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MODELLING AND SIMULATION OF MICRO TURBINE BASED SMART GRID SYSTEM

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Abstract-This paper presents modelling simulation and analyses of load following behaviour of micro turbine as distribution energy resource have been performed. The system comprises as a Micro turbine interconnected to the utility grid. The micro turbine generation is predicated to play an important role in the electric power system in the near future. It is widely accepted that micro turbine generation are currently attracting lot of attention to meet user needed in the distributed generation market. the model consist of speed control, acceleration control and temperature control .the system comprise to the permanent magnet synchronous machine (PMSG) and coupled to the micro turbine This work considers that the MT supplies power to variable and critical loads. The model also used a speed controller to maintain the MT speed constant as the load varies. The load following characteristics of this model observed through simulation studies have been presented and analyzed**.**

Key Words: Distributed Generation. Micro-turbine, Permanent Magnet Synchronous Machine, simulation, speed control.

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 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.[4,5].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 [6,7]. The microturbine generation system is new and a fast growing business and will likely become a dominant DG in the future power supply network [8,9]. 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 [10]

II. Microturbine system modeling

There are essentially two types of micro turbine designs. One is a high-speed single-shaft design with the compressor and turbine mounted on the same shaft as the permanent magnet synchronous generator. The generator generates a very high frequency three phase signal ranging from 1500 to 4000 Hz. The high frequency voltage is first rectified and then inverted to a normal 50 or 60 Hz voltage. Another is a split shaft design that uses a power turbine rotating at 3600 rpm and a conventional Generator (usually induction generator) Connected via a gearbox. The power inverters are not needed in this design. Along with the turbine there will be control systems including speed and acceleration control, fuel flow control, and temperature control. A micro turbine can generate power in the range of 25 KW to 500 KW.A control system regulates the speed, the temperature and the electric power. To control the a gearbox. The power inverters are not needed in this emphasis throughout the paper has been on a general model that can be used in as many different operating ranges as possible.

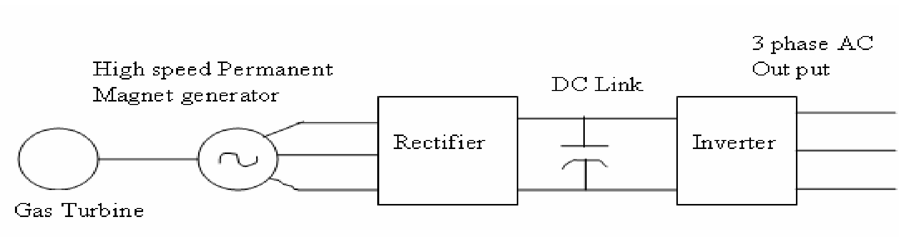

Fig-1 Microturbine generation system

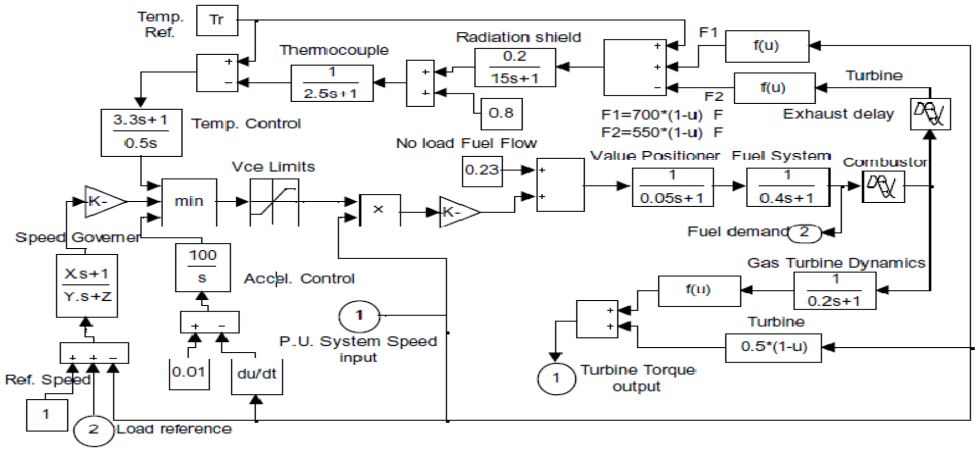

Fig -2 SIMULINK implementation of microturbine

A. Microturbine

The block diagram of microturbine along with its control is shown in Fig. 2 this consists of fuel, speed, acceleration and temperature control along with the combustor and turbine dynamics. The implementation of microturbine model using Simulink of the Matlab

B. Speed and Acceleration control

The speed control operates on the speed error formed between a reference (one per-unit) speed and the rotor speed of the MTG system. It is Primary means of control for the microturbine under different

Load conditions. Speed control is usually modeled by using a lead-lag transfer function or by a PID controller .Acceleration control is used primarily during gas turbine startup to limit the rate of rotor acceleration prior to reaching governor speed. And acts on the error between the derivative of p. u. speed of generator and constant reference signal temperature control and acceleration control are no significance under normal operating condition they are can omitted turbine model. The output of speed control, acceleration control systems go as input to a minimum value selector which selects the lowest value among the inputs

C. Compressor, Combustor and Turbine

Turbine is a linear, non dynamic device with the exception of the rotor time constant. There is a small transport delay, which is the time lag associated with the compressor discharge volume. Another transport delay is due to the transport of gas from the combustion system through the turbine. The values of these delays are given in. Both the torque and exhaust temperature characteristics of the single shaft gas turbines are essentially linear with respect to fuel flow and turbine speed.

D. Permanent Magnet Synchronous Machine

The model adopted for the generator is a 2 pole permanent magnet synchronous machine (PMSG) with non salient rotor the machine output is 30kw and is terminal line voltage is 480v the electrical an mechanical parts of the machine are each represented by the second order state space model. The model assumes that flux established by the PMSG in the stator is sinusoidal. The development of advanced magnetic materials, power electronics and digital control systems are making permanent magnet (PM) machine as an interesting solution for a wide range of applications. The advantages of PMSM compared to other AC machines are its simple structure, high-energy efficiency, reliable operation, high power density and Possibility of super high speed operation. Recent important applications of permanent magnet synchronous machine are in the area of distributed generation, mainly in wind and 192 Distributed Generation microturbine generation systems. An advantage of a high speed generator is that the size of the machine decreases almost in directly proportion to the increase in speed, leading to a very small unit. 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.

Electrical equation

$$\frac{d}{dt} id = \frac{1}{L_d} V_d - \frac{R}{L_d} i_d + \frac{L_q}{L_d} p\omega_r i_q$$

$$\frac{d}{dt} i_q = \frac{1}{L_q} V_q - \frac{R}{L_q} i_q + \frac{L_d}{L_d} p\omega_r i_q - \frac{\lambda p\omega_r}{L_q}$$

$$Te = 1.5p(\lambda i_q + (L_d - L_q) i_d i_q)$$

Mechanical equation

$$\frac{d}{d_t} \omega_r = \frac{1}{J} (T_e - F\omega_r - T_m)$$

$$\frac{d}{d_t} \theta = \omega_r$$

Where

Lq, Ld : q and d axis inductances

R : Resistance of the stator windings

iq, id : q and d axis currents

vq, vd : q and d axis voltages

ωr: Angular velocity of the rotor

λ : Flux induced by the permanent magnets in the

stator windings.

P: Number of pole pairs

Te: Electromagnetic torque

j: Combined inertia of rotor and load

F: Combined viscous friction of rotor and

Te: electromagnetic torque

Θ: rotor angle position

III. Machine side convertor control

$$\frac{d}{dt} i_q = \frac{1}{L_q} V_q - \frac{R}{L_q} i_q + \frac{L_d}{L_d} p\omega_r i_q - \frac{\lambda p\omega_r}{L_q}$$

$$Te = 1.5p(\lambda i_q + (L_d - L_q) i_d i_q)$$

$$\frac{d}{d_t} \omega_r = \frac{1}{J} (T_e - F\omega_r - T_m)$$

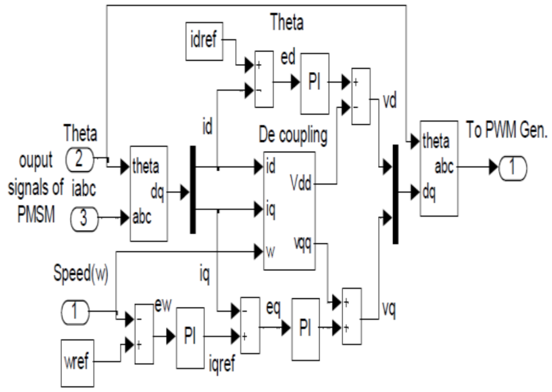

Fig-3 machine side convertor control

Machine side convertor controller implemented in Simulink of the Matlab. The commanded speed ωref is pre-calculated according to the turbine output power and set to the optimum speed Based on the speed error the commanded q axis reference current iqref is determined through the speed controller. In this system the following PI controller is employed as the speed controller.

Where

Kpω: proportional and integral gains of the speed controller, e ω :is the error between the reference speed and measured speed. The commanded optimal d-axis current idref is obtained from the maximum allowed phase voltage and phase current constraints of the drive, which are given in these Constraints, depend upon the machine rating and DC link voltage.

$$v_d^2 + v_q^2 \le v_{\max}^2$$

$$i_d^2 + i_q^2 \le i_{\max}^2$$

Using the above constraints and neglecting the voltage drop due to the stator resistance, the Optimal d-axis current for a non salient PMSM (Ld=Lq)

Considering the relationship

$$i_{\max}^2 = i_d^2 + i_q^2$$

The optimal d-axis current can be given as a Function of the q-axis current iq, as

$$v_d = K_{pi}e_d + K_{Ii}\int e_d dt - \omega_r L_q i_q$$

$$v_q = K_{pi}e_d + K_{Ii}\int e_d dt - \omega_r(L_d i_d + \lambda_m)$$

Where, KPi and Kli are the proportional and integral gains of the controller respectively.eid=is the d-axis current error and iq =iqref iq is the q-axis current error. The decoupling terms (ωr ,Lq, iq) and (ωr (Ld id+ ƛm) are used in respectively for the independent control of d and q-axis currents. The commanded dq-axis voltages (vd, vq) are transformed into a, b, c variables (va, vb, vc) and given to the PWM generator to generate the gate pulse for machine side converter.

A. Line side convertor control

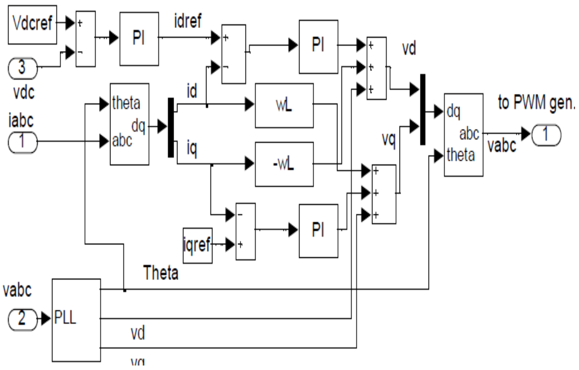

Fig- 4 line side convertor controller

The objective of the Line side converter is to keep the DC link voltage constant, regardless of the magnitude and direction of the rotor power. A vector control approach is used with the reference frame oriented along the line voltage vector position. This enables independent control of the voltage and frequency between the load and line side converter. The PWM converter is current regulated, where the direct axis current component is used to regulate the DC link voltage and q-axis current component is used to regulate the reactive power. Using the Park’s transformation, the voltage equations can be transformed to the dq reference frame.

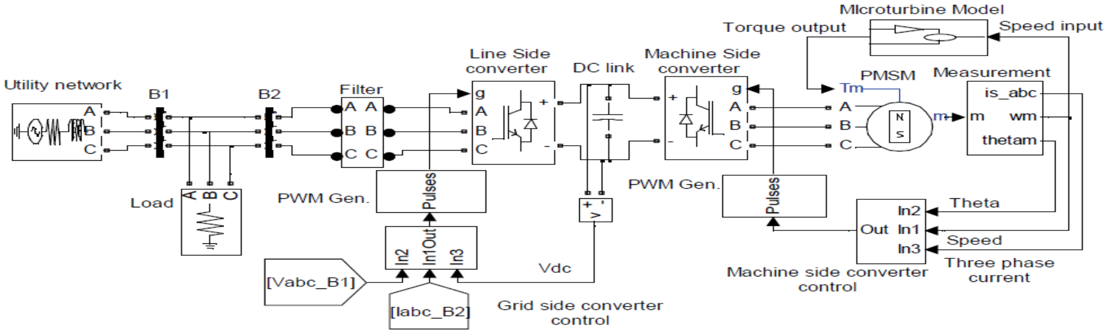

Fig -5 Matlab implementation of MTG system connected to the grid

IV. Simulation results

Grid parameters 480V, 60Hz, Rs=0.4Ωand Ls=2mH
Filter Parameters L=0.97mH, R=0.21Ω
Switching Frequency
Grid side converter = 8 Khz
Machine side Converter =20 KHz
DC link capacitance 5000 µF
PI controllers sampling time 100µsec
PMSM parameters 480 V, 30 kW, 1.6 KHz, 96000 rpm Rs=0.25 Ω, Lq=Ld=0.0006875H
Microturbine parameters
Gain(K)=25,X=0.4,Y=0.05 and Z=1

Figure-5 shows the simulation model implemented in the Simulink of the MATLAB to study the performance of the MTG system operation in grid connected mode The utility network, to which the MTG system is connected, is represented by a 3 phase sinusoidal source with its impedance. The series RL filter is used at the grid side of the MTG system. The simulation parameters of the model are given The micro turbine generation system takes per unit speed of the PMSM as input. The torque output of the microturbine is given as an input mechanical torque (Tm) to the PMSM. The direction of the torque Tm, is positive during motoring mode and made negative during generating mode of the PMSM. The machine side converter controller takes the rotor angle Performance Of Microturbine Generation System in Grid Connected Mode speed and 3 phase stator current signals of the PMSM as inputs. In all the presented cases the voltage across the capacitor is zero, at the starting of simulation. During the start up, the PMSM operates as a motor to bring the turbine to a speed of 30,000 rpm. In this case power flows from the grid to MTG system.

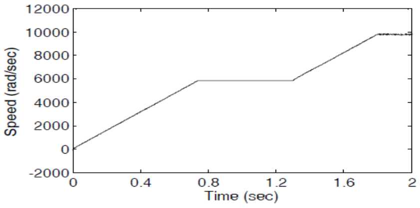

Fig: 6 motoring and generating operation speed variation of PMSG

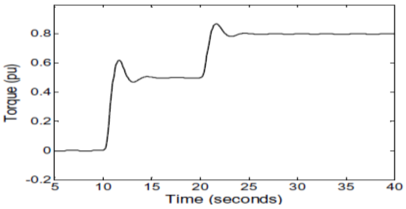

Fig-7 variation of shaft torque

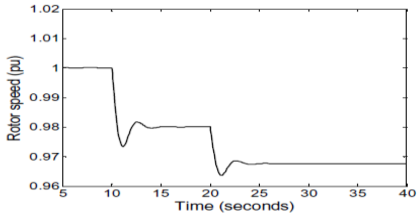

Fig-8 Rotor speed variation with load

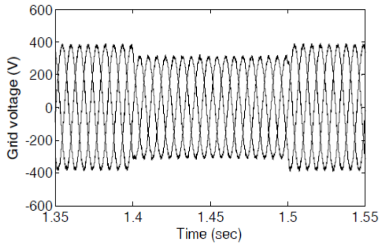

Fig-8 MTG system for grid voltage

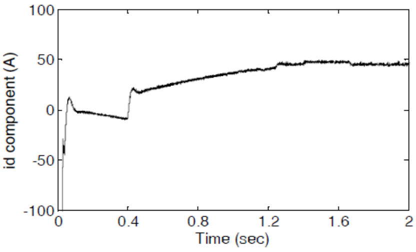

Fig-9 id component injected to the grid current

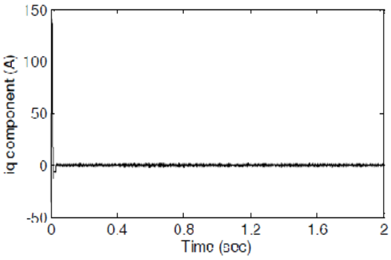

Fig-10 iq component injected to the grid current

V. CONCLUSION

The modeling of microturbine generation system suitable for DG applications. Modeling and simulation of microturbine are performed for its operation of grid-connected mode and mathematical modeling of the control systems of the microturbine is given and following that the detailed simulation model of the MTG system is developed using MATLAB's Simulation has also been performed with a speed control system incorporated to the MT-synchronous generator to keep the speed control for varying load. 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 grid-connected mode as a distributed energy resource to supply customer load demands as and when required.

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