

Modeling and Simulation of Microturbine Generation System for Simultaneous Grid-Connected/Islanding Operation

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Abstract—Recently, global attention to distributed generation (DG) is increasing due to their potential advantages and merits. Between various sources, microturbines (MTs) as one of the most reliable have a significant contribution in this regard. This paper is presented dynamic modeling of a microturbine generation (MTG) system with a new passive filter topology. MTG configuration is consists of a permanent magnet synchronous generator (PMSG), an AC/DC rectifier, a boost converter, a DC/AC inverter and a remove ripple circuit (RRC) which is operated in isolated and grid-connected mode simultaneously. Using the boost converter and RRC filter is a new and efficient method for microturbine operations. Simulation study is carried out in MATLAB/Simulink and results show fast dynamic and desired performance of proposed structure.

Keywords-Microturbine; Distributed Generation; RRC filter; Boost converter;

I. INTRODUCTION

The interest in distributed generation is increasing due to technical, economical, reliability and environmental merits. There are a variety of methods to produce power such as solar cell, wind turbine, fuel cells, microturbine and diesel generators. Microturbine is a small and simple gas turbine that operates based on Brayton cycle.

MTs system includes a turbine, compressor, combustor or combustion chamber, recuperator and a Permanent Magnet Synchronous Generator. Inlet air at ambient temperature is compressed through compressor and then compressed air is mixed with fuel in the combustor and finally, high pressure gasses are passing through the turbine cause to producing mechanical power and rotating PMSG. Recuperator is uses hot wasted gas of turbine to reheat the compressed air before enters to combustor and it is a heat exchanger. MT produces power in range of 25 to 500 kW and its efficiency is around 20-30% that

in recuperated turbine and combined heat and power (CHP) systems is reach up to 80%.

Generally, MT advantages are compact size, reliability, low initial cost, inexpensively maintenance, control simplicity, low emissions level, fewer moving parts and ability to operates with various fuels like natural gas, diesel, propane, kerosene and biogas. MT applications include peak shaving, premium power, remote power and in transportation system.

There are two types of MTG design: single-shaft model and split-shaft model. In the single-shaft design, all component including compressor, turbine and PMSG are mounted on a same shaft. The PMSG creates high frequency AC voltage in the range of 1.5-4 kHz and requires a power electronic interface for converting high frequency to desired frequency. Fig. 1 is shown a single-shaft MT in two operation mode that are grid connected mode (on-grid) and islanding mode (off-grid). In the split-shaft design, there are two parts which are coupled together through a gearbox so, is not required to power electronic interfaces.

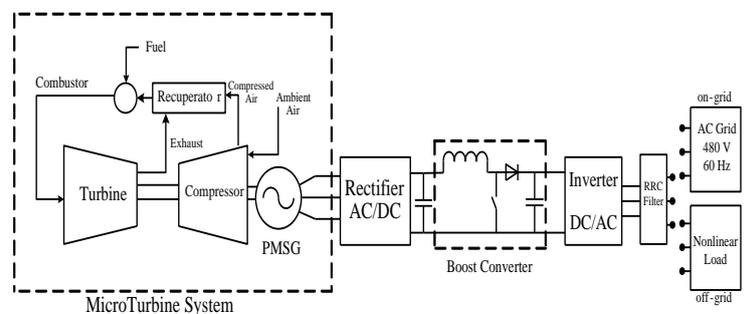


Fig. 1. Microturbine generation system

One method to convert high frequency of PMSG to 50Hz or 60Hz is using of AC/DC/AC structure. In this method, at first AC voltage is converted to DC voltage and then through an inverter is converted to AC voltage again with appropriate frequency. In this paper a boost converter is used to increase rectifier output voltage level and reduction of fluctuations. Inverter output requires an appropriate filter for reduction of harmonics thus, RRC is a good choice for this purpose.

Recently, MTs efficient operation is one of challenges and various methods are proposed. In [1] and [2] the basic principle of MTGs as a distributed resource are presented. In [3] a complete mathematical model of PMSG and a single-shaft MT in isolated mode under MATLAB/Simulink is proposed. The evaluation of MT electromagnetic transients in grid-connected mode is done in [4]. Dynamic model of a MT system and control strategies for grid connected and islanding operation is introduced in [5]. In [6] the model of MTG system as micro grid under PSCAD/EMTDC is presented and the SPWM control strategy is used for power electronic interface. In [7] thermo mechanical system with different control loop like a controller for limiting temperature and a controller for start-up is introduced. In [8] a distribution system embedded with a micro-turbine plant and an integrated fuel cell power plant is used for load-following and economic issues.

In this paper, dynamic modeling of a single-shaft MT with AC/DC/AC structure is proposed. MTG configuration with boost converter and RRC as a new filter topology causes desired power flow and sinusoidal output voltage. For comprehensive analysis, MT is grid-connected with supplying a nonlinear load simultaneously and simulations carried out in MATLAB/Simulink. In section two a dynamic model of micro-turbine and control strategy for grid-connected and islanding operation is proposed and then in section three simulation results is presented when load changing is occurred and finally, section four is conclusion.

II. MODEL DESCRIPTION

A. Modeling of a Microturbine

A dynamic model of a single-shaft microturbine in MATLAB/Simulink is shown in Fig. 2. This model consists of acceleration control, speed governor, temperature control, fuel control and turbine dynamic blocks [5]. In this modeling, suppose that system operates in normal condition without fast dynamics.

Speed controller operates based on speed error between reference and MTG rotor speed and a lead-lag transfer function or a PID controller is used for speed governor modeling. Acceleration control is used for start-up time of micro-turbine and when reference speed is near to rated speed it can be ignored. Governor output and acceleration control with temperature controller output are gone to a MIN block that least value signal is selected. The output of MIN block is scaled by 0.77 and is offset by 0.23 that is representing fuel flow at no load condition. Time delay before fuel flow controls represents delays in the governor control. Finally fuel burn in combustor and enters to turbine for producing mechanical torque. The temperature of exhaust gas is measured by a thermocouple and then is compared with a reference value that

is 950. In normal condition, reference is higher than thermocouple output and caused maximum value for temperature control. If thermocouple output exceeds reference, negative value generates and cause system operates for decreasing temperature.

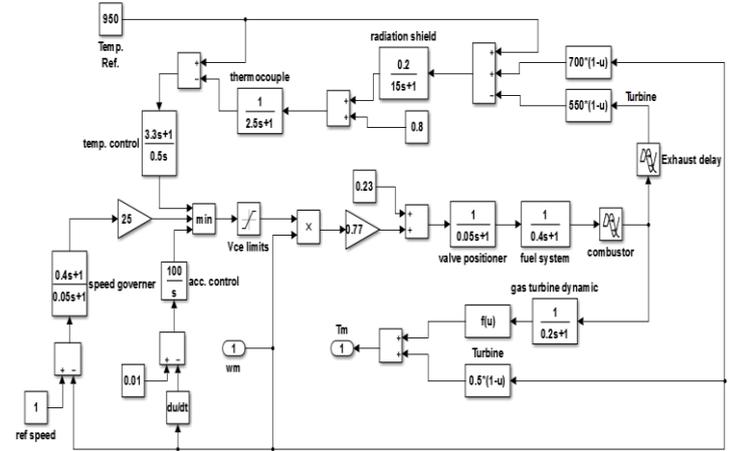


Fig. 2. Dynamic model of microturbine

B. Permanent Magnet Synchronous Generator (PMSG)

MT is required to a synchronous or asynchronous generator to produce electric power and PMSG is superior. Field winding is replaced by a permanent magnet in PMSGs which cause lower power losses and lower maintenance. In this paper, PMSG is 2 poles which is operates at 100,000 RPM and parameters are: $L_d=L_q=0.0006875$ H and $R_s=0.3$. In this model assumes that flux in stator is sinusoidal and caused sinusoidal electromotive forces. PMSG configuration equations in dq0 reference frame are as following:

Electrical equations:

$$\frac{di_d}{dt} = \frac{v_d}{L_d} - \frac{Ri_d}{L_d} + \frac{L_q}{L_d} p\omega_r i_q \quad (1)$$

$$\frac{di_q}{dt} = \frac{v_q}{L_q} - \frac{Ri_q}{L_q} - \frac{L_d}{L_q} p\omega_r i_d - \frac{\lambda p\omega_r}{L_q} \quad (2)$$

$$T_e = \frac{3}{2} p (\lambda i_q + (L_d - L_q) i_d i_q) \quad (3)$$

Where

L_d, L_q : d and q axis inductances

R: Stator winding resistance

i_q, i_d : q and d axis currents

v_q, v_d : q and d axis voltages

ω_r : Rotor angular velocity

λ : Flux linkage

p: Pole number

T_e : Electromagnetic torque

Mechanical equations:

$$\frac{d\theta}{dt} = \omega_r \quad (4)$$

$$\frac{d\omega_r}{dt} = \frac{1}{J}(T_e - F\omega_r - T_m) \quad (5)$$

Where

- J: Rotor and load combined inertia
- F: Rotor and load combined viscous friction
- T_m: Mechanical torque
- Θ: Rotor angular position

C. Boost converter

In this paper a boost converter is used to stabilize fluctuates of output voltage which comes from PMSG [9]. Boost converter and control strategy diagram are shown in Fig. 3.

In boost converter, output voltage is higher than input voltage and duty cycle is used to adjust ratio of output voltage to input voltage.

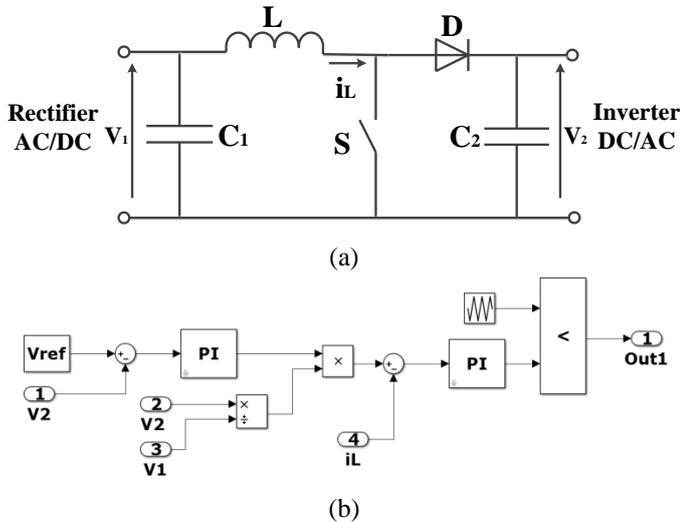


Fig. 3. Boost converter: (a) circuit topology (b) control strategy

D. inverter controller circuits

Microturbines are operated in two modes that are grid-connected mode and isolated mode. In this paper, MT simultaneously is supplying a nonlinear load like a 6 pulse diode rectifier and is also connected to the distribution network.

1) Isolated inverter

For islanding operation mode, V-f control strategy is used. In this mode, voltage magnitude and frequency are adjustable parameters. Fig. 4 shows schematic of inverter control in isolated mode.

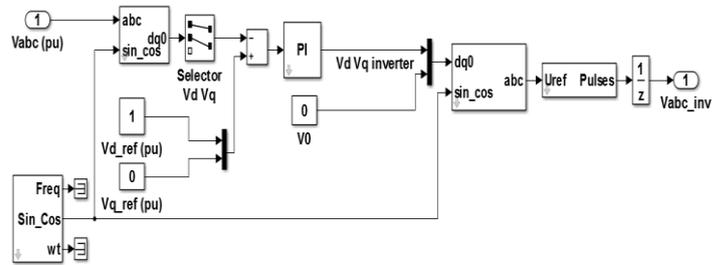


Fig. 4. Inverter control for isolated mode

At first voltage applied to dq0 reference frame and then compared with a reference value. Output of compared value is passing through a PI controller and finally, is converted to desired pulse for inverter. Mentioned block diagram is based on voltage and frequency which is main purpose of V-f control strategy.

2) grid-connected inverter

For grid-connected operation mode, P-Q control strategy is used. In this case, delivering desired active and reactive power to load is considered and power deficit is compensated by the grid. Grid-connected control diagram is represented in Fig. 5.

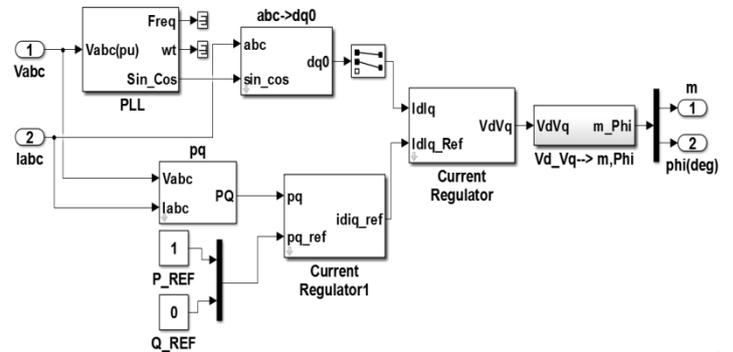


Fig. 5. Inverter control for grid-connected mode

At first, measured voltage and current are converted to active and reactive power and then these values are compared with references. Power error is passing through a PI controller to generate reference currents. On the other side, dq axis currents are produced by frequency of voltage which are compared and then, passing through another PI controller to generate desired pulse.

E. Remover Ripple Circuit (RRC)

Output filter is required for inverter to reduce harmonics and ripples that cause delivering optimum power. In this paper, a new topology RRC filter is used instead of conventional LC or LCL filter. RRC structure is simple and is not required to any additional switches or control circuits [11]. RRC structure and waveforms are shown in Fig.6.

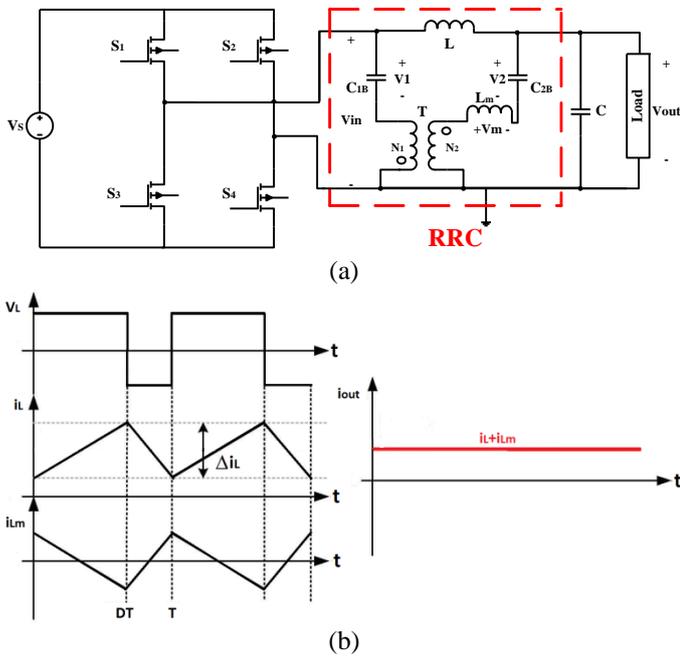


Fig. 6. Proposed filter: (a) RRC structure (b) key waveforms for eliminating ripples

This filter works based on reflected ripples that are automatically induced therefore, output current ripple elimination is occur in each cycle. RRC key waveforms for removing output ripple are shown in Fig. 6(b). The RRC parameters are chosen as Table 1.

TABLE I. RRC PARAMETERS VALUE

parameter	value
L	3 mH
L _m	800 μH
C	1.5 μF
C _{1B}	150 μF
C _{2B}	150 μF

III. SIMULATION RESULTS

For analysis mentioned structure, simulation is carried out in MATLAB/Simulink software. In this model, micro-turbine systems simultaneously feeding a nonlinear load and is also connected to a distribution network. Fig. 7 shows MTG system which is connected to subsystems through a boost converter. Speed of PMSG is enters to microturbine model and output of MT is mechanical torque and mentioned subsystems are nonlinear load and grid.

The purpose of this study is evaluating of MTG dynamic behavior and effective operation of RRC filter. The grid is a 480 V and 60 Hz that is based on a real distribution network and nonlinear load subsystem consist of a 3 leg diode Rectifier with a RL load equal to 1000+j100 VA. Fig. 8 is shown MTG subsystems in detail.

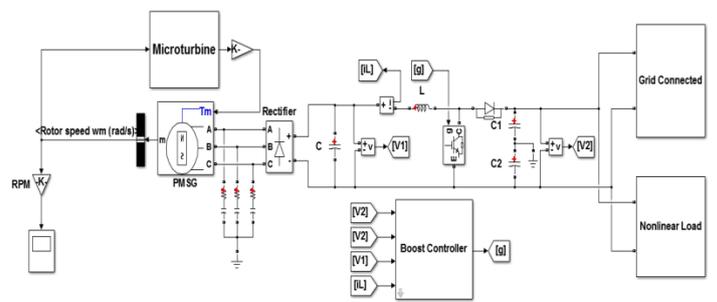


Fig. 7. Microturbine generation system in MATLAB/Simulink

In grid-connected the scenario is as following: According to mentioned above, P-Q control strategy is applied which is based on controlling of active power and reactive power and a 1 kW load is permanently parallel connected. At t=0 S a 25 kW load is applied to system and at t=3.5 S additional load with 20 kW value is applied too. At t=6 S the first load is disconnected from the system and finally, a 40 kW load at t=8S is applied to system. MTG load following is important issue and is purpose of this scenario.

In isolated mode, control strategy is based on V-f control and a nonlinear load is connected to MT through a boost converter and RRC filter.

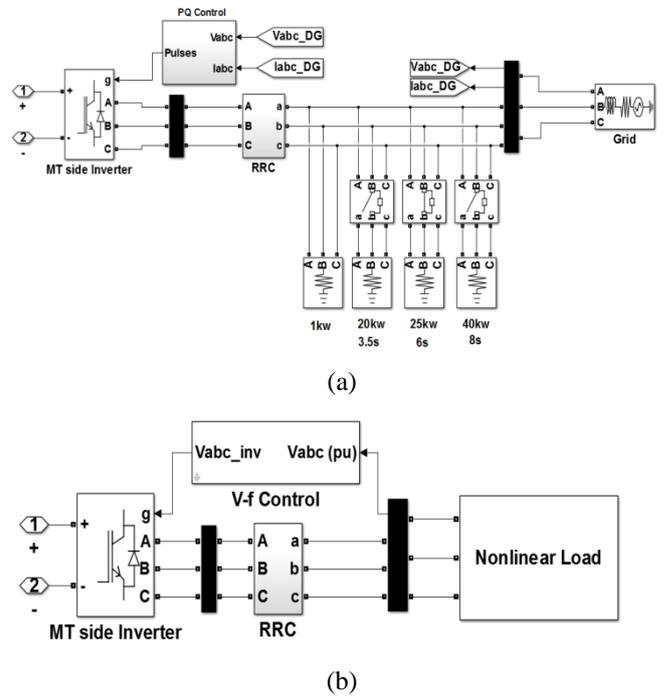


Fig. 8. MTG subsystems: (a) grid-connected mode (b) isolated mode

Fig. 9 is shown load voltage in two operation modes. The load voltages are close to sinusoidal with lowest harmonics. RRC performance as inverter output filter is appropriate and acceptable because of removing ripples.

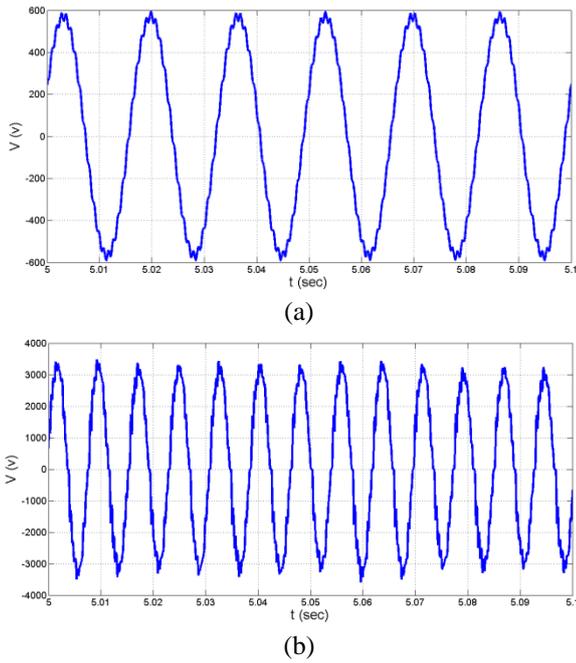


Fig. 9. Load output voltages: (a) grid-connected mode (b) isolated mode

Inverter output voltage in two operation modes is shown in Fig. 10.

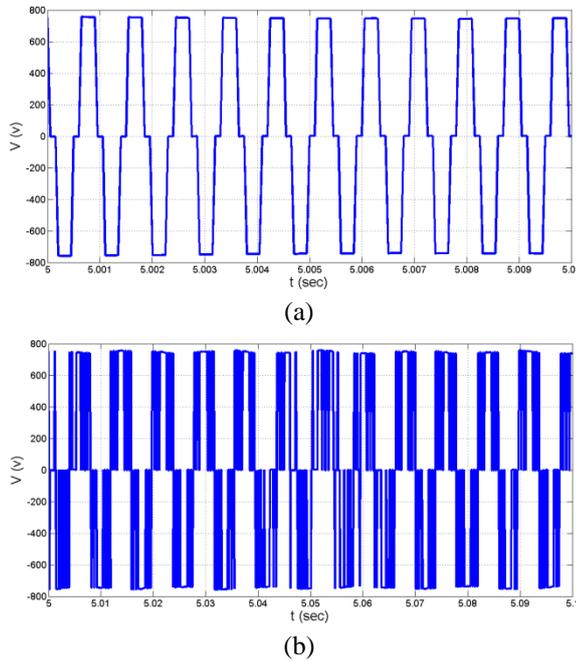


Fig. 10. Inverter output voltages: (a) grid-connected mode (b) isolated mode

Fig. 11 shows DC link voltage that is remained constant around 750 V without significant drop due to loads changing.

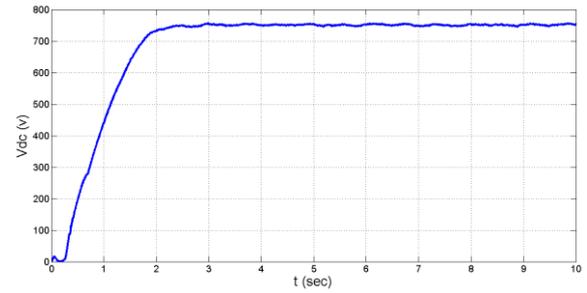


Fig. 11. Voltage at DC side

When load is increasing, output power is increasing too and vice versa. Fig. 12 is shown grid side power changes. MTG load following performance is desirable and any deficit in power is compensated by the grid.

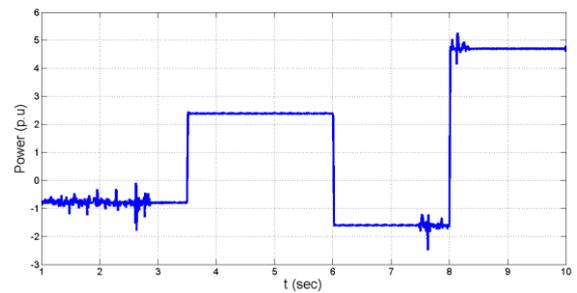


Fig. 12. Grid side Output power

Rotor speed is shown in Fig. 13. Speed of MTG is around 100,000 RPM without significant drop.

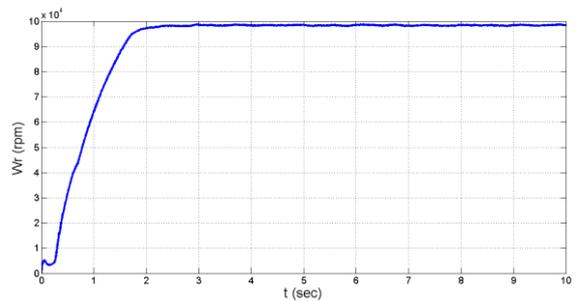


Fig. 13. Rotor speed of the MTG

Fig. 14 is shown MTG output current in two operation modes that is close to sinusoidal waveform with low harmonics and ripples. RRC performance is acceptable because of removing current ripples.

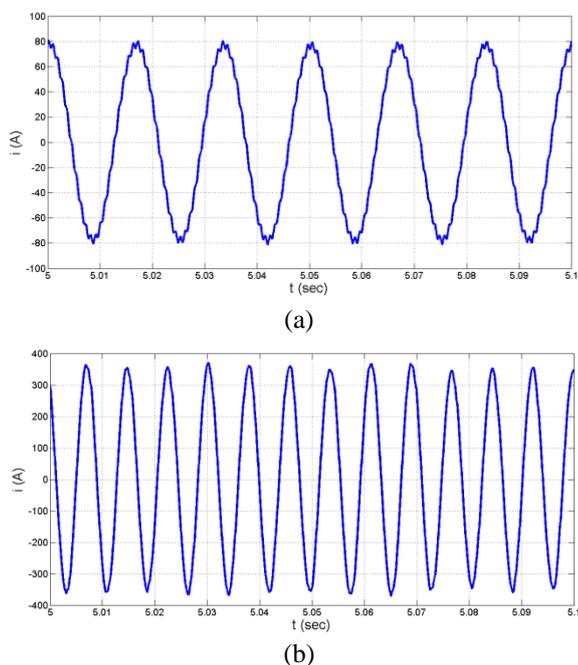


Fig. 14. Load output current: (a) grid-connected mode (b) isolated mode

IV. CONCLUSION

This paper is presented dynamic model of a single-shaft microturbine generation system in MATLAB/Simulink for simultaneous grid-connected and islanding operations. In isolated mode there is a nonlinear load and in grid-connected mode there is a changeable load. A new filter topology that name is RRC is used to achieve output free ripples and results show RRC desirable performance as an inverter output filter. Boost converter is applied for stabilizing of fluctuates and boosting of rectified voltage. Dynamic performance of mentioned structure is desirable and acceptable due to proportional power and speed changes with load variations.

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