Implementation of Model to Analyse the Performance of Microturbine as a Dispersed Generator in Micro Grid

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***Abstract*— This paper implements models of important distributed generators for shearing the load. At first a model which describes and simulates the dynamic performance of a single shaft micro turbine is developed and this model can test the dynamic response for the power demand change from 0% to 120% of the rated value. The stand alone dynamic performance of the developed models is analyzed and evaluated. Results prove the effectiveness of the proposed developed model and this model can be used to describe the behaviour of the Micro Grid (MG) under different disturbance conditions like load following, load shedding, unbalanced loads, failure of one micro source and so on. By using the micro sources a complete model can be built for the description of the overall dynamic performance of the Micro Grid (MG). The viability of the proposed power control mode is simulated by MATLAB/SIMULINK.**

Keywords—Dispersed Generator(DG); Unit Power Control (UPC); droop characteristics; microgrid, Micro Turbine(MT); Dynamic response.

I. INTRODUCTION

Dispersed generation (DG) is predicted to play an increasing attention in the electric power system of the near future. DG is small size of generation (25kW to 1MW) and connected at the substation, distribution feeders or consumer load point [1].The Micro Turbine generation (MTG) system is a typical and practical system of DG source, because of its small scale generation with fuel flexibility, reliability and power quality. It has been applied in various fields, such as power saving, co-generation, remote and premium power applications [2].

Dispersed generators (DGs) are an emerging alternative for energy production. Dispersed generator is directly connected to the load or near the load center. These DGs capacities vary from few kW to few MW (roughly 10 MW or less).The primary objectives (DGs) of power system has ensured a reliable and economic supply of electric energy to their consumers. Dispersed generators are of two different types depending upon the type of energy resources 1) renewable energy, such as: Ocean energy, Geothermal energy, Wind energy, Solar energy, Biomass energy and 2) Non-renewable energy, such as: Diesel generator, Small turbines [1], [2].Incorporating DG into the distribution system may have positive and/or negative impacts on the customer and on the utility equipment depending on the operative condition of the DG and the distribution system. Negative issues of DG may be instability of the voltage profile due to the bi-directional power flows, quality of supply and/or harmonics [3], [4]. Positive impacts and benefits could be summed as [5], [6].

Actually, distribution system is a passive network. If we incorporate DGs in this system, then it converts into active network. Thus its characteristic also changes from passive network to active network. The DGs help in distribution system increases capacity of feeder, improves voltage profile, improves power quality, improves voltage stability and system reliability and it also helps to control the frequency quality by load management of the connected network. To get best out of the DGs and to reduce extra losses during transmission, the proper allocation of DGs is also an important factor. In case of main grid connected Microgrid (MGs) the DGs positioning helps to share extra energy with the main grid [9].

As already we know that the Distributed Energy Resources (DERs) are of mainly two types i.e. renewable & non-renewable. We can use any kind of these resources but we should use a particular kind and or combination of these resources to get best result & efficiency. But availability & positioning of that DER at that particular network depends on the designer's own. It is widely accepted that micro turbine (MT) plays and will play an important role in MGs. Their small size and ratings provide a variety of opportunities to meet applications of distribution systems [10]-[14].

This paper is mainly focused on optimizing the transient behaviour of MT's speed response. It is organized, as follows: the next section reviews the modelling of MT and its control behaviour schemes. The modelling of permanent magnet (PM) generator is also presented in this section. The problem corresponding to the transient response of MT (in a sample daily load variation) is presented. A case study consider in this section is very useful and this shows, the effectiveness of the proposed controller design.

II. MICRO TURBINE MODELING

Micro Turbines are smaller version of heavy duty gas turbines compact in size and components like compressor, heat- exchanger, burner and turbine Micro Turbine is of two types. One is a high-speed single-shaft unit with the compressor and turbine mounted on the same shaft as the electrical alternators; turbine speed mainly range from 50,000 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 conventional generator connected via a gearbox [15].

Here we design split shaft model that uses a power turbine rotating at 3600 rpm. The parts of the model are split shaft power turbine, induction generator, power electronics, heat exchanger, control panel [16]. These are discussed in detail later in this paper.

[a] Characteristics of Micro turbine

Some of the primary characteristics for micro turbines include:

Dispersed generation—stand-alone, on-site applications remote from power grids

Quality power and reliability—reduced frequency variations, voltage transients, surges, dips, or other disruptions.

Stand-by power—used in the event of an outage, as a back-up to the electric grid.

Peak shaving—the use of micro turbines during times when electric use and demand charges are high.

Boost power—boost localized generation capacity and on more remote grids.

Low-cost energy—the use of micro turbines as base load or primary power that is less expensive to produce locally than it is to purchase from the electric utility.

Combined heat and power (cogeneration)—increases the efficiency of on-site power generation by using the waste heat for existing thermal process.

[b] Advantages

Micro turbine systems have many advantages over reciprocating engine generators, such as higher power density (with respect to footprint and weight), extremely low emissions and few, or just one, moving part. Those designed with foil bearings and air-cooling operates without oil, coolants or other hazardous materials. Micro turbines also have the advantage of having the majority of their waste heat contained in their relatively high temperature exhaust, whereas the waste heat of reciprocating engines split between its exhaust and cooling system. However, reciprocating engine generators are quicker to respond to changes in output power requirement and are usually slightly more efficient, although the efficiency of micro turbines is increasing. Micro turbines also lose more efficiency at low power levels than reciprocating engines.

Micro turbines offer several potential advantages compared to other technologies for small-scale power generation, including: a small number of moving parts, compact size, lightweight, greater efficiency, lower emissions, lower electricity costs, and opportunities to utilize waste fuels. Waste heat recovery can also be used with these systems to achieve efficiencies greater than 80%. Because of their small size, relatively low capital costs, expected low operations and maintenance costs, and automatic electronic control, micro turbines are expected to capture a significant share of the dispersed generation market. In addition, micro turbines offer an efficient and clean solution to direct mechanical drive markets such as compression and air conditioning.

[c] Thermodynamic Heat Cycle

In principle, micro turbines and larger gas turbines operate on the same thermodynamic heat cycle, the Brayton cycle. In this cycle, atmospheric air is compressed, heated at constant pressure, and then expanded. The excess power produced by the expander (also called the turbine) is consumed by the compressor to generate electricity. The power produced by an expansion turbine and consumed by a compressor is proportional to the absolute temperature of the gas passing through those devices. Higher expander inlet temperature and pressure ratios result in higher efficiency and specific power. Higher pressure ratios increase efficiency and specific power until an optimum pressure ratio is achieved, beyond which efficiency and specific power decrease. The optimum pressure ratio is considerably lower when a recuperator is used.

Consequently, for good power and efficiency, it is advantageous to operate the expansion turbine at the highest practical inlet temperature consistent with economic turbine blade materials and to operate the compressor with inlet air at the lowest temperature possible. The general trend in gas turbine advancement has been toward a combination of higher temperatures and pressures.

However, micro turbine inlet temperatures are generally limited to 1750°F or below to enable the use of relatively inexpensive materials for the turbine wheel and recuperator. For recuperated turbines, the optimum pressure ratio for best efficiency is usually less than 4:1.

[d] Components

We are mainly focus dynamic performance of micro turbine then we consider some assumption.

i) The system under normal condition (start up and shut down include)

ii) Heat exchanger use only increase in turbine model efficiency.

The main block of the micro turbine is shown in figure.1 below.

Controlling system

The simplified form of control system as a real power Proportional-Integral (PI) is used in this model. The controlled real power, P_{in} is applied the turbine.

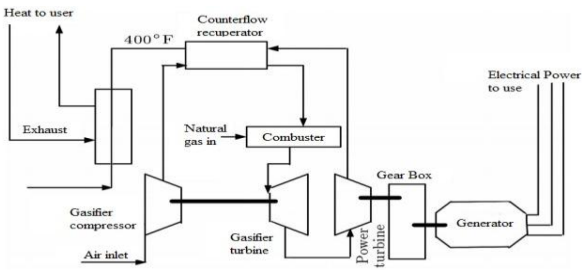

Fig. 1. Micro turbine diagram (Power work)

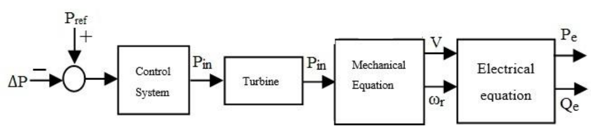

Fig. 2. Main blocks in turbine model

TURBINE:

Split-shaft model design of micro turbine consist of only one combustor and one gasified compressor. This model is simple and follows typical modeling guidelines. Here neglect the droop characteristic.

The mathematical equation of the generator is

$$2H\frac{\partial \omega_r}{\partial t} = \frac{P_m}{\omega_m} - P_e - D_{gen}(\omega_r - 1)$$

(1) Where, $\omega_r = \omega_m$, and $\omega_m = \frac{\omega_m}{\omega_b}$, ω_b is the base speed,

$$2H\frac{\partial \omega_m}{\partial t} = \frac{\omega_b^2 P_m}{\omega_m} - \omega_b P_e - D_{gen}(\omega_m - \omega_b)$$

(2)

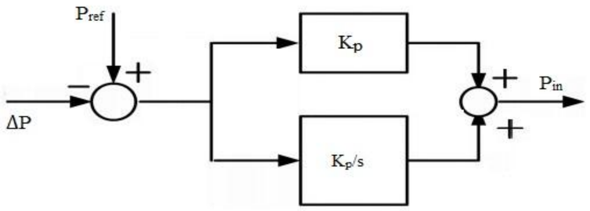

Fig. 3. Control system model

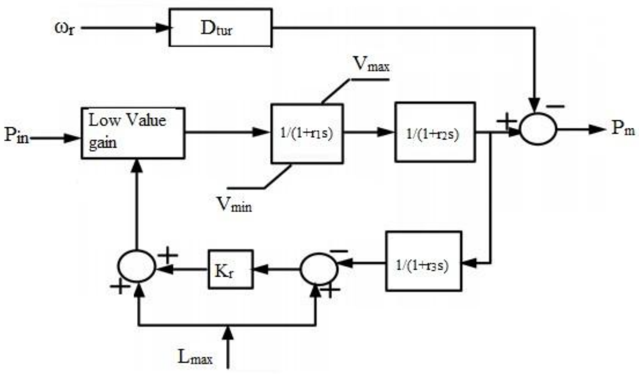

Fig. 4. Turbine model

Where:

P_m=mechanical power output of the turbine which inputs to the generator which is input to the shaft(Watt).

P_e=output electrical power (Watt),

D_{gen}=generator damping coefficient.

[e] Simulink® Model

Turbine model parameter (Split-shaft)

We assume that the rated power of the micro turbine is 3.73 kW and voltage is 380 V. The parameter of the micro turbine model is listed in table 1.

Parameters	Representations	Value
P_{rate}	Rated power	3.73 kW
V_{rated}	Rated voltage	380 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 const.1	10.0 s
T_2	Fuel system lag time const.2	0.1 s
T_3	Load limit time const.	3.0 s
L_{max}	Load Limit	1.2
V_{max}	Max value position	1.2
V_{min}	Minimum value position	-0.1
K_T	Temperature control loopgain	1
P	Number of poles	4
R_S	Resistance of stationary part	0.1Ω
R_r	Resistance of rotor circuit referred to the stationary circuit	0.1 Ω
L_S	Inductance of stationary circuit	0.0059 H
L_r	Inductance of rotor circuit referred to the stationary circuit	0.0059 H
Lm	Mutual inductance	0.2037 H
D_{gen}	Damping of generator	0.1
J	Generator inertia	0.02 kg.m^2
F	Generator friction	0.0057N.m.s

Table.1Parameters of split-shaft turbine model

Detail model developed on the micro turbine and generator model is shown in figure 5.

Assume micro turbine has 120% peak power capacity, therefore L_{maax}=V_{max}=1.2

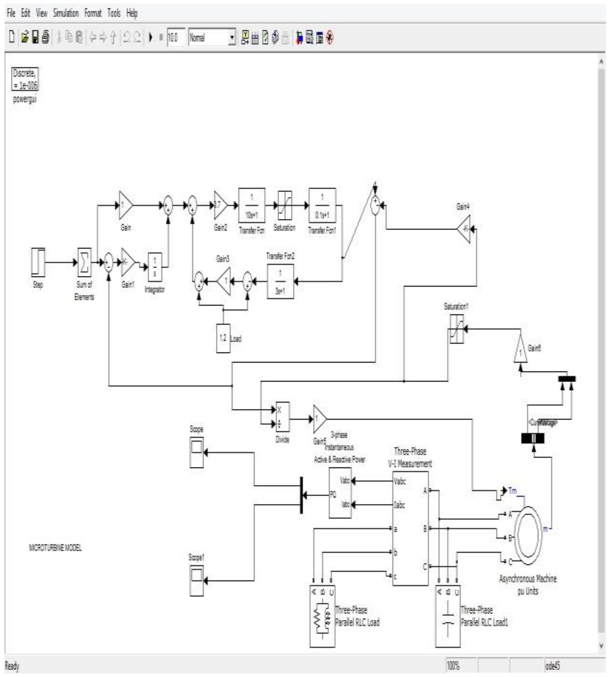

Fig. 5. Microturbine system Simulink model

[f] Performance

Split-shaft micro turbine system is operating with a constant rated voltage, 1.0 (p.u) and a power demand, 0.7 (p.u).Step increase of the power demand is from 0.7 (p.u) to 1 (p.u). The dynamic response of the mechanical power and electrical power demand response are in figure 7 and figure 8.

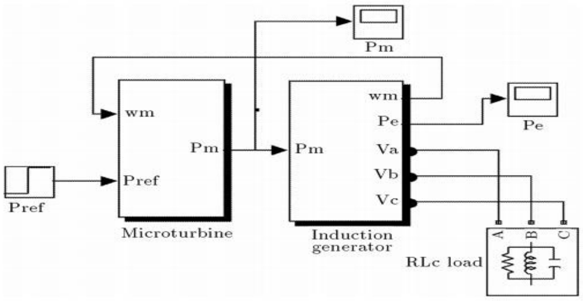

Fig. 6. Micro Turbine system mode

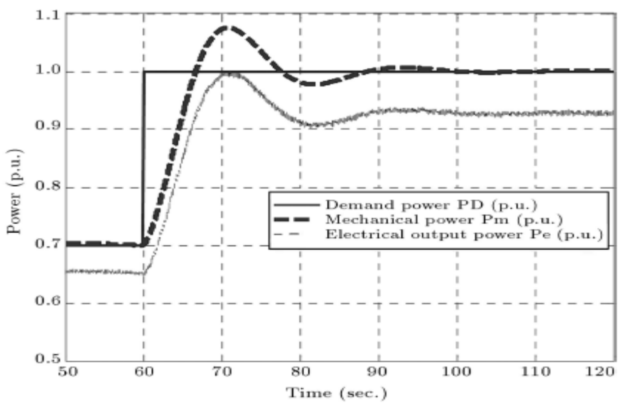

Fig. 7. Dynamic response of the micro turbine when increasing the power demand from 0.7 p.u. to 1.0 p.u.

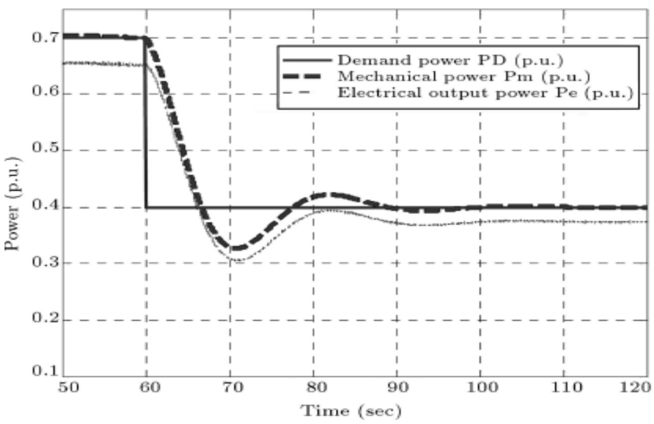

Fig. 8. Dynamic response of the micro turbine when increasing the power demand from 0.7 p.u. to 0.4 p.u.

From the figure 8 the efficiency of the micro turbine is nearly equal to 93%.

From Fig. 9 to 11, performance of the MG can be summarized in the following points:

Before t = 60 sec, MG is at its steady state and its frequency is equal to the nominal value, as shown in Figure 9. The Micro Turbine generates about 40% of its rating (20 kW), as shown in Figure 10. Voltage at bus 6 (Micro Turbine bus) is shown in Figure 11.

At t = 60 sec, the MG islanded from the main grid, which led it to lose certain active and reactive powers supplied by the main grid. Islanding led to frequency and voltage drop, as shown in Fig. 9 and 11, respectively

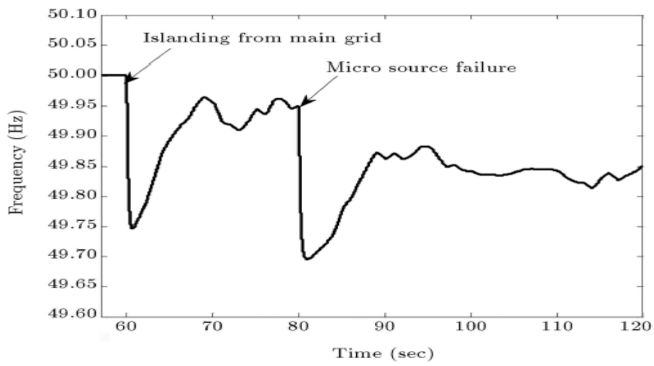

Fig. 9. MG frequency during and subsequent three disturbances.

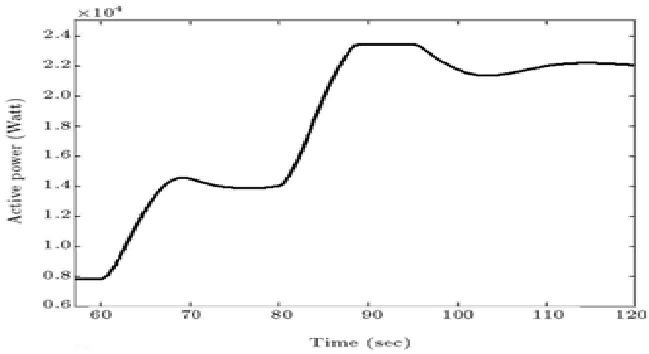

Fig. 10.Micro Turbine response

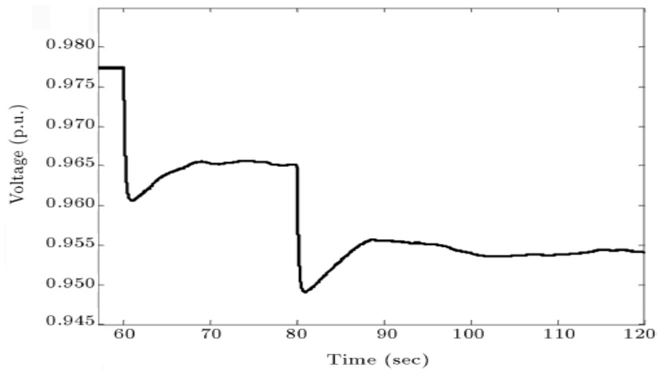

Fig. 11. Voltage at bus 6

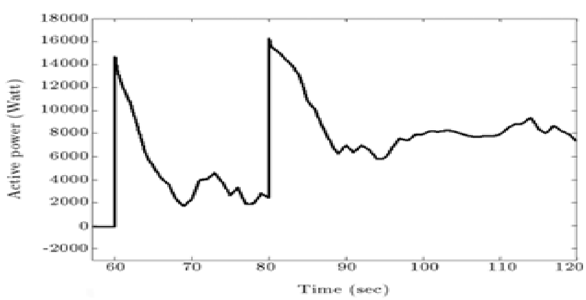

Fig. 11. Power injected by flywheel

[g] Application

Microturbines are widely used in Microgrids these days. As MGs are situated in small size area & like in a small county side area where main grid is unavailable & even in a housing complex where may be main grid is available but it's used as a supportive generator. Due to its compact size & quick energy generation capability MTs easily appear as the first preference of most of the MG planners. In addition, as micro turbines are being developed to utilize a variety of fuels, they are being used for resource recovery and landfill gas applications.

Due to all the above reasons it is used in the from of MGs to restaurants, hotels/motels, small offices, retail stores, and many others.

III. CONCLUSION

In this paper, Matlab® Simulink® dynamic models of a split-shaft Micro Turbine is developed. Evaluation of those stand-alone models shows that they are reasonable and suitable for dynamic simulations. It is found that a Micro Turbine can increase or reduce its output mechanical power (30%) with a response time of nearly 10 secs. 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 are capable of providing a load-following service in the distributed generation system, but the Micro Turbine is more suitable than the conventional method for systems that need a fast dynamic response; for that system, micro turbines can be used to ensure a good performance.

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