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Modeling and Performance Analysis of Microturbine Generation System in Grid Connected/Islanding Mode

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Abstract—**The microturbine based distributed generation (DG) system are predicted to play an important role in the distribution network in the near future. The microturbine generation (MTG) system has great impact on the DG system on real time system management and planning. It is popularly accepted that, MTG system are attracting the more attentions towards customers needs in a power generation market. Thus, to investigate the performance of MTG system and their efficient modeling are needed. This paper presents a dynamic modeling and performance analysis of MTG system in grid connected and islanding mode of operation. The model presented in this paper allows the power flow between grid and MTG system. The model of MTG system is built using mathematical expression in Matlab/Simulink environment. The simulation result shows the performance of MTG system for grid connected and islanding operation.**

Keywords-Distributed Generators, Microturbine, Permanent Magnet Synchronous Machine, Power Electronics Interface, Grid.

I. INTRODUCTION

The interconnection of DG into the distribution network is changing the paradigm, where the electrical power is generating in a large scale and sent to the consumers through a passive distribution network. The interconnection of DG to into a distribution network in current years has transformed them from being passive to active network [1]. The successive progress of DG is an important energy option in the present scenario is the result of combustion of utility restructuring, technological evaluation and environmental impacts. DG is generally accepted as a plant which connected directly to utilities distribution network or can operate independently and it can generally considered being less than 100MW in capacity, not centrally planned and dispatched. DG can be based on renewable and non renewable technologies such as wind turbine, photovoltaic's, fuel cell, gas turbine and microturbine generation system.

It is important to recognize that small gas turbine generators are not a new technology but are being developed for the electric utility industry based on technology with more than *25* years of actual field experience. DG using microturbine generation system is a practical solution because of it environment friendliness and high energy efficiency [2]. The interconnected DG to a distribution network will affect the dynamics of the system whose transient behavior can be assessed only with a detailed non-linear dynamics model is used. Thus, the accurate model of the MTG system is required to analyze the factors such as transient response, stability, power quality including harmonics distortion and voltage regulation.

There are different types of microturbine [3-5] based generation system has been performed in [6-10]. The dynamic model of single shaft MTG system suitable for grid connected and islanding operation has been presented in [6]. In this, the components of the MTG system are built from dynamic of each part with their interconnection. Also, the control strategies for both grid connected and an intentional islanding operation mode has been reported in [6]. The MTG systems with other electrical components are established using PSCAD/EMTDC in [7, 8]. The model developed in [8] is based on dynamics of each part and their interconnections. In addition to that, the double-SPWM control strategies of converter at power electronics interface are adopted. The simulation result reported in [8] can maintain the output voltage constant and meets the power demand when the load changes. The model of thermo-mechanical subsystem includes different control loops, speed controller for primary frequency control, acceleration control loop or in case of start up, and a controller to limit the temperature are developed in [9].Also, the modeling of control schemes in the electrical subsystem is another key issue providing efficient energy production are reported in[9]. The multidisciplinary model of microturbine in combined with fuel cell is developed in [10]. In this, the components of microturbine are developed individually using mathematical expression. The microturbine developed in [10] uses a synchronous generator to generator the electrical power and this power is developed to the load through power interfacing circuit.

This paper presents model of microturbine with all its components using mathematical expression in

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Matlab/Simulink environment. The MTG system uses a PMSM for motoring and generating modes of operation. The developed model considered a bidirectional power flow between the grid and MTG system. The simulation result shows the load following performance of MTG system in grid connected and islanding operation.

II. MICROTURBINE GENERATION SYSTEM

Basically there are two types of microturbine designs available, one is single shaft design with compressor and turbine are mounted on the single shaft runs at high speed usually permanent magnet synchronous machine (PMSM) is used which generates power at power at 150 to 400Hz. the high frequency voltage is rectified to DC and then inverted back to 50 or 60Hz AC voltage. Another one is split shaft design that uses a power turbine rotation at 3600 rpm and conventional generators are used (normally induction generator) connected via a gear box. Due to gear power transmission the speed of the generator turbine can be adjusted. Hence power electronics converter and inverter are not required for these types of microturbine [6]. The model of microturbine generation system used in this work is shown in Fig.1. It consists of individual components like compressor, recuperator, burner, turbine, PMSM and power electronics interfacing circuit.

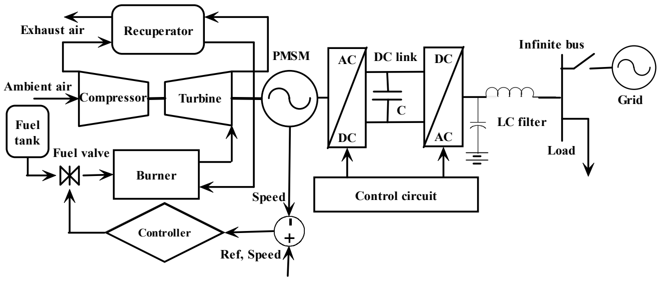

Fig.1 Microturbine generation system

A. Microturbine

The single shaft microturbine including the compressor, recuperator, burner and turbine using mathematical expression is implemented in Matlab/Simulink is shown in Fig.2. The model considered for this work includes fuel control, air control for governing scheme and turbine dynamics. The speed controller operates on the speed error formed between reference speed and microturbine speed. It is basically control the output power of the microturbine under part load condition [8]. The model equations are given in [10]. The compressor will compress the ambient air and passes to the heat exchanger where it will gain the heat form the turbine exhaust gas. The pressurized low temperature gas comes out the heat exchange is allowed to burner along with fuel. The high pressure high temperature gas comes out of the burner is allowed to pass throng the turbine to convert potential energy of gas into rotational mechanical energy.

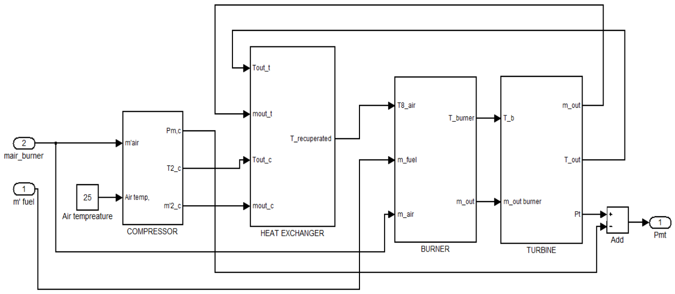

Fig.2 Matlab/Simulink model of microturbine

The rotating shaft of the microturbine is connected to the generator which converts the mechanical to electrical power. The microturbine runs at high speed between the ranges of 25 to 94krmp, this high speed is achieved for quick reason for the load variation and mitigate the changes as soon as possible. The low inertia and high speed of rotation can mitigate the disturbance in power during the load change and improves the power quality.

B. Permanent Magnet Synchronous Machine

The model adopted for the generator is two poles PMSM with non salient rotor. At 1500Hz (96krpm) the machine output power is 45kW and the terminal voltage of 480V. The electrical and mechanical components of the machine are represents states space model. The developed model assumes the flux established by machine is sinusoidal, which implies that, the electromotive force is sinusoidal. Based on the d-q reference frame theory, the stator voltage equation of the PMSM is can be described as,

$$\begin{cases} u_d = \dfrac{d\psi_d}{dt} - \psi_q \omega + r_s i_d \\ u_q = \dfrac{d\psi_d}{dt} - \psi_d \omega + r_s i_q \end{cases} \tag{1}$$

Where, u_d, u_q are the components of stator winding voltage, ψ_d, ψ_q are the d, q components of the stator flux linkages, i_d, i_q are the components of stator winding current, ω is the angular speed and r_s is the stator winding resistance.

The flux linkage of the PMSM can be expressed as,

$$\begin{cases} \psi_d = L_d i_d + \psi_{PM} \\ \psi_{PM} = L_q i_q \end{cases} \tag{2}$$

Where, L_d, L_q are d, q axis inductance and ψ_{PM} is the permanent magnet flux.

The electromagnetic torque equation of the generator is given by an equation,

$$T_e = \frac{3}{2} p\left(\psi_d i_d - \psi_q i_q\right) \tag{3}$$

Where, p is the number of pole pairs.

The motion equation of PMSM is expressed as,

$$T_e = J\frac{d\Omega}{dt} + B\Omega + T_L \tag{4}$$

Where, $\Omega = \omega/p$ i.e mechanical angular speed, J is the rotor inertia, B is damping constant and T_L is machine load.

C. Power Electronics Interfacing

The power electronics interfacing is a critical component for the single shaft MTG system with significant challenge. In particularly design and representing of MTG output power to the required load. There are several configurations available for this power interfacing with load. One of such is to use three phase diode rectifier, voltage source inverter (VSI) and suitable filter. This topology requires a separate starting attunement for the starting of MTG system. The configuration used in this work uses back to back voltage source converter (VSC). The developed topology of back to back converter allows bidirectional power flow between the MTG system and grid hence no separated starting arrangement is required to start the MTG system. To start the MTG system, the PMSM is made to run as motor by taking the power from the grid. During this mode the machine side converter acts as inverter and grid side invert acts as rectifier. Once the turbine reaches to the ignition speed the machine PMSM is made to run as generator. During the generator mode the power flows from the MTG system to the grid. The machine side converter and line side invert acts as rectifier and inverter respectively. In both motoring and generative mode of operation the grid side converter regulates the DC bus voltage while machine side converters control the displacement factor. This control stricture decouples effectively the two control schemes. The synchronization of grid side converter is carried out by the phase lock loop (PLL). Both converter and inverter uses PWM modulation techniques. Depending on the status of the MTG system two different control strategy for the line side converter have been considered. PQ control strategy with DC voltage control can be used for grid connected mode of operation and voltage/frequency control for stand alone or isolated mode of operation.

D. Machine Side Converter

The machine side converter control stricture for a MTG system is shown is shown in Fig.3

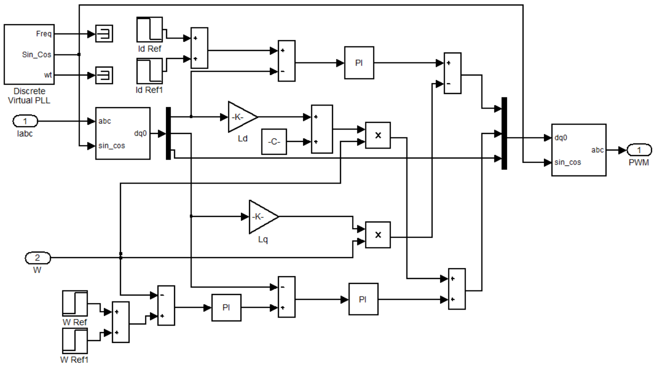

Fig.3 Machine side converter control

The commanded speed reference ω_{ref} is pre-calculated according to the microturbine dynamics, output power and set to the optimum speed. Based on the speed error the commanded q axis magnetizing current i_{qref} is determined by the speed controller. In the designed controller the PI controller with decoupling terms are utilized for the current controllers.

The decoupling equation of machine side converter control is given as,

$$i_{qref} = K_{p\omega}e_{\omega} + K_{i\omega}\int e_{\omega}dt \tag{5}$$

Where, $K_{p\omega}$ and $K_{i\omega}$ are the proportional and integral gains respectively. The commanded d-axis current i_{dref} is predetermined and set to the optimum magnetizing current value. Based on the current error the command dq axis voltage are determined through the current controller. In this developed system the following PI controller with decoupled terms are utilized for the current controllers.

$$V_d = K_{pi}e_d + K_{ii}\int e_d dt - w_r L_q i_q \tag{6}$$

$$V_q = K_{pi}e_q + K_{ii}\int e_q dt - w_r\left(L_q i_q + \lambda\right) \tag{7}$$

The commanded dq axis voltage (V_d, V_q) are transformed into abc quantities (V_a,V_b,V_c) and given PWM generator to generate the gate pulse.

E. Lines Side Convert Control

The line side converter control for a MTG system can be operated in both grid connected and isolated mode of operation.

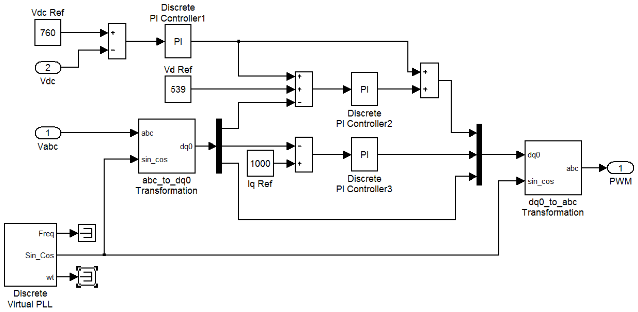

Fig.4 Line side converter control for grid connected

The grid connected mode of operation control structure is shown in Fig.4. The grid side converter operates as a controlled power source. The standard PI controllers are used to regulate the grid current in the dq synchronous frame in the inner control loops. It is seen that a PI controller regulates the DC bus voltage by imposing an id current component. i_d represented the active component of the injected current into the grid and i_q is its reactive component. In order to obtain only a transfer function of active power, the i_q current reference is set to zero. The decoupling terms are used to get the independence control of id and i_q in. a PLL is used to synchronize the converter with grid. The philosophy of the PLL is that the difference between grid phase angel and the inverter phase angel can be reduced to zero using PI controller and thus taking the line side inverter to phase side of the grid.

For the isolated mode of operation the grid is eliminated so the output voltage need to be controlled in terms of amplitude and frequency and thus, the reactive power flow can be controlled. Thus control structure for islanding control mode is dissipated in Fig.5 It consists of output voltage controller and DC link voltage controller. Thus output voltage controller will control the output voltage with minimal influence from the shape of the load transients.

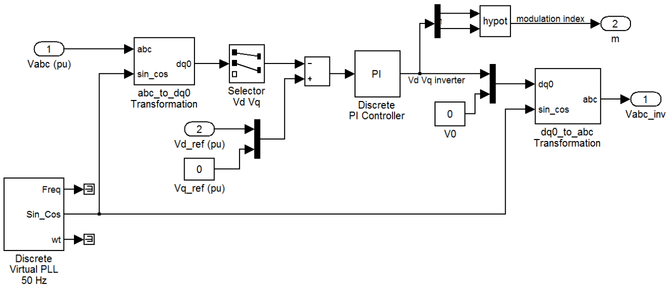

Fig.5 Line side converter for isolated mode

A standard PI controller operating in the synchronously rotating coordinated system where v_q is kept to zero is used. The DC voltage PI controller maintains the DC link voltage to the reference DC link is below the reference and it lowers the voltage reference of the main voltage controller in order to in order to avoid inverter saturation. For first response there is a direct forward connection to the voltage controller output. The frequency regulation has been done using virtual PLL block, which is available in the Matlab/Simulink simpower system library.

F. MTG System Control

The MTG system control structure developed in this work is shown in Fig.6. In this control system the turbine speed is compared with reference speed. The error speed is been compensated with PI controller. When the demand power changes the microturbine will changes its output power by controlling the fuel and air valves to the burner. The fuel and air flow has a linear relationship with fuel flow rates. As the angular speed of the PMSM changes, these flows will changes correspondingly. This is the reason behind the angular speed of the generator is use to control the burner's value.

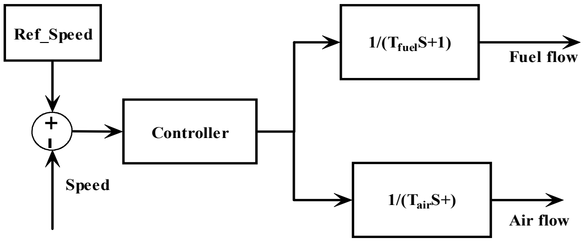

Fig.6 MTG system controller

III. SIMULATION RESULTS

The model used for study the performance of developed MTG system for grid connected and islanding mode of operation is shown in Fig.7. The distribution network to which the MTG system is connected is represented by balanced three phase source. The performance of the model is studied for different values of reference output power.

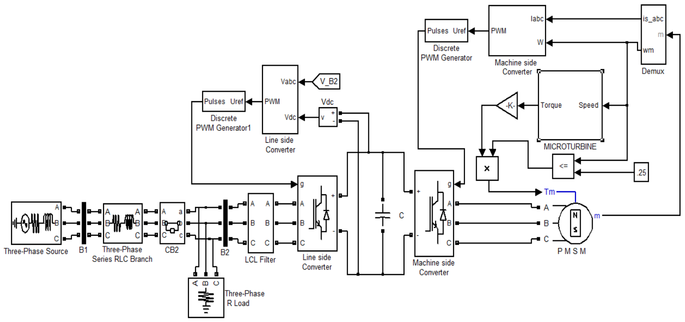

Fig.7 Matlab/Simulink model of MTG system

In this work, the MTG system is started and brought to an ignition speed by taking power from the grid, during the starting of MTG system the PMSM will acts as motor. Once the MTG system attains certain speed the PMSM is made to run as generator this feeds power reverse to the grid. Fig.8 shows that, the microturbine reaches to set value of speed at t=2sec. at this speed MTG system draws power from grid.

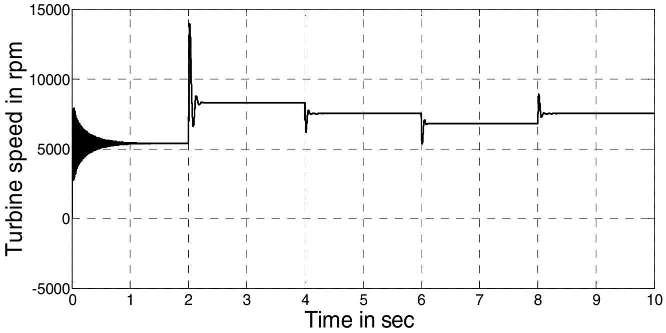

Fig.8 Turbine speed

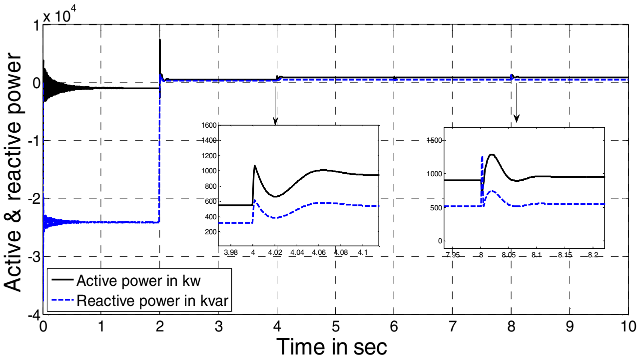

Fig.9 Active and reactive power

Fig.9 shows the resulting active and reactive power for motoring and generating modes of operation. Between t= 0 to 2sce power is negative and after 2sec the power is positive. Fig.10 shows the load current, in this the direction of current change form at t= 2sec, where as the magnitude of current at t=4, 6 and 8 sec, varies according to the load variation. The temperature variation of the turbine during the starting and load variation is shown in Fig.11.

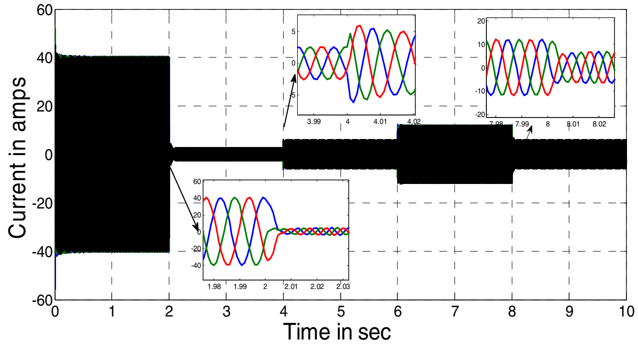

Fig.10 Current

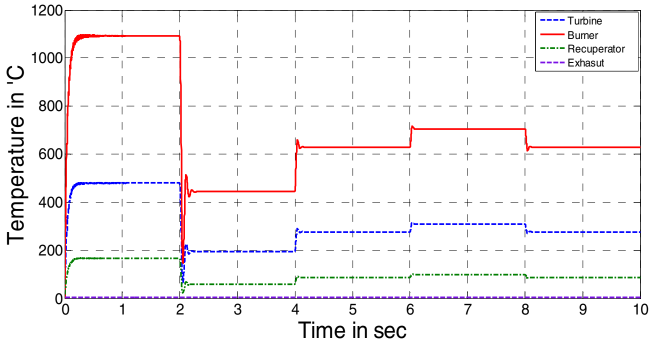

Fig.11 Temperature

The variation of electromagnetic and mechanical torque for motoring and generating operation is shown in Fig. 12. In this, the torque is negative before t=2sec and it positive after t=2sec. The turbine power to drive the PMSM is shown in Fig. 13. Before time t=2sce the PMSM drives the turbine until the ignition speed. Once the turbine is ignited, the turbine will drive the PMSM. The load voltage for motor and generator mode of operation is shown in Fig.14.

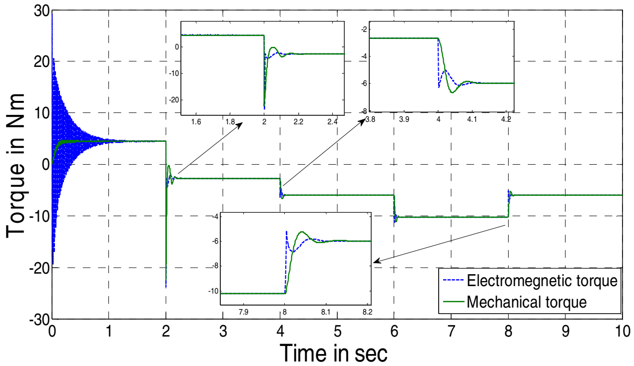

Fig.12 Torque

IV. CONCLUSIONS

The modeling and performance analysis of MTG system in grid connected and isolated mode of operation has been presented in this paper. The model of microturbine is developed using mathematical expression and implemented in Matlab/Simulink environment. The microturbine is used for MTG system with proper control systems for bidirectional power flow between the grid and MTG system. The simulation result shows the developed model has ability to adjust the output power as per the requirement within the system rating.

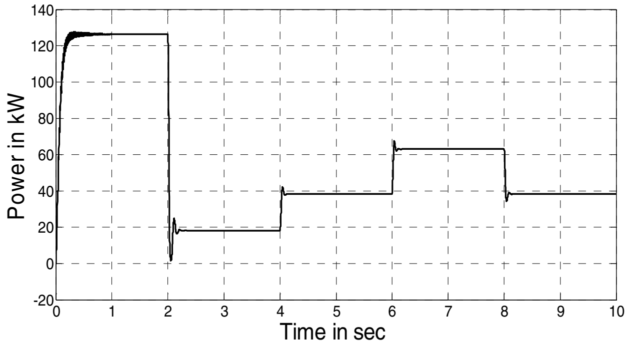

Fig.13 Power

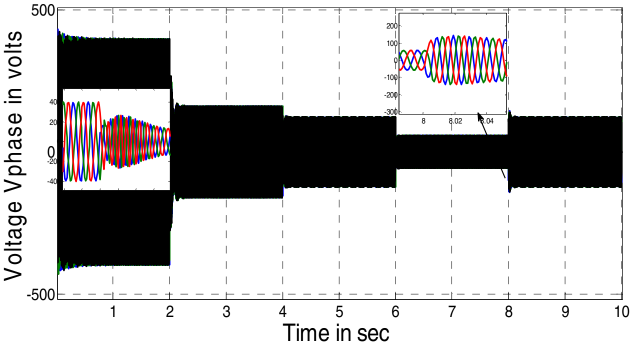

Fig.14 Phase voltage

The simulation results also shows that, the MTG system starts successfully by taking power from the grid and supplies power to the grid, once it started generating a power.

The model developed can be used to sturdy the performance of MTG system connected to grid that happens in a real system.

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VI. BIOGRAPHIES

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