system connected to load and grid

III. RESULTS AND DISCUSSION

A. Stand-alone performance analysis of MTG system

Observations are made for the dynamic performance of the split-shaft MTG system under load connections and results are shown in below figures .Change in power demand can be effectively supplied by MTG system by controlling its load power through controllers as mentioned earlier. Assuming that split-shaft MTG system operating at constant rated voltage of 1.0 p.u, reference power of 1.0 p.u , rated power is equal to 4KW. Variation of power demand in range of 0.7 to 0.1 p.u taken, for increasing demand,0.7 to 0.4 p.u for decreasing power demand. Considering, at t=20 sec, there is a step change of power demand and for which there is change in mechanical torque (Tm) and rotor speed N‖, w.r.t respective increase and decrease in power demands, dynamic response of voltage and current output for MTG system with increasing and decreasing power demand takes place and the dynamic response of mechanical power (Pm) , three-phase electrical power output (Pe), w. r. t power demands are shown in Figure 12&13.

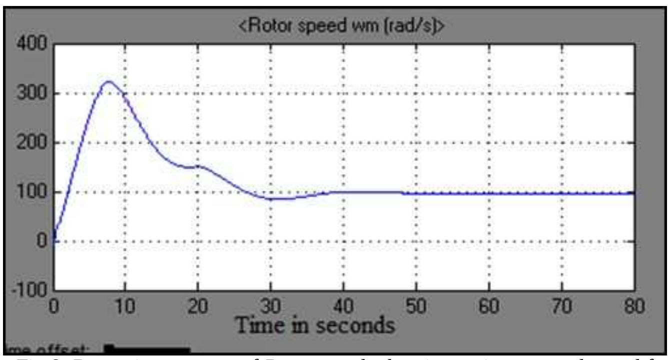

Fig 8. Dynamic response of Rotor speed when increasing power demand from 0.7 p.u. to 1 p.u at 20 seconds.

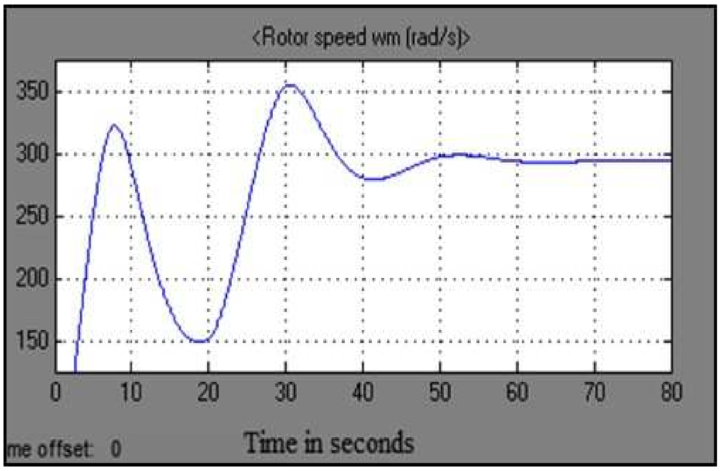

Fig 9. Dynamic response of Rotor speed when decreasing power demand from 0.7 p.u. to 0.4 p.u at 20 seconds.

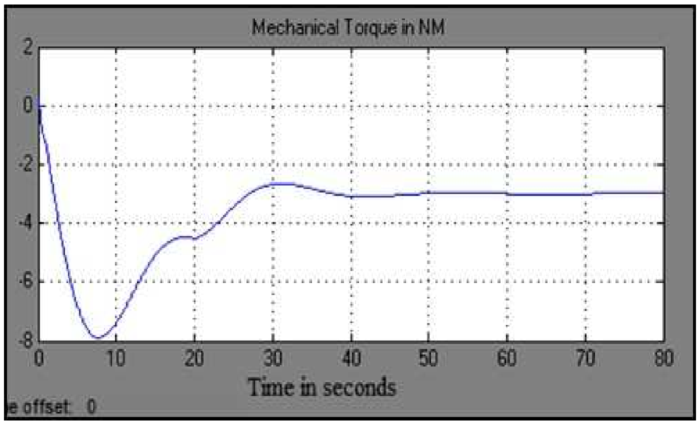

Fig 10 Dynamic response of Mechanical Torque when increasing power demand from 0.7 p.u. to 1 p.u at 20 seconds.

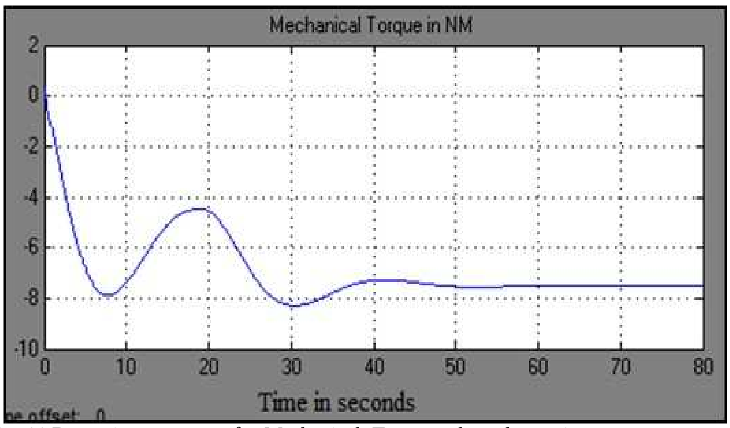

Fig 11.Dynamic response of Mechanical Torque when decreasing power demand from 0.7 p.u. to 0.4 p.u at 20 seconds.

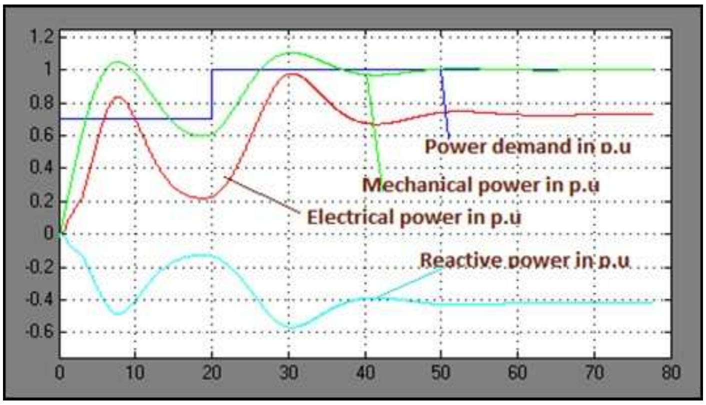

Fig 12.Dynamic response of MTG power when increasing power demand from 0.7 p.u. to 1.0 p.u at 20 seconds

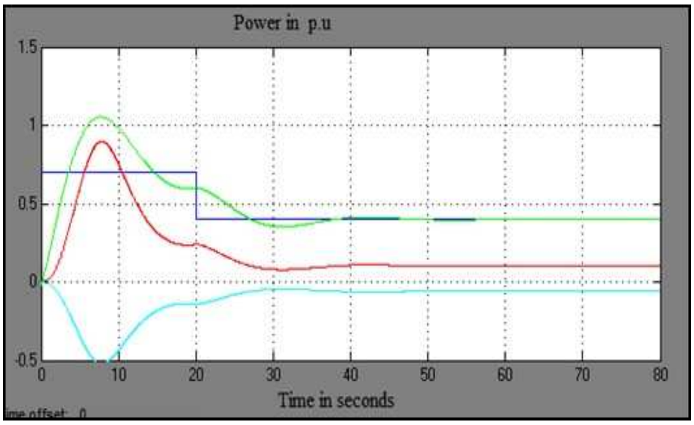

Fig 13. Dynamic response of MTG power when decreasing power demand from 0.7 p.u. to 0.4 p.u at 20 seconds.

B. *Grid Performance analysis of MTG system*

Generated three phase output power of MTG can be exported to grid, as micro turbine has load sharing property. In grid connected mode micro turbine is interfaced to grid through transformer, circuit breaker as well as to load . Change in power demand at load side can be effectively satisfied ,and extra power fed to grid ,it is taken care by the transformer .

Here MTG system is interfaced to 100MVA grid through transformer 47MVA ,25KV/100KV and circuit breaker of transition time [0 20] . Whether the .Increase/Decrease in demand condition of power demand at load side can be effectively supplied and circuit breaker is open till 20secs then closes crossing 20secs, power is fed to grid through transformer. Thus 18MW of power is exported to grid and base value is taken as 18 MVA and unit expressed in p.u, 1p.u equal to 1 .Grid side active and reactive power is shown in fig 14.

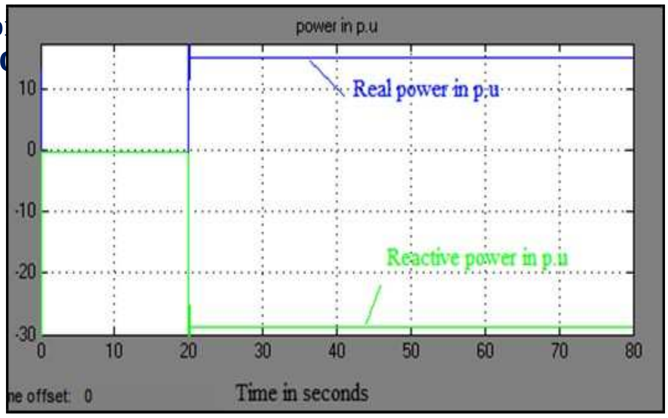

Fig 14. Real and reactive power when MTG interfaced to grid at Increase/decrease of power demand and circuit breaker closes after crossing 20 seconds

IV. CONCLUSION

In this paper, Matlab - Simulink dynamic model of a Split-shaft microturbine and is developed. Evaluation of stand-alone and Grid models shows that a Micro Turbine can increase or reduce its output mechanical power w r t demand response time of nearly 10 sec. When voltage drops then reactive power increases vice versa. The output mechanical power of the Micro turbine suffers from some oscillation due to the small inertia of the Micro Turbine. It is demonstrated that Micro Turbines capable of providing a load-following service in the distributed generation system, that can be used to ensure a good response.

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