Impact of Advance Control on Microturbine Generation System Performance

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**Abstract.** Advance control employed in microturbine generation system (MTGS) is expected to improve its performance in responding to grid faults. This paper compares the effect of advance control of MTGS power conversion topology on the performance in riding through the grid faults. The analysis and investigation study through simulation shows there is no significant different on MTGS output performance even advance control is employed for its rectifier.

1. Introduction

Microturbine generation system (MTGS) is a distribution generation (DG) technology which is initially microturbine (MT) was designed for air transport vehicle such as aircraft and helicopter but now found itself as one of the most prospectus technology to be used as DG [1-2]. They can be used to supply a customer’s base-load requirements or can be used for standby, peak shaving and cogeneration applications [3].

The typical output power of MTGS is usually between 30 kW and 400 kW for distributed DG application [4] with energy conversion efficiency between 20-30\%, but can be increased up to the 60-85\% if the waste heat is recovered for combine heat and power system [5]. It also has fuel flexibility where capable of using alternative/optional fuels including natural gas, diesel, ethanol, landfill gas and other bio-mass derived liquids and gases [3].

Power electronic converter is needed in order to connect a MT to the utility or to the grid [6] because the rotational speed of turbine is very high. The most common power converter topology used AC-DC-AC. The high-frequency AC power from MT generator is converted to DC first, then DC component is converted to 50/60 Hz components [2]. Different types of MTGS are available for example in [1] which operates with unidirectional power flow and in [6] which operates with bidirectional power flow.

Converting AC to DC is performed normally by passive rectifier but active rectifier is also utilized. DC to AC conversion is performed using voltage source converter. The selection of using passive or active rectifier depends on the MTGS task. For example, if MTGS is used in shaving peak and only online for certain period, so active rectifier is consider for this task. If MTGS is used for operating continuously and to supply part of based load, in many years major overhaul which is happen only once in a few years so passive diode rectifier is consider [3].

DG connected to electrical grid, in some region has to operate under stringent requirements. The requirement is to make sure DG will not degrade power quality, stability, security and reliability. The example of operating requirements are to lower emission of power quality characteristic parameters,
ability to reduce active generation and lastly ability to perform voltage regulation by providing reactive power. During fault condition requirements are such as fault ride-through capability with limitation of short circuit current [1,3].

This paper compares the effect of advance control of MTGS power conversion topology on the performance to ride through the faults. MTGS technology is first reviewed, then the modelling method is described and finally the results of performance study are compared.

2. MTGS Technology and Modelling

There are two primary types of microturbine designs, single shaft and split shaft [4]. The single shaft operates at high speeds of 90,000 to 120,000 rpm where the design is mounted together with compressor and turbine [5]. This type of MTGS is interfaced with the grid through power electronic converter [1]. For the split shaft, the shaft rotates at 3600 rpm where generator and turbine are not mounted together with shaft [2]. The generator usually connected via gearbox, so power electronic converter is not needed for the split shaft design [6].

2.1. Microturbine

MT model is developed based on the gas turbines model that has been suggested in [7]. The model has been used in by several authors and researchers, for example in [1], [3], [5] and [6]. The equation for the system is given by:

$$t_m = f = 1.3 (w_F - w_{MIN}) + 0.5(\omega_R - \omega_{\text{ref}})$$  \hspace{1cm} (1)

where $t_m$ is mechanical torque, $\omega_R$ is the speed of PMSM, $\omega_{\text{ref}}$, $w_F$ is speed reference, $w_{MIN}$ is fuel signal for turbine and $w_{MIN}$ is fuel value at no load operation.

2.2. Rectifier

AC component from machine is converted to DC by rectifier. For the active rectifier control, Hall Effect method is used where it provides logic signal back electromotive force (e.m.f.) in controlling power switch [9]. The relationship between Hall Effect and back e.m.f can be represented in Table 1 which is known as “Block Commutation” or “Brushless DC Motor Timing Diagram”. Table 1 shows high and low state of power switch or converter device. Usually, this information is provided by manufacturer in datasheet [9].

| Hall | Emf | Rectifier |
|------|-----|-----------|
| a    | b   | c        | Q^1 | Q^2 | Q^3 | Q^4 |
| 0    | 0   | 0        | 0   | 0   | 0   | 0   |
| 0    | 1   | 0        | -1  | +1  | 0   | 0   |
| 0    | 1   | 1        | -1  | +1  | 0   | 1   |
| 1    | 0   | 0        | +1  | 0   | -1  | 0   |
| 1    | 0   | 1        | +1  | -1  | 0   | 1   |
| 1    | 1   | 0        | 0   | +1  | -1  | 0   |
| 1    | 1   | 1        | -1  | +1  | 0   | 0   |

2.3. Line Side Converter

In grid connected mode, MTGS operates as the current source [1]. The other objective of the controlling of inverter is to keep the DC-link voltage constant, regardless of the magnitude and direction of the rotor power [6]. Inverter is typically controlled using technique of field control or vector control originates from electrical machines theory. Voltage and current in a-b-c axis is converted to d-q-0 axis. This method reduces the complexity of coupled electrical quantities. Referring to the figure 1, the inverter control algorithm can be derived based on the relationship between converter voltage $U_{CON}$ and grid voltage $U_G$ behind its grid inductor [1].
From Figure 1 above, the voltage grid in d and q component after mathematical manipulation are \[ U_{gd} = \frac{d\theta_{sped}}{dt} - \omega l_i_{CONq} + U_{C0,3d} \] \[ U_{gq} = \frac{d\theta_{senq}}{dt} - \omega l_i_{CONd} + U_{C0,nq} \] Equations (2) and (3) are the basis of converter controller algorithm. With this controller, active power is controlled through d component and reactive power output is controlled through q component [1]. All these equation of the current controller is implemented in Matlab/Simulink software [8].

3. Simulation Result and Discussion
This section compares the results of the simulation. The comparison is made between the output of 60 kW-MTGS which used passive rectifier and the 60 kW-MTGS which used active rectifier. For both models, LSC converter controlled is set to follow grid code that requires the fault ride through and injection of reactive current for voltage support.

3.1. Under Fault Occurrence Operation
During fault operation, the MTGS must be able to operate without disconnecting the system and at the same time must able to inject the reactive current for supporting. The maximum current that can be injected by converter is 2.0 p.u [10], but in this study 1.5 p.u of rating current is allowed to be injected by LSC to the grid [1].

In Figure 2 and Figure 3, the output of the both MTGS responding to temporary fault at \( t = 0.5 \) s until \( t = 0.65 \) s are presented. The faults were single-phase to earth fault and three-phase to earth fault. During the fault, the voltage grid dipped about 50%-60% for single phase fault and 80%-90% for three phase fault. The total nominal current injected to grid during fault for both systems look the same at about 1.5 p.u. of the nominal current injected to the grid for both single phase to earth fault and three phase to earth fault.

DC voltage during the faults rises above nominal value until the fault is cleared. The rising of DC voltage is due to imbalance of power transfer between the rectifier and converter. During the fault the required power cannot be transfer to the grid due to low voltage condition. The power accumulates in DC circuit and causing voltage rise. After fault is cleared, the DC voltage returns to nominal value after power transfer is balanced. From the comparison made, it is seen that the performance of MTGS in riding through grid faults is not influence much on the power conversion topology on the machine side.

4. Conclusion
This paper compares the effect of advance control of MTGS power conversion topology on the performance to ride through the faults. The analysis and investigation study through simulation shows there is not significant different on MTGS output performance even advance control is employed for rectifier.
Figure 2. Single-phase to earth fault: (a) MTGS use passive rectifier (b) MTGS use active rectifier.

Figure 3. Three-phase to earth fault: (a) MTGS use passive rectifier (b) MTGS use active rectifier.

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