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Dynamic Model of Micro Turbine Generation System Power Quality Enhancement with HVDC Converter

[1]Chandrakant Shende , [2]Prof. Radharaman Shaha
[1]M. Tech. Student, Electrical Engineering Department, Tulsiramji Gaikwad Patil College of Engineering Nagpur, India[2]Assistant Professor, Electrical Engineering Department, Tulsiramji Gaikwad Patil College of Engineering Nagpur, India

***Abstract*- Due to their prospective benefits and qualities, distributed generation (DG) has recently attracted more interest on a global scale. Microturbines (MTs), one of the most dependable sources, provide a substantial contribution in this area. In this article, dynamic modelling of an MTG system with a novel passive filter architecture is provided. A permanent magnet synchronous generator (PMSG), an AC/DC rectifier, a boost converter, a DC/AC inverter, and a remover ripple circuit (RRC) are all components of the MTG architecture. The RRC can work in both an isolated and connected to the grid mode at the same time. A novel and effective technique for operating microturbines involves the use of the boost converter and RRC filter. A simulation analysis is conducted in MATLAB/Simulink, and the results demonstrate the suggested structure's fast dynamic and desired performance.**

***Index Terms*- Distributed generation (DG), Power conditioning unit, Micro turbine (MT), Permanent magnet synchronous generator (PMSG).**

I. INTRODUCTION

The advantages of distributed generation in terms of technology, finances, dependability, and the environment are growing in popularity. There are numerous ways to generate electricity, including solar panels, wind turbines, fuel cells, microturbines, and diesel generators. A microturbine is a little, straightforward gas turbine that runs on the Brayton cycle. A turbine, compressor, combustor or combustion chamber, recuperator, and a permanent magnet synchronous generator are all components of the MTs system. Compressed air from the inlet is first heated to room temperature before being combined with fuel in the combustor. High pressure gases then travel through the turbine, which generates mechanical power and rotates the PMSG. Recuperator, a heat exchanger, reheats compressed air before it enters the combustion chamber using hot turbine exhaust gas. MT generates electricity in the 25–500 kW range with an efficiency of 20–30%, reaching up to 80% in combined heat and power (CHP) and recuperated turbine systems. In general, the benefits of MT include their small size, dependability, low initial cost, affordable maintenance, control simplicity, low emissions level, few moving parts, and ability to run on a variety of fuels, including biogas, natural gas, diesel, propane, kerosene, and diesel. Application areas for MT include transportation systems, premium power, remote power, and peak shaving. The single-shaft model and the split-shaft model are the two different sorts of MTG designs. The compressor, turbine, and PMSG are all positioned on the same shaft in a single-shaft arrangement. A power electronic interface is needed to convert the high frequency AC voltage produced by the PMSG, which ranges in frequency from 1.5 to 4 kHz, to the appropriate frequency. A single-shaft MT is seen in Fig. 1 in both the grid-connected (on-grid) and islanding (off-grid) operating modes. It is not necessary to power electronic interfaces because the split-shaft design has two components that are related to one another through a gearbox.

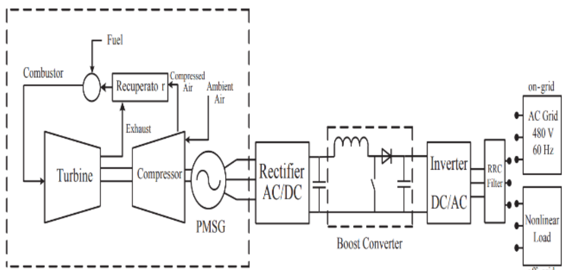


Fig. 1. Microturbine generation system

Using an AC/DC/AC structure is one way to convert the high frequency of PMSG to 50Hz or 60Hz. This method first converts AC voltage to DC voltage, which is then transformed back to AC voltage with the proper frequency using an inverter. In order to raise rectifier output voltage level and reduce fluctuations, a boost converter is employed in this paper. To reduce harmonics in inverter output, a suitable filter is needed; RRC is a good option in this case. Recently, one of the issues has been MT's efficient operation, and several solutions have been put forth. The fundamental idea of MTGs as a distributed resource is presented in [1] and [2]. A comprehensive mathematical model of a single-shaft MT operating in isolated mode and using MATLAB/Simulink is proposed in [3]. In [4], the grid-connected mode MT electromagnetic transients are evaluated. [5] introduces a dynamic model of an MT system and control algorithms for grid-connected and islanding operation. In [6], a model of the MTG system implemented as a microgrid using PSCAD/EMTDC is shown, and the power electronic interface is controlled by SPWM. in [7] introduces a thermomechanical system with various control loops, including a controller for temperature limitation and a controller for startup. For load-following and financial concerns, in [8] uses a distribution system equipped with a micro-turbine plant and an integrated fuel cell power plant. This research proposes a dynamic model of a single-shaft MT with an AC/DC/AC configuration. Desired power flow and sinusoidal output voltage are produced using an MTG design that uses a boost converter and RRC as a new filter structure. MT is grid-connected for thorough examination, while simultaneously delivering a nonlinear load and running simulations in MATLAB/Simulink. A dynamic microturbine model and control approach for grid-connected and islanding operation are proposed in part two, followed by the presentation of simulation results when load changes in section three, and the conclusion in section four.

II. MODEL DESCRIPTION

A. Modeling of a Microturbine

Fig. 2 shows a dynamic model created in MATLAB/Simulink of a single-shaft microturbine. This model is made up of dynamic blocks for the turbines as well as acceleration control, speed governor, temperature control, and fuel control [5]. Assume that the system runs normally in this description without fast dynamics. A lead-lag transfer function or a PID controller is utilized for modelling the speed governor, and the speed controller operates based on the speed inaccuracy between the reference and MTG rotor speeds. When the reference speed is close to the rated speed, the acceleration control for the microturbine can be disregarded. The output of the governor, acceleration control, and temperature controller are sent to a MIN block where the least value signal is chosen. The output of the MIN block is offset by 0.23, which represents fuel flow under no load conditions, and scaled by 0.77. Delays in the governor control are represented by the time before fuel flow controls. The fuel is finally burned in the combustor before entering the turbine to generate mechanical torque. A thermocouple is used to gauge the temperature of exhaust gases, which is then compared to 950 as a reference. Normally, the reference value causes the maximum value for temperature control since it is higher than the thermocouple output. The system runs to lower the temperature if the thermocouple's output exceeds the reference value.

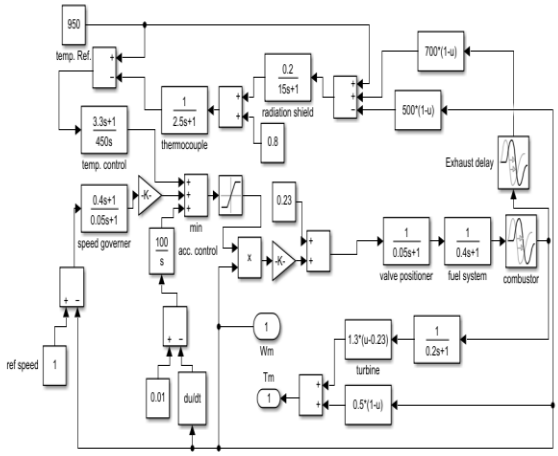


Fig. 2. Dynamic model of Micro turbine

B. Permanent Magnet Synchronous Generator (PMSG)

Electricity must be produced by a synchronous or asynchronous generator, and PMSG is better. In PMSGs, a permanent magnet takes the place of the field winding, resulting in lower power losses and less maintenance. In this study, the PMSG has two poles, spins at 100,000 revolutions per minute, and has the following parameters: Ld=Lq=0.0006875 H and Rs=0.3. The flow in the stator, which generated sinusoidal electromotive forces, is assumed to be sinusoidal in this model. The following are the PMSG configuration equations in the dq0 reference frame:

Electrical equations:

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

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

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

Where
Ld, Lq: d and q axis inductances
R: Stator winding resistance
iq, id: q and d axis currents
vq, vd: q and d axis voltages
ωr: Rotor angular velocity
λ: Flux linkage
p: Pole number
Te: Electromagnetic torque

Mechanical equations:

$$\frac{d\theta}{dt} = \omega_r \tag{4}$$

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

Where
J: Rotor and load combined inertia
F: Rotor and load combined viscous friction
Tm: Mechanical torque
Ө: Rotor angular position

C. Boost converter

In this study, output voltage fluctuations from PMSG are stabilized using a boost converter. In Fig. 3, a boost converter diagram is displayed. In a boost converter, the output voltage is greater than the input voltage, and the duty cycle is utilized to control the ratio of the two voltages.

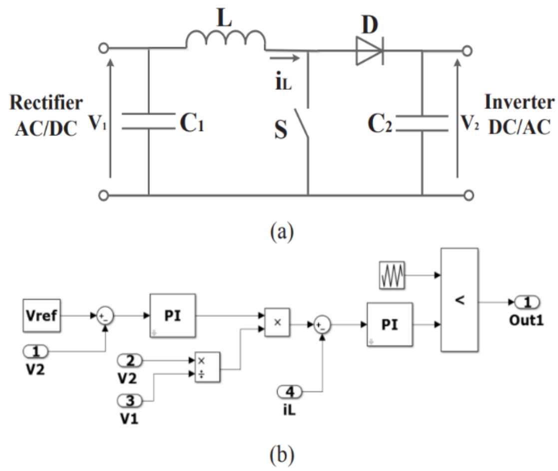


Fig. 3. Boost converter: (a) circuit topology (b) control strategy

D. Inverter controller circuits

Microturbines can run in either the gridconnected mode or the isolated mode. In this study, MT is concurrently connected to the distribution network and supplying a nonlinear load, such as a 6 pulse diode rectifier.

1) Isolated inverter

V-f control strategy is employed in islanding operating mode.Voltage magnitude and frequency are programmable variables in this mode. The isolated inverter control concept is shown in Fig. 4. First, voltage was delivered to the dq0 reference frame, and the results were then compared to a standard value. A PI controller transforms the output of the compared value into the desired pulse for the inverter. The block diagram that was mentioned is based on voltage and frequency, which is the primary goal of the V-f control technique.

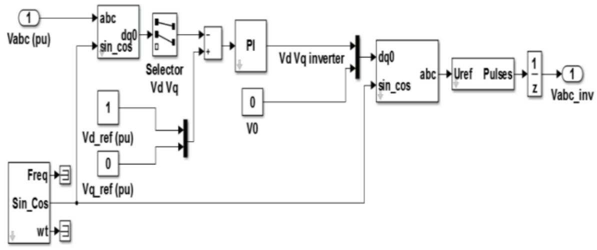


Fig. 4. Inverter control for isolated mode

2) grid-connected inverter

Using a P-Q control method, a grid-connected operating mode is operated. In this scenario, providing desired active and reactive power to load is taken into account, and the grid is used to make up for any power deficits. Fig. 5 shows a grid-connected control diagram.

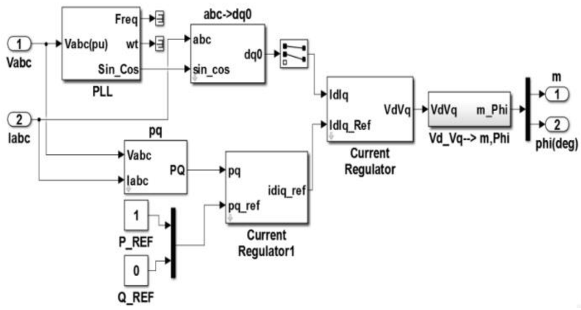


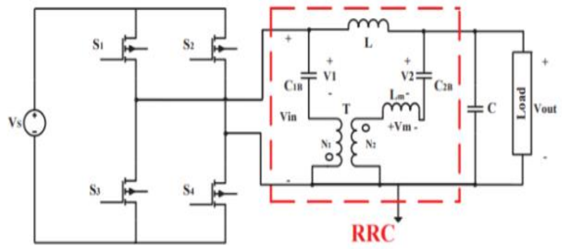
Fig. 5. Inverter control for grid-connected mode

Before being compared to references, recorded voltage and current are first converted to active and reactive power. A PI controller uses power error to provide reference currents. On the other hand, to generate the desired pulse, dq axis currents are generated by frequency of voltage that are compared and then passed through another PI controller.

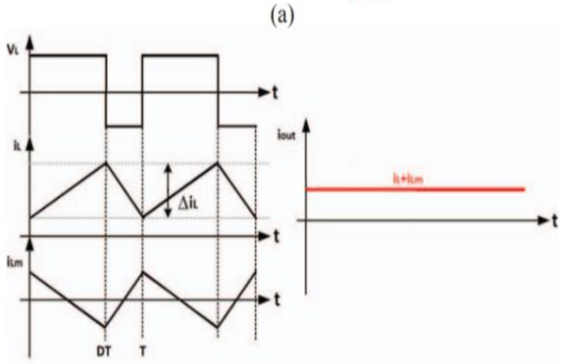
E. Remover Ripple Circuit (RRC)

In order for the inverter to supply the best possible power, harmonics and ripples must be reduced. Instead of using a traditional LC or LCL filter, a new topology RRC filter is utilized in this paper. The RRC structure is straightforward and doesn't require any extra switches or control circuits. In Fig. 5, the

RRC structure and waveforms are displayed. Since the operation of this filter depends on automatically generated reflected ripples, output current ripple removal takes place every cycle. Fig. 5(b) shows the RRC critical waveforms for eliminating output ripple. Table 1 has been chosen as the RRC parameters.



(a)



(b)

Fig. 5. Filters: (a) RRC structure (b) key waveforms for eliminating ripples

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

Simulation is done using the MATLAB/Simulink software for the examination of the aforementioned structure. In this scenario, a distribution network is coupled to micro-turbine devices that are simultaneously feeding a nonlinear load. A boost converter connects the MTG system to the associated subsystems. Microturbine model uses the speed of the PMSG as an input, while the model's mechanical torque output comes from the nonlinear load and grid subsystems. This study aims to assess the dynamic behaviour of MTG and the efficiency of the RRC filter. Based on a genuine distribution network, the grid is 480 V and 60 Hz, and the nonlinear load subsystem consists of a three-legged diode rectifier with an RL load of 1000 + 100 VA. Figure 8 depicts MTG subsystems.

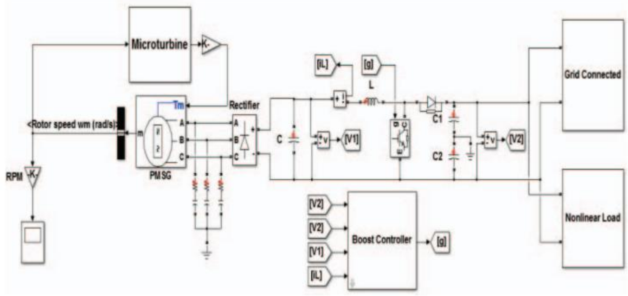
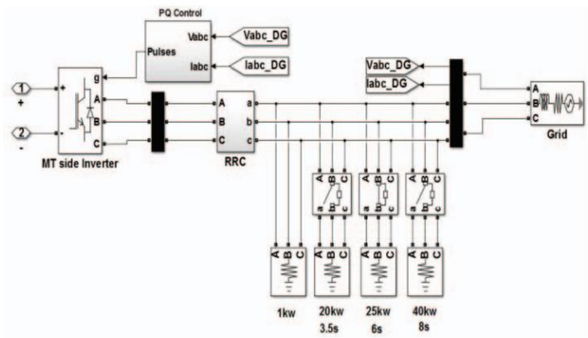
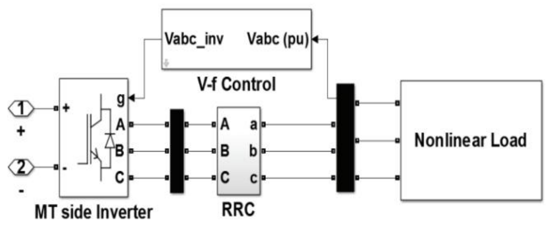


Fig.6. Microturbine generation system in MATLAB/Simulink

The scenario in grid-connected is as follows: A 1 kW load is permanently parallel connected and the P-Q control method, which is based on managing active power and reactive power, is used, as indicated above. A 25-kW load is applied to the system at time t=0 S, and another load with a 20-kW value is added at time t=3.5 S. The first load is disconnected from the system at time t=6 S, and at time t=8 S, a 40-kW load is then supplied to the system. The goal of this scenario is to highlight the significance of MTG load following.



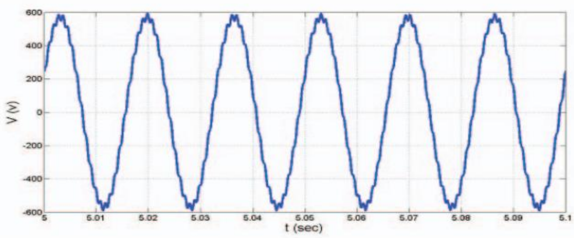
(a)



(b)

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

Load voltage is shown in two operating modes in Fig. 9. Lowest harmonic load voltages are nearly sinusoidal. Because RRC eliminates ripples, its performance as an inverter output filter is adequate and acceptable.



(a)

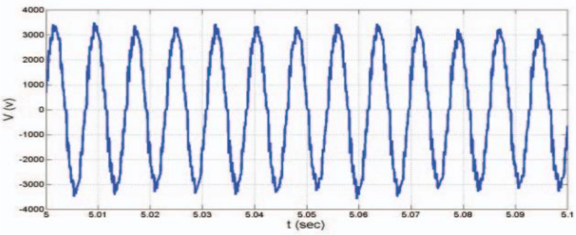


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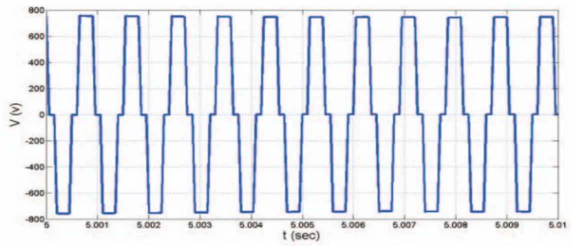
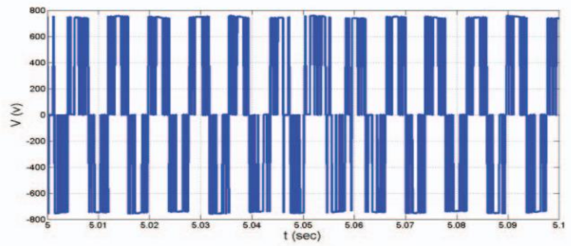
Fig. 9. Load output voltages: (a) grid- connected mode (b) isolated mode

Fig. 10 shows the inverter output voltage in two different operating conditions.



(a)



(b)

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

Fig. 11 shows a DC link voltage that is kept constant at roughly 750 V without experiencing a major drop due to shifting loads.

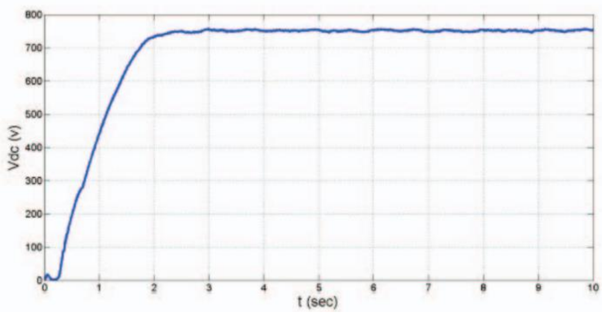


Fig. 11. Voltage at DC side

The output power increases along with the load and vice versa. Grid side power variations are shown in Fig. 12. MTG load following performance is preferred, and the grid makes up for any power shortfall.

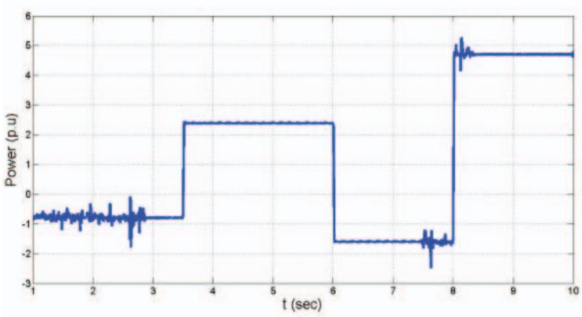


Fig. 12. Grid side Output power

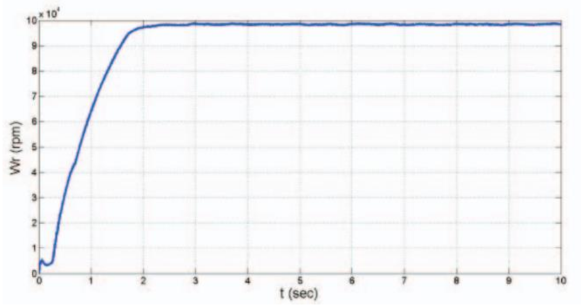
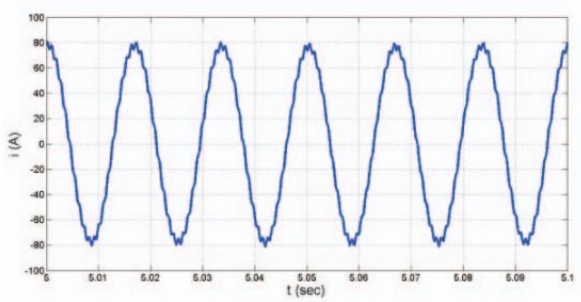
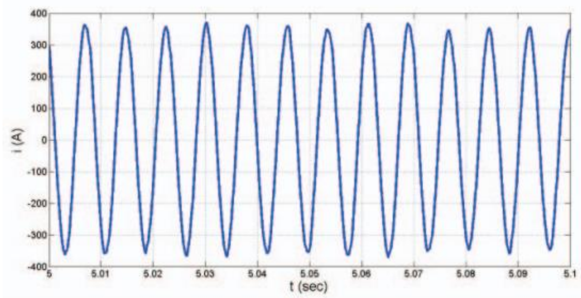


Fig. 13. Rotor speed of the MTG

Fig. 14 shows the MTG output current in two different operating modes. The waveform is nearly sinusoidal and has little harmonics and ripples. The elimination of current ripples has improved RRC performance.



(a)



(b)

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

IV. CONCLUSION

For simultaneous grid-connected and islanding operations, a dynamic model of a single-shaft microturbine generation system is described in this paper using MATLAB/Simulink. A nonlinear load is present in isolated mode, while a variable load is present in grid-connected mode. To achieve output devoid of ripples, a new filter topology known as RRC is applied, and the results demonstrate RRC's favorable performance as an inverter output filter.

Boost converters are used to boost rectified voltage and stabilize fluctuations. Due to proportional power and speed changes with load variations, the dynamic performance of the described structure is desirable and acceptable.

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