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Modelling of Microturbine Generation System Using Matlab/Simulink

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ABSTRACT

Microturbine is one type of the Distributed Generation (DG). DG resource is small ranging about kW to fractional of MW. Nowadays, enhancement in technology of microturbine has become most promising technologies for small modular installation because desired features such as simplicity in mechanism, compact size, light weight, low emission and ability to operate with a wide range of fuels, as well as combined heat and power possibilities. In order to understand the microturbine's operation, their efficiency model is required. This paper presents the modelling of microturbine generation system using MATLAB/SIMULINK. Dynamic simulation model of a microturbine was conducted by implementing SimPowerSystem in MATLAB/SIMULINK. Each of the microturbine was represented by mathematical model. By using the model, signal analysis is conducted during start-up of the model. The model is conducted in grid-connected mode and islanded mode. The simulation shows the operation of microturbine in both modes.

Key words : Distributed generator, Microturbine. Model and Simulink..

1. INTRODUCTION

The advancement of DG technology has been increased recently. This includes the recent advances in renewable energy technology such as wind turbine, photovoltaic and small hydroelectric turbine and gain resource range from conventional technology such as diesel engines to emerging technologies such as microturbines or fuel cell [1, 2]. Besides, DG contributes high efficiency of the energy conversion process and cleanliness, better than the conventional power plants. DG is small ranging system where less than 100MW in capacity and connected directly to grid at the distribution level voltage or on the user side. The benefit of DG application depends on the type of distribution system, DG technology and size, location of DG in distribution system and level of DG penetration and load characteristic [1-3]. Moreover, DG is normally installed near the consumers. This leads to reduction in the generated electricity. DG can also be extended to heat and co-generation. Utilization of DG into distribution system affects the system dynamic operation, reliability, power quality, stability and protection [1]. Those parameters should be considered during design stage to sustain the reliability. Microturbine technology is one of DG that becomes most preferable power generation systems because it is more effectively utilized than the conventional gas turbines. Microturbine has power level ranging between 25 to 500 kW. Microturbine operates with higher frequency between 1500 Hz to 4000 Hz rather than conventional gas turbines so, microturbine moving with higher speed ranging 50000 to 120000 r.p.m..

Microturbine operates using various fuels such as natural gas, sour gases (high sulfur, low Btu content), and liquid fuels such as gasoline, kerosene, and diesel fuel/distillate heating oil to produce electricity and more efficient than the gas turbines while keeping low emission [1-4]. There are two types of microturbine, one with single shaft and the other one with split shaft. Split shaft model uses the compressor drive turbine's exhaust to power a second turbine that drives the generator via a gearbox to produce power. The ingle-shaft models generally operate at speeds over 60,000 revolutions per minute (r.p.m) and generate electrical power of high frequency, and of variable frequency [3, 4].

In this study, a simulation model of single shaft 30kW microturbine is developed. The model consists of microturbine, permanent magnet synchronous generator (PMSG) and power conditioning system (PCS). Microturbine drives the PMSG to generate the output power. The output power is distributed to the load and the utility grid through PCS. PCS is designed to ensure the desired performance of the system is achievable. This model is designed to simulate the operational of microturbine that interfered with the utility grid. The simulation is conducted within two modes, islanded mode and grid-connected mode. The simulation model of the system is built in the MATLAB/Simulink environment and implemented using SimPowerSystem toolbox.

2. MICROTURBINE GENERATION SYSTEM MODELING

In this paper single shaft microturbine is developed where the turbine and the generator are in single shaft. A single shaft microturbine system is shown in Fig. 1. A microturbine drives the permanent magnet synchronous generator (PMSG) with high level of speed typically 96000 r.p.m. and generate variation in high frequency i.e. 1500 Hz to 4000 Hz. Then, the high frequency voltage is rectified. The capacitor smoothens the peak-to-peak ripple voltage in Vdc to a reasonable value before inverted to a normal frequency 50 Hz or 60 Hz. Power conditioning system (PCS) controller is needed for controlling the active and reactive power during grid-connected operation and to control the voltage magnitude and frequency during the islanded mode. A pulse width modulation (PWM) control scheme is typically employed to control the MTG outputs. The LC filter is used to filter out the unwanted output component from the PCS. Finally, the output is distributed to the load and the utility grid.

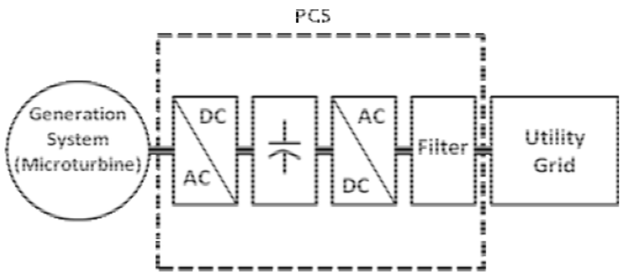

Figure 1: Microturbine Generation System

2.1 Microturbine System

A mathematical model represents a microturbine is shown in Figure 2. The model consists of temperature control, speed control, acceleration control, fuel system and compressor turbine system. Each component in the blocks has different function in controlling the torque of the turbine and represented in mathematical model. The detail functions are explained in the following section. Figure 2 illustrates the model of Microturbine System. From the figure, the speed of the turbine is determined by the fuel and feedback of the rotor speed. The amount of fuel flow to the compressor-turbine system is determined by the fuel system. The fuel system received the fuel demand from the minimum signal select (MSS).

The terminal MSS selects the minimum signal of the input and the smallest signal controls the amount of fuel flow to the compressor-turbine system. The MSS signal sources are from the temperature control, speed control and acceleration control. At normal/steady state operation, the signal V_{fmin} is dominantly controlled by the speed controller [1-9].

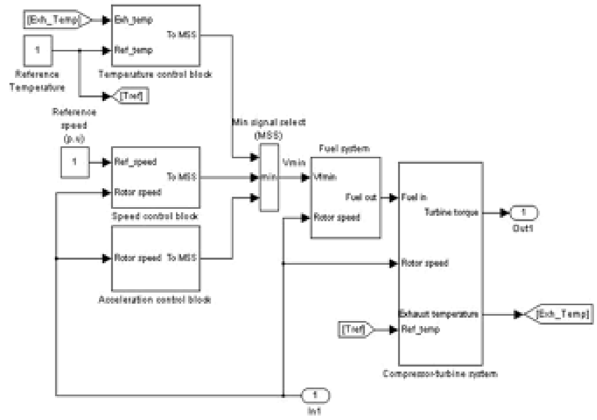

Figure 2: Model of Microturbine System

The speed controller is shown in Figure 3. The speed controller operates based on the difference between the per unit reference speed and the rotor speed from the PMSG. The speed difference is then passed through the mathematical model of lead-lag transfer function. In the lead-lag transfer function, the block with parameter T1, T2 and Z which can be adjusted so that the governor can act with droop or as isochronous governor [1-5].

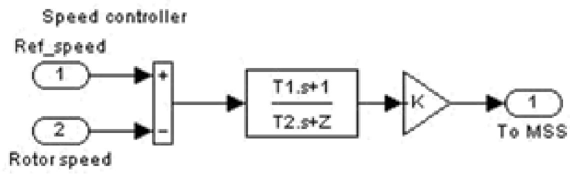

Figure 3: Speed Controller

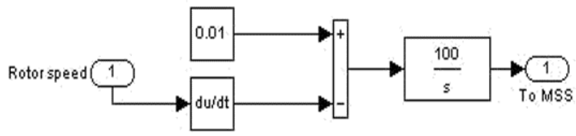

Figure 4: Acceleration Controller

Figure 4 shows the acceleration controller block. The acceleration controller is used to limit the acceleration rate of the generator during start up to prevent from over speeding. If the operating speed reaches the pre-set speed limit, the model can be eliminated [1-4]. The temperature control block shown in Figure 5 is used to avoid the microturbine system from overheating. In the microturbine, there is a combustion chamber where the fuel and compressed air are ignited by spark to drive the turbine. The ignition produced heat and the heat is controlled to prevent the operating temperature from exceeding the body temperature. The thermocouple measured the exhausted gas temperature incorporated with the radiation shield. The temperature controller is derived from the error resulted from the difference between the measured exhaust temperature T_x and the reference value T_{ref}. Conventionally, T_{ref} higher than T_x, which sets the temperature to the maximum limit, allowing speed controller to control the fuel flow to the combustion chamber. A negative output will be produced which then reduces the temperature due to the increment of the thermocouple output above the reference temperature. Hence, the output signals become lower than the output signals from the speed controller, the fuel flow controlled by temperature control system [1-4].

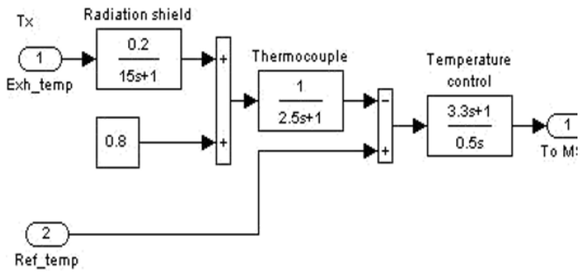

Figure 5: Temperature Control System

The fuel system shown in Figure 6 controls the fuel flow to the compressor-turbine system. At no load and rated speed, the minimum amount of fuel to keep the turbine system running represents of value 0.23. Under load condition, the signal from *Vf* min is scaled down and further offset by 0.23, thus, valve positioner and fuel system actuator acts to control the flow of fuel to the combustion chamber.

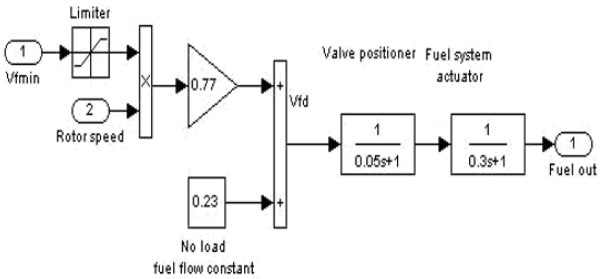

Figure 6: Fuel System

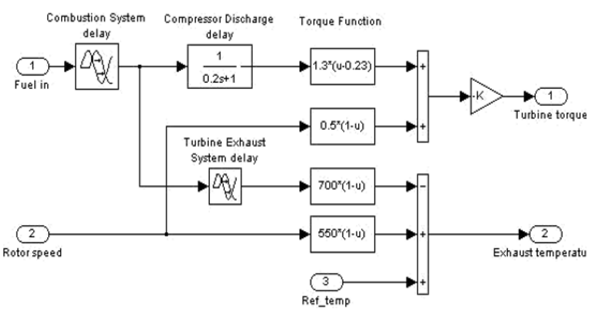

Figure 7: Compressor-Turbine System

Figure 7 shows the compressor-turbine system that represents the compressor system, combustion chamber and turbine system. This model considered the compressor discharge delay and torque exhaust system delay. The time constants are set according to the values employed in the most microturbine models. Both the torque and exhaust temperature generated by the compressor-turbine unit are linearly characterized by the fuel flow and turbine speed. The turbine torque and the exhaust gas temperature are determined by the following equations:

$$Torque = KHHV\,(u1 - 0.23) + 0.5(1-N) \quad (1)$$

$$Exhaust\ Temp = T_{ref} - 700(1-u2) + 550(1-N) \quad (2)$$

Where, *KHHV* is a coefficient which depends on the enthalpy value of the gas stream in the combustion chamber, T_{ref} is the reference temperature and N is the turbine speed [2, 4].

2.2 Permanent Magnet Synchronous Generator

A permanent magnet synchronous generator (PMSG) can be considered just like a standard synchronous generator. However, the excitation part was substituted by a permanent magnet coupled with a compressor-turbine system. A two-pole PMSG was utilized with the rated speed of 90,000 r.p.m.. This is a high speed generator which is able to generate an ouput power worth 30 kW, working with a high frequency condition of 1600 Hz. The second order state-space model is normally used to represent the electrical and mechanical representation. In this case, the flux derived in the permanent magnet in the stator is assumed sinusoidal [1].

2.3 Power Conditioning System (PCS)

Power conditioning system comprises of three phase diode-rectifier, DC link capacitor, voltage source inverter (VSI) and LC filter. PCS is used to convert non-sinusoidal and high frequency signal from PMSG to meet 415V, 50 Hz grid connected. The uncontrolled rectifier converts the high frequency of AC output from the PMSG to DC voltage. Then, the DC link capacitor is used as voltage reference and smoothed the peak-to-peak ripple voltage in DC voltage to reasonable value. The VSI converts the DC voltage to AC output to meet the grid connected. The output voltage of VSI control by PWM control system and high power, fast switched IGBTs. The output signals from VSI then enter the LC filter to filter out the unwanted harmonic components. The PCS can operate in two modes, due to grid-connected mode or islanded mode. During grid-connected mode, the PCS control the real and active power and for islanded mode, PCS controls the magnitude and the frequency of the output [16].

A. Grid- Connected Operation

Figure 8 shows the control system for grid-connected operation. During this operation, active power Pref and reactive power Q_{ref} is set and derives the active and reactive currents, I_{d_ref} and I_{qref} respectively. The P_{ref} and Q_{ref} determined the amount of active and reactive power (*P* and *Q*) injected to the grid. The inverter is current controlled in the rotating *dq* reference frame, where the *abc*/*dq* transformation block converts the inverter currents (in abc coordinates) into *dq* current values, I_d and I_q. Then, the Proportional-Integral (PI) controllers are used in the current controller to produce *dq* control signals. These signals are converted back to *abc* coordinates control system before entering the PWM control logic. The PWM control logic sends control signal to inverter to regulate the output voltage according to the active and reactive power [5, 16].

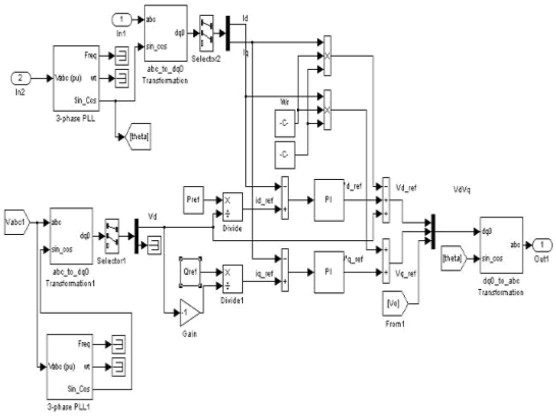

Figure 8: Grid-Connected Mode Control System

B. Islanded Operation

During the islanded mode operation, the microturbine system is isolated from the utility grid. The control system for islanded operation is shown in Figure 9. Under this condition, reference bus voltage and frequency of the grid are used to regulate the output voltage. The V_{dref} and V_{qref} are set in the control system. Bus voltage in *abc* coordinates is converted to *dq* signal and compared with the reference values. The PI controllers are used to keep the measured voltages at the set points. Then, the *dq* voltage signal are converted to *abc* coordinates control signals. The output voltage is regulated by the inverter through the PWM control logic and the frequency is regulated through the virtual PLL [1, 16].

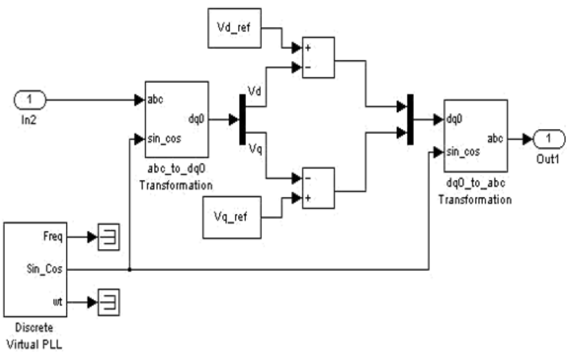

Figure 9: Islanded Mode Control System

3. RESULT AND DISCUSSION

Figure 10 shows the complete model of the microturbine generation system. To analyze the operation of microturbine generation system, there are two modes of operation of microturbine, grid-connected and islanded mode. The model is performed in MATLAB/SIMULINK environment. During the simulation, observation is taken at microturbine system side and utility grid side to study the output signal during start up for each operation mode. The microturbine model is rated at output power of 30kW and operates at nominal speed of 96000 r.p.m.. The system is connected to utility grid at 415V, 50Hz.

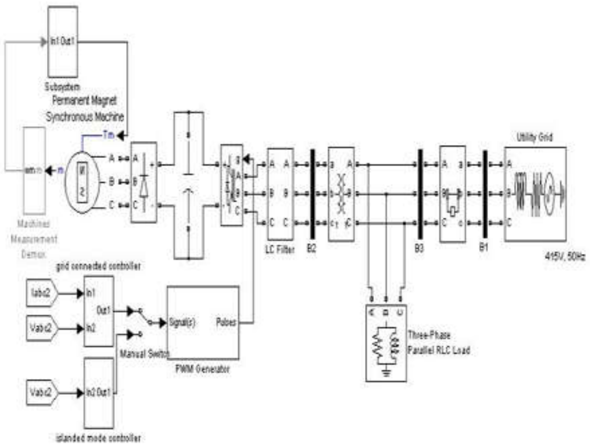

Figure 10 Simulation Model of the Microturbine Generation System

3.1 Grid- Connected Operation

During this operation, the microturbine is connected to utility grid where the circuit breaker is set close and PWM logic control receives input signal from the grid-connected controller. At start up, the microturbine acts as motor and needs input voltage to energize the excitation system. At this stage, rotor moves anti clockwise and becomes permanent magnet. Therefore, PMSG and load receives input power from the utility grid. After PMSG has reached 75% of the rated speed, i.e. 96000 rpm, the excitation cut in and allows the PMSG to reach its nominal voltage at 415V.

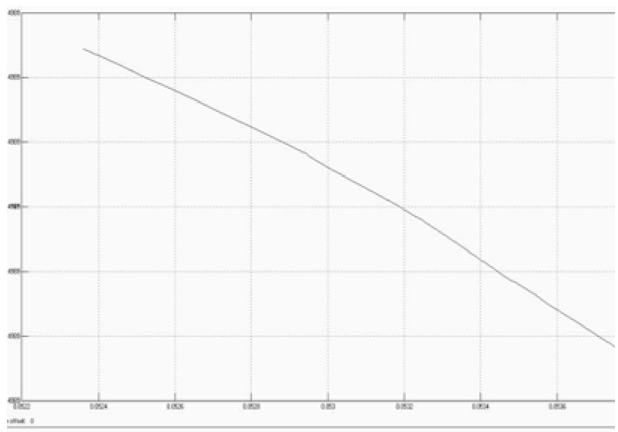

Figure 11: Active Power at Microturbine System

Figure 11 shows decline of active power at microturbine because PMSG and load required input from the utility grid. Hence, active power at utility grid also declined because of the demand from microturbine system. The decline of active power at utility grid is shown in Figure 12. Figure 13 and Figure 14 show the augmentation of reactive power because

PMSG acts as motor and the three-phase inductive load. Inductive loads required positive reactive power. Thus, the reactive power in the system is increased [15].

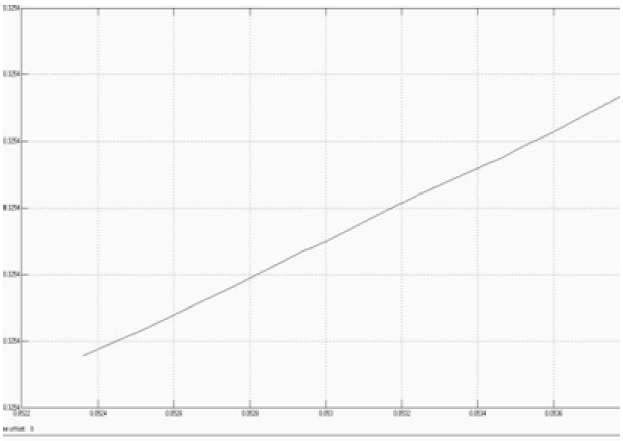

Figure 12: Reactive Power at Microturbine System

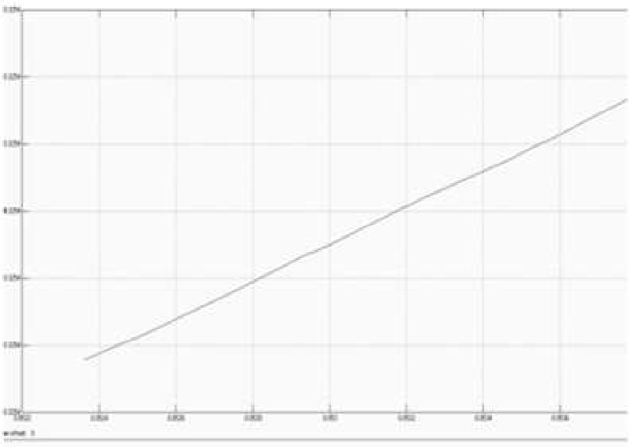

Figure 13: Active Power at Utility Grid

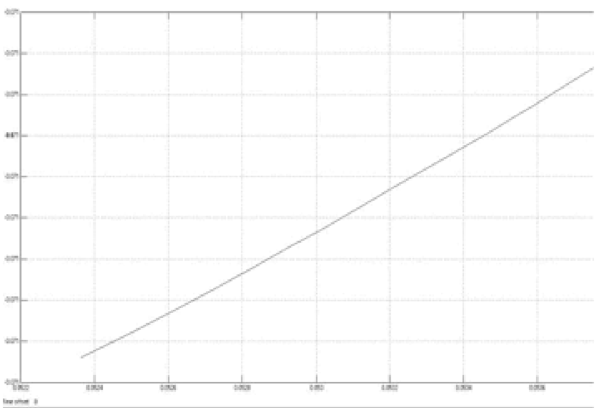

Figure 14: Reactive Power at Utility Grid

3.2 Islanded Operation

During this operation, the "island" was formed due to the disconnection between the microturbine system and utility grid. This was activated by the opening of the interface circuit breaker and the voltage-frequency (*Vf*) control. Although, there is no external supply from the utility, the figures show there is power flow in the microturbine system which means that microturbine can be a self-operating system.

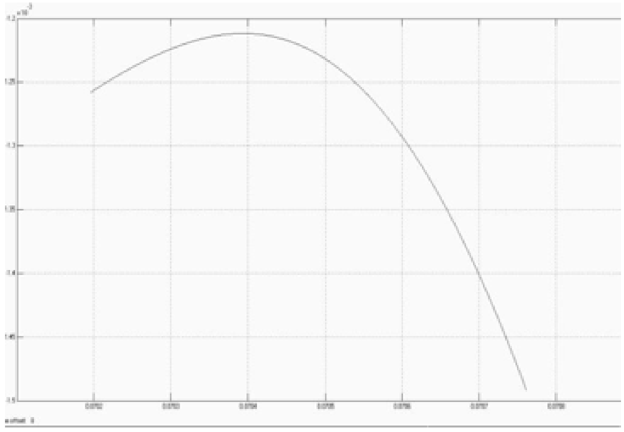

Figure 15: Active Power at Microturbine System

Figure 15 shows the declined of power because the three-phase load absorbs the active power and the PMSG also needs supply to start-up by the energized excitation system, so that rotor starts to move.

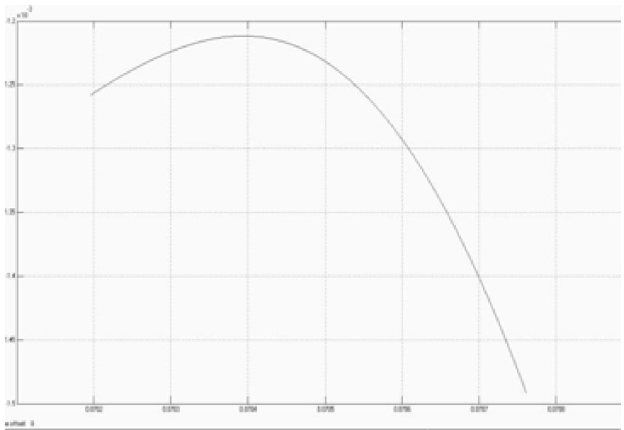

Figure 15: Active Power at Microturbine System

From Figure 16, it shows that the reactive power is negative value. During start-up, PMSG act as a motor and needs reactive power. Therefore, microturbine becomes capacitive to support the PMSG that need reactive power. When the microturbine system is capacitive, the reactive power is negative [15]. At utility grid, from Figure 17, the active power is declined during start-up because of sudden load and the utility grid needs to support the loads. For Figure 18, the reactive power is increased at the first interval before it drops down. This occurred due to the utility system is not stable during start-up and take times before it maintains at the demand value.

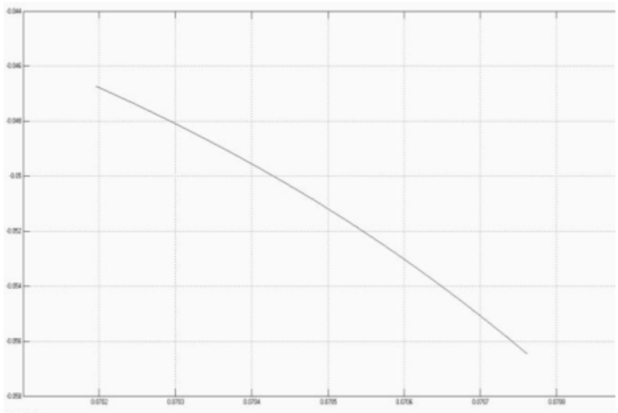

Figure 17: Active Power at Utility Grid

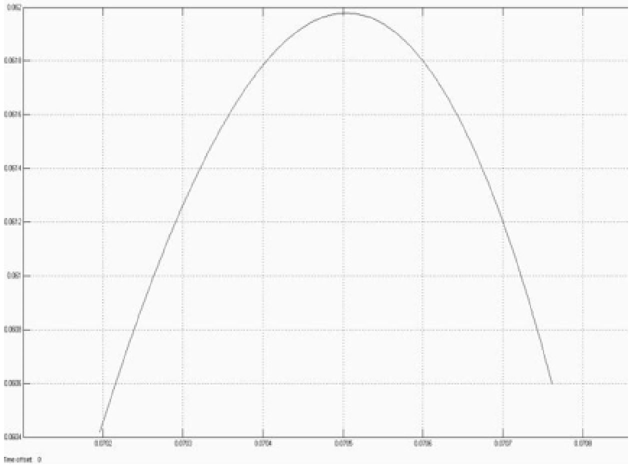

Figure 18: Reactive Power at Utility Grid

4. CONCLUSION

This paper has presented the modeling of microturbine generation system using MATLAB/SIMULINK. In this study, a model of single shaft microturbine system is developed to understand the operation of microturbine system and to analyze the power during start up. The simulation results demonstrate the operation of microturbine during grid-connected and islanded mode. The results also show the power flows at microturbine and utility grid. The results obtained are comparable with actual situation. Thus, the development of microturbine model shows the operation of microturbine during grid-connected and islanded mode successfully and effectively.

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